Balance disorder after traumatic brain injury:
a multifactorial observational study

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Acknowledgments

Many survivors of traumatic brain injury seek assistance and advice from rehabilitation professionals in the process of trying to adapt and rebuild their lives in the months and years following injury. We are often limited in what we have to offer. This study emanates from a desire to do better in this regard and to repay the trust vested in health and social care professionals with improved outcomes for TBI survivors.

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Abstract

Purpose
This research was undertaken to improve the assessment and treatment of balance disorder after Traumatic Brain Injury (TBI). It had three aims:

- to identify factors that have shaped healthcare practice concerning balance disorder and describe barriers to improved practice
- to develop understanding of the nature of TBI balance disorder
- to establish proposals for an improved healthcare response for those with balance disorder following TBI.

Relevance
TBI is a significant cause of disability in the young adult population and problems with balance are consistently reported.

Description
A mixed methods approach was employed to address the aims within a common framework. This comprised a series of subject reviews, an observational study and a systematic analysis of emergent findings. Topics for the subject reviews were chosen for their relevance to TBI physiotherapy practice. The observational study involved 27 participants in the recovery and rehabilitation phase after TBI and was structured using a new comprehensive assessment protocol developed from first principles. Findings were explored using frequency analysis and thematic analysis generated from the development of individual participant narratives. Emergent topics were then considered with reference to the literature, existing theories and concepts of postural control.

Observations
Different conceptualisations of balance were identified, influenced by discipline tradition, their evidence base, the evolution of ideas, and past and current purpose. Practice development was constrained by the lack of a comprehensive conceptualisation of human balance, inconsistent and fragmented service response and limited knowledge concerning the nature and prevalence of impairments affecting balance function after TBI. Balance disorder was found to be highly prevalent and multifactorial in nature. New sensorimotor characteristics of TBI balance disorder were identified, including observations of importance to the contentious debate concerning symptomatic minor TBI. Issues of key importance in the structure and process of assessment were also identified.

Conclusions and benefits
Balance disorder is prevalent in the rehabilitation and recovery phase following TBI and is multifactorial in nature. Assessment and treatment of suspected balance disorder could be enhanced by the adoption of a single comprehensive conceptualisation of human balance, a systematic approach to assessment and formulation of causal hypotheses and a service process focused on the functional requirements of individuals. Research for the enhanced development of assessment and intervention strategies should also be pursued in the same context.

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1 INTRODUCTION

1.1 Balance

Balance is a term in daily use by health professionals working within the field of rehabilitation and is employed to describe a core component of functional human movement. Balance is considered by physiotherapists and other rehabilitation professionals to be a key domain to address within a range of restorative programmes following injury or disease (Pollok, Durward, Rowe et al., 2000). Assessment of balance function and intervention to promote recovery in the presence of disorder is therefore a common focus in programmes with the objective of restoring optimal motor performance (Shumway-Cook & Woollacott, 2001e). However, despite its apparent importance there is a lack of clarity around the meaning of the term as applied to functional human movement and an inconsistency in the use of the term in healthcare practice (Pollok et al., 2000). There is also a range of approaches to the definition and clinical management of balance disorder.

Pollock and colleagues (2000) discuss the lack of a universally accepted definition of balance within clinical practice and identify other commonly used clinical terms, such as stability and postural control, that are used with similar imprecision within the same context. This lack of precision in the use of language, and an associated underlying confusion in clinicians' intuitive understanding of human balance, is cited as a past and present barrier to the development of optimal patient care. It is argued that the adoption of a set of agreed definitions would provide a foundation for future developmental work in this area. The authors suggest standard definitions for the imprecisely used clinical terms of human balance, human stability and postural control, derived from detailed reference to mechanical principles but also taking into account factors that differentiate human balance from that of the inanimate objects referred to in mechanics. The suggested definitions are:

- <u>human balance</u> a multidimensional *concept* referring to the ability of a person not to fall,
- <u>human stability</u> the *inherent ability* to maintain, achieve or restore a state of balance, and

- postural control the *act* of maintaining, achieving or restoring a state of balance.

A different approach to the same issue is taken by Shumway-Cook and Woolacott, who equate (human) balance to (human) postural stability and discuss postural control in terms of achieving stability and orientation (Shumway-Cook & Woollacott, 2001e). Within this conceptualisation balance or postural stability are defined as "the *ability* to maintain the projected centre of mass within the limits of the base of support". While this definition is, like that of Pollok and colleagues, clearly routed in mechanics, there are subtle differences in the conclusions drawn and in the language used.

The term balance is, within one approach used to describe *a concept* and, within another, to describe *a skill.* This illustrative example highlights both inconsistency in the use of language and differing approaches to conceptualisation and categorisation of these commonly used phrases within rehabilitation practice.

1.2 Traumatic brain injury

Traumatic brain injury (TBI) is a common cause of death and disability worldwide, with peaks of incidence in the moderately young and relatively old subpopulations (Sorenson & Kraus, 1991). In young adults injury is often linked to high-energy insults, for example, in road traffic accidents, assaults with weapons or high-risk sports. Consequently, TBI affecting this population often results in diffuse brain damage with additional extracranial injuries (Campbell, 2000d).

Over the last thirty years there has been significant progress in early medical management with a concomitant increase in survival rates. Developments in rehabilitation have been slow to follow due to a number of interrelating factors such as the poor profile of rehabilitation, the timing of emerging need in a 'new' population, the complexity of outcomes and lack of investment in clinical research (Campbell, 2000c). Understanding of many of the changes and limitations that occur after TBI remains superficial. Balance disorder falls into this category.

1.3 Balance disorder after traumatic brain injury

Complaints of balance disorder after TBI are reported in a small series of studies but the nature of TBI balance disorder is imprecisely or incompletely described (Campbell & Parry, 2005). Studies are largely reported in isolation without reference to a wider context and there is often an (incorrect) assumption that balance is a universal concept that requires no definition or description. Understanding of the nature of balance disorder after TBI is therefore limited by the lack of reference to a common framework within which to consider the findings of individual studies as well as the issues of definition and labelling common to other areas of healthcare practice as introduced in section **1.1**.

1.3.1 Physiotherapy for balance disorder after traumatic brain injury

Physiotherapy is concerned with human function and movement and with maximising potential (Chartered Society of Physiotherapy, 2002). The assessment and management of factors interfering with a return to pre-injury levels of physical function for people recovering from TBI is, therefore, a key responsibility for physiotherapists working in the field of TBI rehabilitation.

While the precise nature of TBI balance disorder remains unclear it is known to variously limit the ability of affected individuals to safely perform physical activities and participate in a range of normal life roles. There is, therefore, a continuing demand on physiotherapists within TBI rehabilitation services for a clinical response to manage the functional impact at the level of the individual.

As a practitioner working in this area my initial response was to apply assessment and management approaches common to wider physiotherapy practice. Regular clinical evaluation then allowed experientially-based adjustment and development of assessment processes and approaches to management. Within this approach effective and progressive management of symptoms and functional limitations was achieved.

However, attempts to relate these management programmes to the published literature, in order to progress to formal evaluation of the developed approach and communicate this to the wider health community, proved difficult. The literature was inadequate and confused. In addition, the process of review highlighted that much of 'established' physiotherapy practice was derived from the same confused knowledge base.

1.3.2 The wider healthcare response

Limitations and inconsistencies in the wider healthcare response were also identified when trying to develop collaborative approaches in individual cases and from the reports of patients' experience outside specialist TBI services.

Responses to requests for a clinical opinion from medical specialities to enhance the development of physiotherapy and other rehabilitation management plans were unpredictable and inconsistent. With a few exceptions they were commonly associated with a negative message about management or recovery. Follow-up discussions with clinicians in non-TBI medical specialities, and with their associated scientific and academic colleagues, identified that they were aware that their knowledge base with respect to TBI was limited but that they also had little expectation of any potential for improvement. These discussions also suggested that there was a variety of conceptualisations of balance disorder between disciplines.

In terms of individuals who had consulted medical colleagues prior to engaging with TBI rehabilitation services there were recurrent issues of their problems not being recognised as genuine or of them being advised that there was no scope for remediation of their symptoms or any available effective management advice.

The negative messages commonly expressed by medical practitioners were not consistent with the positive outcomes associated with the physiotherapy assessment and management programmes developed through the evaluation of direct clinical practice.

Characteristics of the healthcare response

The observed healthcare response to people who experienced balance disorder after TBI was characterised by inconsistent advice and prognoses. The response received was dependent on the discipline consulted and the personal experience of the practitioner seen. Much of the medical response was negative, either in terms of a failure to validate the problem or in terms of failure to offer constructive management advice or onward referral.

Underlying factors

The primary factors underlying the poor healthcare response were:

- Specific limitations of knowledge concerning TBI and balance disorder after TBI
- Inconsistencies in the conceptualisation of balance and balance disorder in its wider context
- Lack of understanding of the potential to manage balance disorder after TBI for positive effect. The ability to communicated clinical success by isolated practitioners was significantly limited by the clack of a common conceptualisation of balance and an accepted description of TBI balance disorder.

1.4 Research Aims

The research programme reported in this thesis was undertaken, therefore, to develop the knowledge base upon which clinical practice for suspected balance disorder after TBI is founded. The research programme had three primary aims:

- to identify and describe factors that have shaped and influenced healthcare practice concerning balance and balance disorder and so understand barriers to improved practice
- to develop a better understanding of the nature of TBI balance disorder
- to establish proposals for an improved healthcare response for those with suspected balance disorder following TBI.

1.5 Methodology

A mixed methods approach was employed to achieve the three inter-related outcomes outlined above. The research design was, in part, emergent, influenced by the knowledge and understanding developed from the primary review of the literature. This process revealed wide, complex and sometimes conflicting influences on practice in general and limitations of knowledge in the area of TBI balance disorder in particular. The nature of the literature precluded straight forward critical review and synthesis resulting in the generation of testable hypothesis relating to the nature of balance disorder. However, analysis did allow the development of understanding of the context for current healthcare practice and the distillation of a theoretical context within which to explore the nature of TBI balance disorder.

The complex research process that emerged approximates to a Grounded Theory (Strauss & Corbin, 1998) approach, acknowledging the contextual influences on healthcare practice, observing the nature of TBI balance disorder without the constraints afforded by those historical influences and interrogating the emergent observations in a thematic format with reference to a wide secondary literature review. Finally, the knowledge developed via this process is applied to the limitations previously identified in standard healthcare practice resulting in the generation of a new theoretical framework and suggestions for change in healthcare practice.

1.6 Thesis design

The structure and content of the thesis is consistent with the research design and comprises a primary narrative and a series of appendices. The primary narrative is presented in three main sections which are broadly congruent with the three aims of the research programme.

1.6.1 Factors that have shaped and influenced healthcare practice

Section I (Chapters 2 to 7) sets the context for the data collection phase of the research programme. The scope and focus of the literature reviewed, therefore, is structured to allow description of the contextual influences on the development and content of physiotherapy practice, including wider healthcare influences, and to summarise current understanding of TBI and TBI balance disorder. As well as the citing and critical evaluation of pertinent research studies, leading voices are used to summarise issues and approaches in complex or contentious areas. This is presented in the format of a series of focused subject reviews.

Three subjects reviews:

- Motor control: theories and practical applications
- Balance: concepts and derivations
- Balance: assessment and evaluation

are employed to provide a broad understanding of influences on physiotherapy practice in the context of healthcare practice. As balance is considered within physiotherapy practice to be an expression of motor performance, motor control was chosen as a key subject to understand the content of neurophysiotherapeutic practice. Concepts of balance and approaches to assessment were chosen to explore the perceived confusions in wider healthcare practice.

Two further subject reviews:

- Traumatic brain injury
- Balance disorder after traumatic brain injury

are used to describe current knowledge of this pathology and its effects and how this is reflected in clinical practice. With reference to the latter, the clinical problem is described from practice-based knowledge linked with key issues raised in the preceding subject reviews. The presentation of this knowledge, while not evidenced by any significant literature, is crucial to the development of understanding of the primary need for the research programme as a whole and the third aim of the programme in particular.

The composite understanding derived from these reviews is that current knowledge of TBI balance disorder and the healthcare response to it is inadequate and that this is a function both of historical factors and continuing limitations of knowledge and clinical practice. The development of core knowledge to inform the development of clinical practice requires a fresh analysis from first principles.

1.6.2 The nature of TBI balance disorder

The nature of TBI balance disorder is, therefore, examined via a focused observational study of participants in the rehabilitation and recovery phase after TBI. The development, process and findings of this study are presented in Section II (Chapters 8 to 12). This includes a full discussion of the emergent themes with respect to a wider literature, consistent with a grounded theory approach.

1.6.3 Development of proposals for an improved healthcare response

The validity of the research programme and the knowledge generated from is applied to previously identified limitations in healthcare response for those with suspected TBI balance disorder in Section III (Chapters 13, 14 and 15). A series of recommendations for improvement in practice and further research are made. Finally, a comprehensive framework of understanding for balance is proposed as a basis for discussion and development of ideas with respect to complex balance disorder.

2 MOTOR CONTROL: THEORIES AND PRACTICAL APPLICATIONS

2.1 Context and definitions

Before exploring concepts of human balance it is important to define the context within which the discussion sits. That context is human motor control. Motor control is the name given to the study of the nature and control of movement (Shumway-Cook & Woollacott, 2001c). This field of study has been approached from a variety of perspectives and issues of key importance categorised in different ways dependent on the view point of the summarising author. A review of key summary approaches is given below followed by a distillation of important factors derived from consideration of each approach.

2.1.1 Perspectives on motor control

Rosenbaum (1991b) defines the scope of motor control as being inclusive both of how movement is controlled and how stability is maintained. He identifies two primary approaches to experimental studies and theory development relating to motor control; the physiological and the psychological. In this view motor control considered from the physiological perspective is strongly focused on the physical components that underpin the motor system including muscles, bones, joints and the nervous system. It also considers the relationship between these physical components. By contrast, the psychological perspective focuses on describing how motor control might be achieved with respect to theoretical frameworks and processes, without necessarily identifying the underlying physical mechanisms.

Macgill (2001) adopts a different approach to the categorisation of theories of motor control, focusing almost entirely on behaviourally-based models. In this view the primary distinction is made by considering the relative emphasis given to central (central nervous system) and environmental factors. Central-based theories have in common the concept of the motor programme, a memory-based construct that controls co-ordinated movement. Theories grouped under the heading of being environmentally influenced have at their core the belief that human movement control is a complex system, similar to other complex biological or physical systems, adhering to the theories of non-linear dynamics.

Rosenbaum's (1991a) and Macgill's (2001)differing approaches to categorisation, and the apparently arbitrary nature of the distinctions they choose to make, raises awareness of potentially varying assumptions underlying research studies undertaken from differing perspectives. It also begins to hint at the complexity of synthesising literature in this and related fields. This is one factor contributing to the confusion of approaches in healthcare practice (see 2.2 below and chapters 3 and 4). However, while Rosenbaum's physiological/psychological conceptualisation and Macgill's central/environmental conceptualisation offer alternative frameworks for the consideration of new knowledge and developing theories within the field of motor control, they lack comprehensive coverage.

Bernstein and colleagues in the Moscow School of Biometrics pursued a programme of research and theory development in the first half of the twentieth century, some of which was summarised and published in English shortly after Bernstein's death in 1967 (Bernstein, 1967b). This body of work is characterised by the cross referencing of multiple facets of knowledge, not only across biomechanics, anatomy and neurophysiology but also considering the impact of a changing environment. Theories developed within this programme were tested in terms of mathematical laws. It is not until the last quarter of the twentieth century that this work is given full credence in western literature (Latash, 1998) and reference is still often limited to fragments rather than to the work as a whole, for example (Allum, Bloem, Carpenter et al., 1998; Shumway-Cook & Olmscheid, 1990; Zattara & Buouisset, 1998) .

It might be argued that Bernstein was a physiologist who developed to some extent a psychological approach but in any event it is important to stress the inclusivity and comprehensive nature of his work, in that he addressed structural, behavioural and environmental factors. As well as developing novel ways of studying human movement, Bernstein rejected the reflex-based theories popular with other neurophysiologists of his time, such as those described by Sherrington (Sherrington, 1947) and Magnus (Magnus, 1926), recognising that the relationship between action and the external environment was significantly more complex:

> "A movement never responds to detailed changes by a change in its detail; it responds as a whole to changes in each small part, such changes being considerably distant both spatially and temporally from those initially encountered." (1967a)p23

He suggested that movement appropriately controlled for purpose was probably achieved via the co-operation of a range of neural structures rather than movements being dependent on a single topological location:

> "..the co-ordinational regulation of each complete cognitive motor act is constructed on a kind of multiple hierarchical system of circuits of regulation and adjustment."(1967d)p178

He also concluded via the analysis of cycles of movement that movement had to be organised with some accuracy in advance and postulated that this was achieved via a system of stored memories (engrams) combined with a system of activation sufficiently flexible to allow a degree of on-line adjustment. Thus he modelled human motor control as an example of a self-regulating system and, given the mechanical complexities of the human system, at the same time elucidated the complexities of achieving postural control and efficient co-ordinated movement:

> "The coordination of a movement is the process of mastering redundant degrees of freedom of the moving organ, in other words its conversion to a controllable system." (1967c)p127

The resonance of Bernstein's work today is at least in part a function of its comprehensive coverage. It is also because his logical and analytical approach resulted in innovative postulations about the central nervous system, and its role in motor control, which continue to hold true.

Understanding of motor control is also informed by research in the fields of motor learning and skill acquisition and for some authors the link between these areas is so strong as to make differentiation unhelpful. Schmidt and Lee (1999) categorise movements as being genetically defined or learned and argue that many everyday movements are a complex mix of genetic determinants modified through practice or experience. From this standpoint the influence of practice or experience and the mechanisms by which they modify performance are key to the understanding of motor control and are not usefully excluded. Within this wider definition of the field of study, Schmidt and Lee offer a three-way construct to underpin their approach: behaviour, biomechanics and neural control. Motor skills (behaviours) are considered via two sets of classification. The first comprises discrete, serial or continuous movements, a method of classification of individual actions that is dependent on observable features. The second set is open versus closed skills, with classification being dependent on the predictability of the environment within which an action takes place.

What is clear from consideration of all the approaches summarised here (see table 2.1) is the lack of agreement on what constitutes the scope of motor control and how its constituent parts are best described. There is not a settled theory of motor control.

Table 2.1

AUTHORS	SCOPE & LANGUAGE	CONCEPTUAL CATEGORIES		DETAIL
Rosenbaum (1991)	Movement control & maintenance of stability	Physiological ***versus*** psychological		Tangible ***versus*** abstract/virtual
Macgill (2001)	Movement & motor skill	Behavioural		Motor programme driven ***versus*** complex biological system
		CNS	Environment	
Bernstein (1967)	Co-ordination & regulation of movement	Structural ***plus*** behavioural ***plus*** environmental		A self-regulating system overcoming huge complexities to achieve control and action for purpose
		Task, action, prediction, adjustment		
Schmidt & Lee (1999)	Motor skills & learning (genetically determined movement modified through practice or experience)	Behavioural / (biomechanics) / (neural control)		Two sets of skill classification dependent on either observable features of the movement ***or*** on the predictability of he environment
		Motor skills		
		Discrete / serial / continuous	Open ***versus*** closed	

Perspectives on motor control

However, while authors approach description and categorisation from different perspectives and continue to focus on specific aspects central to their own interests, there are some elements that are core and from which general statements can be derived.

- Motor control (how movement is controlled and stability maintained) is dependent on a range of distinct control parameters and levels of control within the nervous system, such as affects movement planning, selection, timing, force and co-ordination.
- Motor control is not just about observable action but is dependent on complex systems of sensory perception that provide information about the environment and the relationship between the human organism and the environment.
- Theories of motor control must take into account the biomechanics of the human organism, its neurophysical and neuropsychological properties and its capacity for self-organisation.

So human motor control must be governed by an intelligent, self-regulating system that comprises a set of properties including:

1. A knowledge base
    a. Understanding body components and their interrelationships, their properties, possibilities and limitations
    b. Understanding the nature of environments, the rules that pertain, from which to develop predictions based on expectations
    c. Having a sense of self, a knowledge of vulnerability and a range of emotional responses linked to prior experience.
2. Sensors to monitor the body and its components
3. Sensors to monitor the environment
4. Mechanisms to link 2 and 3 to develop an understanding of the relationship between the body and the environment
5. Mechanisms to organise body components and orientate the body for purpose.
6. Ability to access and link all of these 'on-line'.

2.2 Theories and practical applications

Neurophysiotherapy in the United Kingdom as it developed into a distinct speciality during the 1970's became dominated by an approach to treatment which became known as the Bobath Concept. The Bobath Concept was the product of an innovative and highly skilled physiotherapist, Berta Bobath and her doctor husband, Karel. Mrs Bobath worked initially with children with cerebral palsy and then with adults with acquired neurological deficits and particularly with hemiplegia (The Bobath Centre). She demonstrated significant treatment successes, as compared to previous interventions that were based on the promotion of compensatory strategies and the use of various splinting and walking aids. The neurophysiology literature cited in support of this assessment and treatment approach (Bobath, 1970, 1978) was that of Magnus (1926) and Sherrington (1947), focusing on reflex inhibition and facilitation of 'normal' movement in the context of a hierarchically organised central nervous system (CNS). Treatment progressions were also strongly influenced by an assumption of recovery patterns paralleling the developmental sequence seen in the normal child from birth through to physical maturity.

The Bobath Concept was one of several 'neurophysiological approaches' to treatment in the presence of neurological dysfunction developed in the mid twentieth century, for example, The Rood Approach (Goff, 1969; Stockmeyer, 1967) and Proprioceptive Neuromuscular Facilitation (Kabat & Knott, 1954; Voss, 1967), which remained popular for longer in the United States. Although these approaches were qualitatively different in the specific techniques employed, and to some extent the defined target population, they all relied heavily on the handling skills of therapists and the basic principle that it was possible to influence the CNS via its peripheral sensory endings in skin, muscles and joints.

Various explanatory hypotheses of effect, set in the context of a reflex dominant, hierarchically controlled CNS, were proposed by both the originators and later followers of each approach but robust theoretical models were slow to emerge. However, clinical practice, particularly in terms of the Bobath Concept, continued to extend independent of theory via the application and development of techniques that were found to influence negative symptoms and promote normal movement. These techniques, and an underpinning observational assessment to guide appropriate application, were then taught as the basis of treatment. The original neurophysiological theory, when given alongside the practical courses, appeared increasingly tenuous in its linkage.

While much of what was practised under the label of the Bobath Concept in the UK produced positive outcomes, some practitioners began to recognise limitations in this and other facilitation approaches (Lennon, Baxter, & Ashburn, 2001; Matteo, 2003). Initially this was in relation to applied movement or the carryover of movement achieved in therapy sessions into day to day living. Subsequently there was growing recognition of potential conflicts between existing practice and emerging knowledge, for example, in the fields of motor learning and in muscle physiology (Gordon, 2000). There were some, however, who dismissed the importance of such conflicts on the grounds that theory development in these and other related areas were not applicable to clinical practice, since they were developed to reflect the normal as opposed to the pathological human system.

Other treatment approaches to address physical dysfunction associated with neuropathology have been proposed, influenced by research and theory development in a range of academic fields. These include a variety of educational, psychological and biomechanical approaches, as well as those based on theories of motor control and skill acquisition, for example, Conductive Education(Brown & Mikula Toth, 1997)and Movement Science(Carr & Shepherd, 2000b). It is not intended here to provide a full historical review of the development of neurophysiotherapy or to evaluate the relative merits of the various approaches. The purpose of this discussion is to highlight the erratic nature of the theoretical context within which neurophysiotherapy sits and in particular to recognise that practice in the UK was for a period of time almost completely dissociated from a credible theoretical base. As a result, practice is now a mixture of experiential and knowledge based procedures.

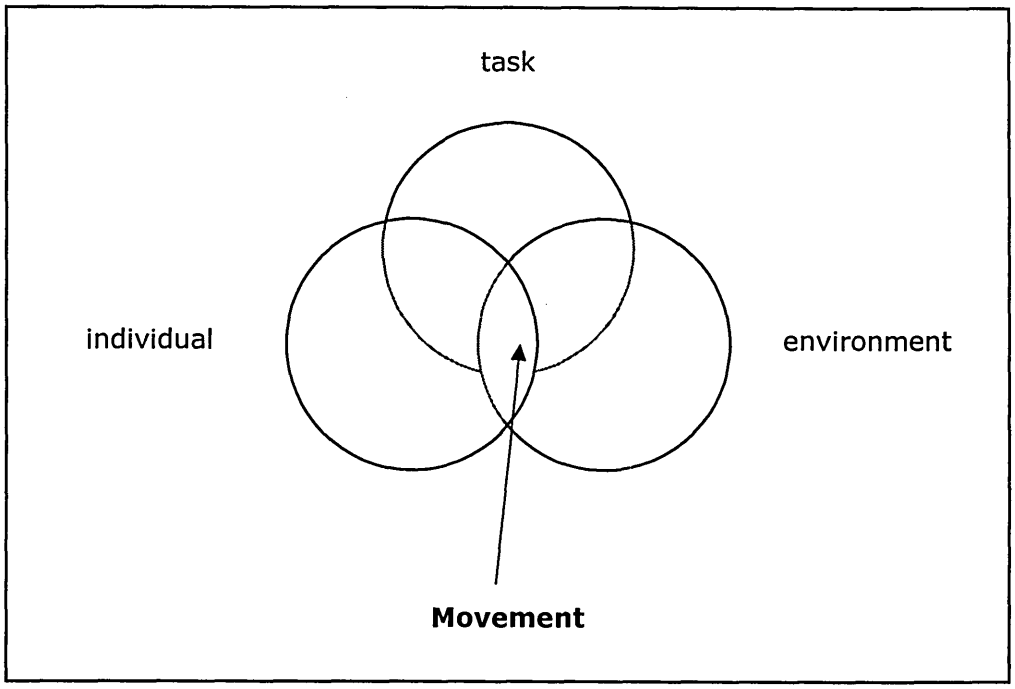
It is also important to note that physiotherapy has developed in the context of healthcare provision that is strongly influenced by medical practices and where medicine still holds the locus of control. This should be recognised as a salient factor regarding practice development and its relationship to accepted theory and also with regard to knowledge development through research. Thus while the reflex dominant hierarchical model of CNS control was increasingly challenged in the academic world and evidence to support the plastic nature of the whole neuromuscular system, including the CNS, was growing, lack of potential for recovery of lost function was still a prominently held belief within medical circles until very recent times. This, coupled with the lack of a robust underpinning theory for 'successful' clinical interventions, has contributed to the lack of value given to rehabilitation practices, poor access to research funding and limitations on the development of evaluation programmes.

2.2.1 Current theory-practice links

While there have been significant challenges to the development of a comprehensive evidence-base, increasingly ideas and developments from a wide range of fields of enquiry have been synthesised to inform assessment and intervention in clinical practice, for example Carr and Shepherd (1998b) and Partridge (2002). Motor control theories developed and presented in the latter part of the twentieth century have moved away from regarding the nervous system as requiring a stimulus in order to produce movement and towards the recognition that the brain has an inherent ability to initiate action and beyond that to suggest that the exploration of the environment to satisfy the human organism's needs may be the pre-eminent factor (Gibson, 1966). Movement is increasingly recognised not as a distinct entity in itself but as being more effectively associated with a purpose, for example, the achievement of a concrete outcome such as beating a drum (van der Weel, van der Meer, & Lee, 1991). Thus, movement is more accurately considered as something that transpires when there is a task to be achieved.

Following this line of thought, Shumway-Cook and Woolacott describe movement as occurring at the interaction of three factors: the individual, the task and the environment (Shumway-Cook & Woollacott, 2001c) (see figure 2.1). In this conceptualisation all three factors influence the emergent movement, with the type of movement required being determined by the type of task and the environment within which it is undertaken. Equally, the inherent abilities of the individual will influence movement selection and performance. This framework, while relatively simple in its concept, clearly identifies movement as a complex process.

Figure 2.1

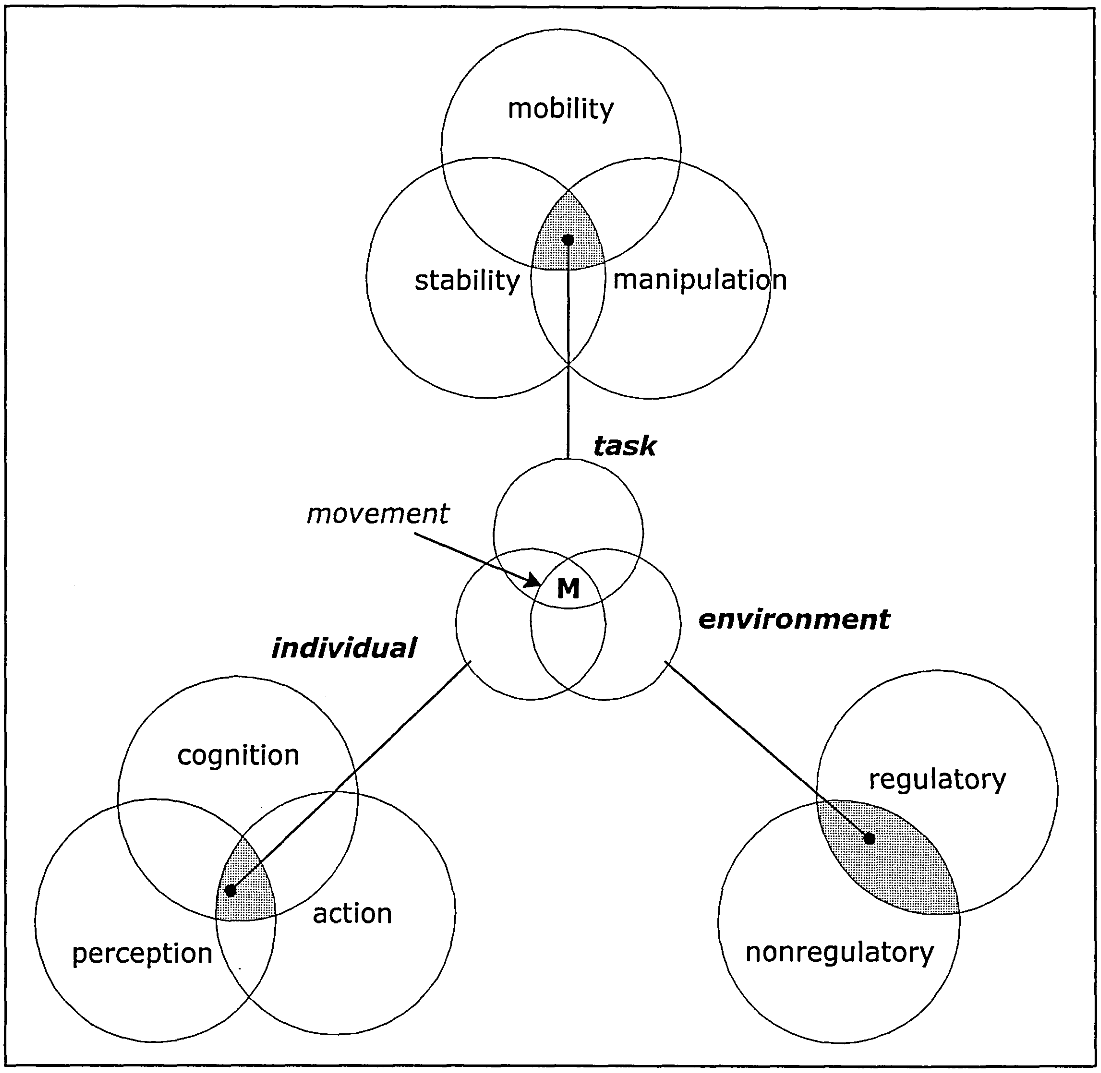


Movement occurring at the interaction of individual, task and environment (Shumway-Cook & Woollacott, 2001e)

Shumway-Cook and Woolacott further define aspects pertaining to each of the primary factors that constrain the emergent movement, amplifying the complexity that underlies the successful production of everyday movement. In defining the three primary factors (individual, task and environment) and the constraints that apply to them (see figure 2.2) they draw on evidence and ideas associated with a variety of theories of motor control, incorporating them into a new conceptual framework, rather than aligning with one particular perspective. By implication this suggests that they do not consider any single theory of motor control sufficient to apply directly to clinical practice.

The framework is a useful step in the process of linking clinical practice to theory in that it clearly illustrates the perceived relationships between key factors affecting the production of normal purposeful movement, derived from a wide body of evidence. It

Figure 2.2



Factors constraining movement (Shumway-Cook & Woollacott, 2001e)

provides a working conceptualisation and a framework within which to develop clinical thinking and practice. However, because the links with research evidence are indirect and the concept is not developed into a working theory of action and perception, limitations remain for direct evaluation of individual components or the conceptual model as a whole. A greater level of understanding of how the sub-factors interrelate and how they are affected by pathology will also be required to further assist the development of assessment processes and critical analysis of findings in therapeutic practice.

Summary

Motor control is the study of the nature and control of movement and is approached from various perspectives, categorised in a variety of ways and set in a range of contexts. Theories of motor control address physiological (tangible) and psychological (abstract) domains or may be developed from behavioural analyses and attributed to central (nervous system) or environmental factors. Comprehensive approaches, such as that of Bernstein and colleagues, are inclusive of structural, behavioural and environmental factors. Authors with an interest in the practical application of theories of motor control give a stronger emphasis to the plastic nature of motor control and so to the roles of experience and practice. Motor control is an active process dependent on a constant state of vigilance of self and the environment and actioned by a complex network of control parameters within the nervous system and via a range of physical structures. Links between the study of motor control in the normal and therapeutic approaches to movement disorders associated with pathology have been tenuous, confused and assumed. Theory-based and research derived clinical practice is a relatively recent development in neurophysiotherapy which requires ongoing development.

3 BALANCE: CONCEPTS AND DERIVATION

3.1 Balance, basic science and medicine

Healthcare practice today is the result of an evolutionary process. Its nature is strongly dictated by medicine but it is also influenced by developing concepts in the basic sciences. In some areas this influence is overt, for example, the use of biomechanics in the development of prosthetics and orthotics. In terms of neurophysiotherapy the links are not so clearly seen. In order to understand influences on current knowledge and practice it is important to briefly review this genesis and to explore its impact and utility.

The term balance as applied to functional human movement within physiotherapy practice is probably derived from two quite separate traditions, from the physical sciences and from medicine. In terms of the physical sciences the link is via biomechanics to Newtonian mechanics. In terms of medicine the primary influences are found in neuroanatomy, physiology and pathology.

3.1.1 Mechanics

Mechanics is a field of study within physics that deals with forces and the effects of forces on solid, liquid and gaseous matter. It comprises a set of basic laws that are applied to a range of sub-disciplines, including a discipline called the mechanics of rigid bodies (Bell, 1998c). The mechanics of rigid bodies comprises three further subdivisions: statics, kinematics and kinetics. Statics is concerned with the description and analysis of forces that tend to cause motion, kinematics is concerned with motion (without reference to mass or force) and kinetics is concerned with motion, mass and the forces that produce motion (Bell, 1998b). The term body when used in mechanics refers to any object, animate or inanimate (Bell, 1998b). Much of Newtonian mechanics is based around Newton's Laws of Motion which variously state that:

- A body at rest or moving with constant velocity in a straight line will remain at rest or continue to move in the same way unless an external force acts upon it

- Force is the product of the mass of a body and acceleration (the rate of change of speed)
- Action forces are always opposed by an equal reaction force (Bell, 1998b).

Discussion of the application and impact of each of these laws centres around three primary phenomena: force, motion and deformation and is dependent on the acceptance of a whole range of mathematical concepts such as mass and time and the rules of mathematical disciplines such as algebra and calculus (Bell, 1998c). Thus diagrammatic representations and mathematical calculations are used to explain or predict the effects of external forces on a body or to define the optimum conditions or qualities required of a body to meet the demands of a particular task.

3.1.2 Biomechanics

Biomechanics is both a concept and branch of applied science. In terms of a concept it is described simply by Bell (1998c) as the application of mechanics to the human body and by Adrian and Cooper (1995a)as the physics of human motion. Winter (1990a) describes biomechanics in terms of two primary components, mechanics and the biophysics of the musculoskeletal system, influenced by the neural system. Taken on their own, the concise definitions given by Bell, and Adrian and Cooper, are seemingly easy to understand but it is the more descriptive outline given by Winter that begins to hint at the complexity of the subject. This tension between the seemingly simple concept of applying mechanics to the human body and the ability to achieve this meaningfully in practice is also apparent in the development of physiotherapy practice (see 3.2.1).

Balance as a mechanical/biomechanical concept

Within mechanics and biomechanics the term balance does not generally appear as a stand-alone concept but is strongly associated with discussion of equilibrium. Equilibrium (from the Latin meaning equal balance) is a core concept relating to the stability of a body. Static equilibrium is the state when there is no net force acting in any direction and no net moment of force about any point in the body (Bell, 1998a), that is, a state of balanced forces. Stable, unstable and neutral equilibrium are terms used to define how a *body* will behave in response to an external force causing slight displacement, directly related to its current level of stability. The stability of a body is a factor of its base of support (the larger the better), centre of gravity (the lower the better) and line of gravity (to remain within the area of the base of support) (Bell, 1998a). Thus in mechanics only static equilibrium is regarded as a true state of balance and this can only occur when a body is at rest.

In relation to biomechanics, Adrian and Cooper define balance as a constant adaptation to forces in order to momentarily attain dynamic equilibrium before adapting and establishing new equilibrium (Adrian & Cooper, 1995b). This suggests that in biomechanical terms balance is not a concept applicable only to a body at rest but that it is an active process of repeatedly achieving an approximation to static equilibrium while not truly being at rest or even when in motion. This use of the term balance to describe a dynamic process is taken further by Winter (1995), who defines it as "a generic term describing the dynamics of body posture to prevent falling". This definition of balance is already somewhat removed from the pure mechanical concept of balanced forces associated with static equilibrium. It does, however, hold up to examination when considered alongside the colloquial use of the term within rehabilitation practice.

3.1.3 Anatomy and physiology

In anatomy the term balance is associated with one of the two divisions of the eighth cranial nerve and with its sensory end organ, housed in the middle ear. The function of the eighth cranial nerve is designated as hearing and balance but the two divisions of the nerve are termed cochlear and vestibular, reflecting the formal anatomical names given to the sensory end organs of hearing and balance respectively (Nolte, 1999c). Anatomical texts refer to balance as a function associated with the eighth cranial nerve and its connections, including the vestibular end organ[1] but they do not define balance function in itself.

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[1] Also known as *the balance organ, the vestibular apparatus* or *the labyrinth*

The structure and function of the constituent parts of the vestibular end organ and its neural connections are clearly described. In summary, there are three semi-circular canals that detect angular acceleration in each of three planes, and two otolithic organs that detect linear acceleration (Nolte, 1999c). Sensory afferent information is conducted from the balance organ to four brainstem nuclei (known collectively as the vestibular nuclei) and to the cerebellum. The vestibular nuclei also receive projections from the cerebellum, the contralateral vestibular end organ and the spinal cord (Nolte, 1999c). The vestibular nuclei project to the spinal cord and cerebellum and also to the nuclei of the third, fourth and sixth cranial nerves (associated with eye movements and vision). There are further projections to the cerebral cortex (via the thalamus) and to the reticular formation (Nolte, 1999c). The neural connections are indicative of functional links with antigravity muscles and neck muscles, eye movements (including the vestibulo-ocular reflex) and whole body position sense (in association with information provided by other proprioceptive systems and the visual system).

Vestibular science

Vestibular science is a subdivision of the wider discipline known as audiological science. Audiological science is based around the study of the structure and function of the organs of hearing and balance and of the pathologies affecting them. Audiological scientists are essentially involved in the development and application of assessments of hearing and balance function, usually within the context of medical practice. The medical practitioners who most commonly provide that context are ear, nose and throat (ENT) surgeons and audiological physicians, who focus on non-surgical interventions. Beyond the UK these practitioners are known collectively as otolaryngologists. A further medical speciality, from a neurological base, known as neuro-otology, may also be linked to audiological science. Physicians and scientists working in this field have in recent years developed a particular non-surgical response to vestibular disorders, which they term vestibular rehabilitation. Centres that provide assessment and rehabilitation in this context are known as centres for balance disorders.

Balance as medical construct

In medical science, then, the term balance is most commonly used with reference to the structure and function of the vestibular (or balance) organ of the inner ear and its neural connections. In keeping with the historical development of medicine, where pathological signs and symptoms tend to be given labels derived from the anatomical structures implicated in the disease process, symptoms associated with dysfunction of the balance organ are known as balance disorders. By inference, the function that is disturbed by these disorders is 'the balance'.

The accepted use of the term balance disorder in medical practice is derived primarily from this focus within the specialities of ENT and audiology, and with neurology and neurosurgery becoming involved in the diagnosis and management of pathologies that extend beyond the middle ear. In the wider neurological context balance may also be used to refer to a physical skill but this usage remains peripheral to the primary focus on the balance organ.

3.2 Concepts of balance in physiotherapy practice

Physiotherapy is defined as a science-based healthcare profession, which views human movement as central to the health and well being of individuals (UK Chartered Society of Physiotherapy, 2002). The physiotherapy profession is a broad church, encompassing practitioners who work in a whole range of health promotion, preventative healthcare, treatment and rehabilitation settings. There is a core undergraduate curriculum but also a diverse range of postgraduate specialisms.

Physiotherapists work with people who have very different levels of physical ability from the elite athlete working to achieve advanced skills or protect against injury, through the person recovering from musculoskeletal injury to the individual who has injury or disease affecting a number of organs or human systems. As a result of working in different contexts, and often without a great deal of contact with other physiotherapy specialisms, professional practice and use of terminology may more closely relate to other disciplines working in the particular field of interest rather than other physiotherapists working in different specialisms.

This discussion does not attempt to review concepts of balance in all areas of physiotherapy practice. It focuses on historical influences on undergraduate teaching and early professional practice and the impact of the emergence and maturation of the postgraduate specialism of neurophysiotherapy.

3.2.1 Early influences

Historically, physiotherapy core skills relate to the application of manual, electrical and exercise-based interventions. Texts for all of these were strongly based on principles derived from the basic sciences and, combined with the study of anatomy, physiology and pathology, were intended to develop an understanding of the active elements of the recommended interventions and the effects of those interventions on the human being in normal and pathological states. As practice developed from the initial focus on massage and the use of light and heat to include the use of electrical currents and therapeutic exercise, texts were expanded to include more physical principles.

For example the seventh edition of Clayton's Electrotherapy and Actinotherapy (Scott, 1975) was the first to include a section on physical principles related to exercise. This section comprised two chapters, one on mechanics and one on the physical principles of exercises in water. In terms of mechanics, Newton's laws are clearly cited and described along with energy, work and power, the principles of levers, pulleys and springs. All are given context in the form of examples of application to the human body or to apparatus that may be used as part of therapeutic exercise programmes. However, the human examples are limited and do not necessarily add clarity. For example, while equilibrium (or balance) is defined as occurring when a body remains at rest, it is also stated that continual adjustment is required of the human body during movement so that equilibrium is maintained. There is a fleeting and global reference to neurological mechanisms that control the body but no reference to the vestibular system.

As the study of human movement and the use of therapeutic exercise become more central to physiotherapy practice, whole texts related to these topics begin to appear. Brunnstrom's Clinical Kinesiology (Brunnstrom, 1962), includes one chapter on

Mechanical Principles which focuses on applied kinematics and kinetics and another entitled Erect Posture, which uses the mechanical principles of equilibrium as its foundation. In the latter chapter the term balance is applied to the whole body and to individual joints in turn to describe the optimum position of equilibrium within and between body segments to achieve a standing position termed comfortable symmetrical posture and "body balance" in other commonly adopted antigravity positions.

A whole chapter entitled Balance (Waddington, 1976) appears in Practical Exercise Therapy (Hollis, 1976), which also includes a chapter on Applied Mechanics and another on Simple Machines. While the latter two chapters revisit a similar range of subjects as covered by Scott (1975) under the heading of Mechanics, the chapter entitled Balance includes only a few paragraphs recognisable as theoretical principles before describing methods of balance re-education. There is brief and simple reference to base of support, centre and line of gravity, with the assertion that depending on the relative position of these three factors, "a body is either balanced – in equilibrium – or not" (Waddington, 1976) p226.

In the style of physiotherapy texts of the time there is no direct referencing of the included material (including no cross-referencing with earlier content in the same book) and the information that is presented is given as fact. Maintenance of balance is said to be "dependent on the one hand upon the integration of sensory input.... and on the other on an integrated motor system and the basic postural reflexes" (Waddington, 1976) (p226). It is said to occur almost completely at a subconscious level and so the recommended approach to treatment is to provide external stimuli to provoke a motor reaction rather than to encourage conscious effort to maintain equilibrium.

Two facets of balance are described by Waddington as necessary for normal function: static balance and dynamic balance. Re-education of static balance (essentially skills of co-contraction to stabilise joints and body segments) is then described as being based on the principles of Proprioceptive Neuromuscular Facilitation. Re-education of dynamic balance (allowing small adjustments to perturbations and a return to the starting position) is described as being based on Bobath principles and techniques. Both of these approaches as described in the text rely on progression through a set of contrived, increasingly unstable positions. The therapist is instructed to give advanced warning of imminent stimuli (for safety), somewhat contrary to the stated requirement of avoiding conscious effort.

Balance as an early physiotherapy construct

The construct of balance in early physiotherapy practice is derived from textbooks and not from independent research studies. These texts are almost entirely based on mechanical principles.

The application of physical principles to physiotherapy intervention was already established in the use of light, heat and electricity prior to movement analysis and therapeutic exercise becoming a core focus of the profession. Extending this approach to include the application of principles of mechanics to human movement appears to have translated reasonably well in terms of providing guidance concerning equilibrium around joints and between body segments. It was used in this regard both to provide benchmarks for assessment and to provide target outcomes for therapeutic interventions such as segmental alignment, whole body postural correction and efficient muscular control for stability. There is also some clear logic in the general application of the laws of stability to the whole human body, promoting understanding of the relative stability of commonly adopted positions and postures.

However, the adherence to a singular approach with inherent issues of application had clear limitations and, although there is some evidence of linkage with the concept of neural control, this is confused and confusing. It is also of interest to note the lack of influence on these early texts of the strong emphasis on the vestibular organ and its connections, so apparent in medicine.

Waddington's chapter on Balance (Waddington, 1976) is unusual in that it is clearly intended to direct treatment in the presence of balance disorder. Underpinning principles, biomechanical or otherwise are sparse and the target group for the treatment approach outlined is inclusive of a range of injury and disease. Treatment details borrow from the developing speciality of neurophysiotherapy but are presented without context. There is no discussion of assessment of the nature of the disorder and an implicit understanding that remediation should be tackled by eliciting reflex motor responses to maintain equilibrium in either static postures or dynamic situations.

Balance as an early physiotherapy construct is, then, closely related to that of mechanics but is also seen to depend on effective muscular control. There is lack of clarity about how effective muscular control is achieved and an almost complete absence of attention to sensory factors.

3.2.2 Neurophysiotherapy

Definition of the physiotherapist's role within neurology is also primarily textbook-based. These texts begin to appear in the 1970's. The emphasis on biomechanics, so apparent in the non-neurological texts of the same era, is notable by its absence. Instead there is a focus on applied anatomy and physiology, neural reflexes and patterns of movement. For example, Bobath (1970; 1978) discusses the range of components required to effect sufficient background control for normal functional movement under the composite heading of the Normal Postural Reflex Mechanism. This mechanism, which to all intents and purposes is indistinguishable from Winter's definition of balance (a generic term describing the dynamics of body posture to prevent falling) (Winter, 1995), is said to comprise righting reactions, equilibrium reactions and automatic adaptation of muscles to changes in posture. Similarly, Atkinson (1977a) discusses the importance of the suprasegmental reflexes concerned with postural activities, subdivided into antigravity mechanisms, reflexes concerned with obtaining an upright position and body alignment, and equilibrium and tilting reactions. Both Bobath (1978) and Atkinson (1977b) stress the importance of integration of the multiple factors cited for effective postural control and describe apparent loss of that integration in the presence of pathology as a regression to more primitive movement patterns. Both acknowledge the impact of sensory dysfunction on performance and potential for recovery and Atkinson includes an eyes closed condition in the assessment of balance, but neither author refers directly to vestibular organ or system dysfunction.

Balance as an early neurophysiotherapy construct

Balance as an early neurophysiotherapy construct is inextricably linked with mechanisms of postural control. In turn, postural control is understood as comprising interrelating neural reflexes developed and modified over a period of maturation and via a recognisable progression through a series of physical milestones. This analysis is consistent with the generally accepted neurophysiological theories of the time. The belief that the 'regressions' seen in the presence of pathology could be positively influenced or even reversed via manipulation of the peripheral sensory system was a more radical view. General statements acknowledging the importance of afferent sensory information are not developed and even when included within proposed assessment parameters there is no description of how this should link into any formulation process. Treatments focus on motor performance and primarily on motor response to contrived stimuli. References to the impact on motor performance of musculoskeletal or environment factors are not prominent and, like sensory factors, are not overtly integrated into problem analysis or treatment planning.

Developments associated with a maturing speciality

Neurophysiotherapy has over the last twenty years been engaged in a change process with reference to the basic assumptions that underpin its practice. The dynamic for change has had three major components: increased demand for rehabilitation, dissatisfaction with treatment outcomes and advances in the understanding of the neural bases of movement (Gordon, 2000). The dominant theoretical base, which has been termed the Neurophysiological Approach, has faced increasing challenges as its applications have failed to produce the levels of successful outcomes required in the current healthcare context, including higher levels of expectation in the patient population (Gordon, 2000).

Current texts are more likely to offer a range of potentially applicable evidence-based theories, critically appraised, and to recognise the need for inclusive models or wider systematic approaches to the analysis of any perceived movement difficulties, for example, the Systems Approach of Woolacott and Shumway-Cook (2001e; 1990) and Movement Science as presented by Carr and Shepherd (2000b).

The Systems Approach (Shumway-Cook & Woollacott, 2001e) sees balance as synonymous with postural stability and this is defined as the ability to maintain the body in equilibrium. Postural stability and postural orientation (defined as the ability to maintain an appropriate relationship between body segments and between body and the environment for task) together result in overall postural control. A conceptual model of seven overlapping systems underpinning postural control is given to include:

- Musculoskeletal components
- Neuromuscular synergies
- Individual sensory systems
- Sensory strategies
- Anticipatory mechanisms
- Adaptive mechanisms
- Internal representations.

The demands on each system and how they are required to work together are clearly identified as being interdependent with the task in hand and the environmental context.

Within Movement Science, balance is defined as the process by which the body's equilibrium is controlled for a given purpose and the ability to control the body mass or centre of gravity relative to the base of support (Carr & Shepherd, 2000a). Postural adjustments and the need to control body segments are given prominence, as are the importance of task and environmental context. As within the Systems Approach, a range of body systems and subsystems is recognised as contributing to the achievement of appropriate body equilibrium at rest and during movement, including sensory, motor, musculoskeletal and various neural systems.

De Weert and Spaepen (1999) present their analysis of balance from a different perspective than the standard focus on postural control. They divide their discussion into two components: the sense of balance and the mechanism of balance. The sense of balance is said to comprise the vestibular system and in normal circumstances to be a sense that we are relatively unaware of. But equally they recognise that this is easily changed to a clear perception of sensation in circumstances where balance is lost or there are higher levels of stimulation. The mechanism of balance is described as being dependent on an intrinsic cooperation between the vestibular system, proprioceptive and tactile information and vision, and on central interpretative mechanisms and musculoskeletal properties (de Weerdt & Spaepen, 1999).

Balance as a construct within developing neurophysiotherapy practice

The intellectual activity associated with the maturation of the neurophysiotherapy specialism has begun to test assumptions underlying clinical practice (Ragnarsdóttir, 1996), has uncovered a wide range of applicable literature (Carr & Shepherd, 2000b; Shumway-Cook & Woollacott, 2001e) and led to balance being discussed in a wider context (Huxham, Goldie, & Patla, 2001). Not all authors give equal emphasis to the same subsystems and there are variances in the scope and detail of the context that is described. However, the need for some sort of systems analysis, based on a range of contributory factors is constant and there are some core messages. The focus on postural control remains but is accompanied by a clear acknowledgement of the influence of central nervous system processes beyond movement execution, and of other body systems (Browne & O'Hare, 2001). Environmental context and the importance of task or purpose are also given prominence (Huxham et al., 2001). Postural control is seen as a dynamic, multifactorial and purposeful process.

De Weert and Spaepen (1999) introduce an interesting dimension in the definition of balance in making reference to two components: the sense and the mechanism. This rather neatly overcomes prior limitations enforced by the focus on postural control and gives an overall matrix within which the senses and sensory process have equal standing with physical structure and motor function. Awareness of the importance of the sense of balance is increasing within neurophysiotherapy practice (Kammerlind, Bergquist Larsson, Ledin et al., 2005; Maskell, chiarelli, & Isles, 2006)but inclusive assessment practices and clinical reasoning to determine management programmes based on consideration of all the factors have yet to be fully developed.

Summary

Concepts of balance within physiotherapy practice were originally derived from mechanical principles borrowed from the physical sciences and have been modified over time to reflect changes in neurophysiological understanding and knowledge development over a wide range of biomedical sciences. While medical practitioners have predominately considered balance to be associated with the peripheral vestibular system, physiotherapists have variously focused on biomechanical models and/or motor outputs of the central nervous system that achieve postural control. Current neurophysiotherapy paradigms incorporate a range of developing knowledge including the results of critical analysis of the content and efficacy of clinical practice. They reflect a more holistic analysis of balance function in the context of inclusive multi-system models of postural control and movement that extend beyond the person to include task and environmental influences. Nomenclature remains an issue within the speciality and across disciplines. The term balance continues to be used:

- generically to describe effective physical performance that prevents falling
- more precisely to mean the state when the body is stabilised over the base of support
- interchangeably with the term postural control
- to refer (sometimes indirectly) to a human sense.

4 BALANCE ASSESSMENT AND EVALUATION

4.1 Academic influences

Interest in human balance is not limited to clinical practice nor confined to the study of balance disorder. It is also a focus for research associated with the development of theory in relation to balance itself, and to wider sensorimotor performance. The scope of research and the relative emphasis on balance within research programmes varies, and there is a spectrum of work involving so-called 'normal' subjects (Carpenter, Allum, & Honegger, 1999), elite athletes (Ageberg, Roberts, Holmstrom et al., 2005) and other specialist groups, for example, astronauts (Paloski, 1998). Some research teams confine themselves to non-pathological subjects but others have interest in a wider variety of participants. Increasingly, research groups will comprise a range of personnel from a variety of academic and clinical areas. Hypotheses and findings from academic studies, and methods of investigation used within them, are sources of influence on clinical practice. There are, however, issues of applicability and feasibility in directly employing scientific approaches or laboratory findings within clinical practice.

4.2 Approaches to assessment

Approaches to, and methods of, balance assessment and evaluation are diverse and varied in focus. Assessment approaches and methods may relate to how balance is conceptualised or to the rationale for performing an assessment or to both. Some assessment methods are clearly set within a theoretical context, some loosely derived and others more overtly linked to a practical outcome.

4.2.1 Influence of purpose

Balance assessment and investigation is undertaken for a variety of purposes. In the clinical field this is most commonly to establish a pathological diagnosis, identify the location of a lesion or guide decisions about treatment (Herdman, 2000; Shepard &

Telian, 1996e; Shumway-Cook & Woollacott, 2001d). In research there is an infinite variety of reasons to explore balance, for example, to describe new syndromes (Brandt, 1996; Bronstein, 1995; Karlberg, 1995), to understand the limitations of existing tests (Di Fabio, Emasithi, & Paul, 1998; Lempert, 1998), to develop new tests (Bath, Harris, & Yardley, 1998), to understand and develop the effects of treatment programmes (Hamman, Mekjavic, Mallinson et al., 1992) or to question the meaning of assessment findings (Bonanni & Newton, 1998; C. R. Gordon, Fletcher, Jones et al., 1995). Programmes of enquiry may also aim to add to the understanding of subsystems, for example, vision (Leigh & Zee, 1991), associated functions such as spatial orientation (Berthoz & Viaud-Delmon, 1999) or the role of individual subcomponents in achieving postural control (Allum et al., 1998). To present a comprehensive review of all the methodological approaches would be beyond the scope of this contextual chapter so description is limited to common approaches to the evaluation of balance skills and ability as a whole.

4.2.2 Biomechanics and motor control

Biomechanical assessment, as opposed to assessment based on biomechanical principles, takes a quantitative approach to movement analysis. In this context, balance assessment is seen as a dimension of motor control. Various techniques are applied to allow the analysis of postural stability and movement characteristics during a range of natural and contrived tasks. Winter describes this process of assessment (or diagnosis) as comprising initial measurement and descriptive phases, which are usually followed by model-based analysis (Winter, 1990b).

The techniques most commonly applied to questions of balance are kinematics (describing movement without reference to forces) and kinetics (describing forces associated with movement) (de Weerdt & Spaepen, 1999). Other techniques, such as anthropometry (measurements and properties of body parts and significant structures), muscle and joint biomechanics (mechanical and behavioural characteristics) and electromyography (EMG) (neural signals and muscle activation) are also used to develop biomechanical models (Winter, 1990b).

Kinematics

Movement is measured with reference to segmental displacement, velocity or acceleration, focusing on either individual body segments or on composite segments as if they are one, depending on the experimental model in use (Winter, 1990c). Various photographic or cinematographic techniques have been developed to aid movement analysis (Winter, 1990c). Computer hardware and software developments have more recently resulted in a choice of commercially produced systems allowing three-dimensional video analysis with automated data conversion from a series of reference points on the subject, for example, The MotionMonitor[2] or ViconMX[3].

Kinetics

Forces associated with movement are measured indirectly via ground reaction forces and muscle moments using force plates and EMG. The process by which the forces are calculated is called linked segmental modelling (Winter, 1990d). Models are developed from known values calculated via prior anthropometric studies to have an anatomical equivalence, although some approximations and assumptions are accepted to simplify data collection and analysis (Winter, 1990d).

Research paradigms

In research, balance is commonly studied via a combination of kinetic and kinematic techniques which record body segment motion, reaction forces and torques before, during and after balance is perturbed (Balasubramaniam & Wing, 2002). Perturbations vary across paradigms and may be predictable or unpredictable, or self-generated, for example, via limb movement or more subtly via the active process of maintaining equilibrium during upright stance in the presence of gravity (Balasubramaniam & Wing, 2002).

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[2] Northern Digital Inc., Waterloo, Ontario

[3] Vicon Motion Systems, Oxford, UK

Applications

Balance assessment via kinematic and kinetic analysis assesses motor behaviour under a variety of circumstances and may be used to increase understanding of normal balance strategies and influencing factors. It can also be used to identify variances of behaviour between normal subjects and those with a variety of pathologies. There is significant potential to develop more advanced understanding of the impact of underlying deficits on balance performance when combined with other clinical and laboratory assessment. However, access to systems is currently limited by cost and the need for laboratory space and significant technical support. In addition, research paradigms incorporating more mobile conditions beyond standing and stepping need to be developed to allow exploration of balance abilities during more dynamic activities.

4.2.3 Neuro-otology, otolaryngology and vestibular science

Neuro-otology and otolaryngology are medical specialisms whose scope of practice includes people with balance disorders. Vestibular scientists work in parallel with these medical specialisms, assisting diagnosis and sometimes contributing to management. Balance assessment in the neuro-otological, otolaryngological and vestibular science field ranges across an extensive series of clinical and laboratory tests. Texts and review articles usually describe the range of possible tests, rather than describe a definitive protocol. This partly relates to the range of conditions that may be seen but is also a function of the targeted focus and imprecise nature of some tests and to limitations of access to more costly alternatives.

History taking

Shepard and Telian (1996b) state that

> "A complete clinical history is probably the single most important portion of the diagnostic evaluation of the balance disorder patient". p33

They stress the importance of understanding the temporal development of signs and symptoms and make it clear that without this knowledge is it impossible to differentiate between many potential diagnoses using only test findings. Honrubia (2000) similarly stresses the importance of the individual's description of any dizziness and the key role of the clinical evaluation in the overall diagnostic formulation. The clinical history is also of importance in guiding treatment decisions and, in particular, establishing who may benefit from rehabilitation therapy (Shepard & Telian, 1996b). Information about past and current medication is important as it may have had or may be continuing to have an impact on compensatory processes (Shepard & Telian, 1996b).

Physical examination

In addition to tests focused on the balance system, the physical examination will routinely include full otoscopic[4] and cranial nerve examination. Clinical tests of balance system function can be grouped under the headings:

- ocular motor function/gaze and spontaneous nystagmus
- vestibulo-ocular reflex (VOR) function, and
- vestibulo-spinal reflex and postural control function (Shepard & Telian, 1996b).

Essentially, the clinical examination looks in turn at visual, vestibular and postural behaviours (and sensation in the distal lower limbs). Shephard and Telian (1996b) describe these clinical tests as variations of the related laboratory tests but with less ability to quantify the outcomes. And while laboratory tests may produce invaluable permanent records, they are not always as sensitive as visual inspection, for example, in the case of electronystagmography (ENG), a method of recording eye movements via the changes in electrical potential between the cornea and the retina (Honrubia, 2000).

Laboratory testing

ENG can be used to record eye movement during ocular-motor assessment, rapid positioning and other positional tests, and most commonly to record eye response during caloric testing (Baloh & Furman, 1989).

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[4] examination of the ear canal and integrity of the eardrum

Caloric testing

The bithermal caloric test is a method of assessing imbalance between the two balance organs which involves the introduction of a non-physiological stimulus (either water or air) that creates a temperature gradient, primarily across the horizontal semicircular canal (Honrubia, 2000). The test measures only low frequency response (0.002 to 0.004Hz) (Shepard & Telian, 1996a) and there is a great deal of intersubject variability in terms of response (Honrubia, 2000), limiting the test's immediate usefulness only to assessing loss or reduction in low frequency response. Accurate results also depend on symmetrical anatomy and the achievement of an equal stimulus to both sides (Shepard & Telian, 1996a).

Ocular motor testing

Various paradigms are employed to assess visual fixation[5], smooth pursuit[6] and saccadic[7] eye movements, and optokinetic nystagmus[8] (Shepard & Telian, 1996c). Eye movement testing is commonly standardised via a light bar which produces a predictable stimulus (Shepard & Telian, 1996c). Analysis can be effected via predetermined computer algorithms and against established normative data (Honrubia, 2000). Optokinetic testing is most accurately achieved via full field stimulus (using a striped or other repeating pattern) rather than by handheld drum, which is unlikely to fill the 90% of the field required to achieve a full optokinetic response (Honrubia, 2000; Shepard & Telian, 1996c).

Rotational chair testing

A further test, aimed at assessing the peripheral vestibular system beyond the limitations of ENG and caloric testing is rotational chair testing (Baloh & Furman, 1989). This is generally undertaken in the form of whole body rotation. Testing is possible across a range of frequencies up to 2 Hz and is not dependent on the physical features of the ear

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[5] ability to hold an image steady on the fovea

[6] ability to track a moving object with the eyes when the head is stationary

[7] ability to move the eyes from one stationary target to another when the head is stationary

[8] nystagmus caused by the movement of objects in the visual field

or temporal bone (Baloh & Furman, 1989; Honrubia, 2000), although difficulties in ensuring the prevention of differential movement between skin and skull at higher frequencies means that testing is generally only regarded as reliable up to 1 Hz (Shepard & Telian, 1996f). Indications of peripheral vestibular system pathology can be demonstrated via rotational chair testing in individuals with completely normal ENG's (80% in one study) (Shepard & Telian, 1996f). However, not all who have ENG abnormalities demonstrate pathology on rotational chair testing (Shepard & Telian, 1996f). Various test protocols are used to explore the desired stimulus-response target, most commonly sinusoidal or step test protocols (Baloh & Furman, 1989; Shepard & Telian, 1996f).

Postural evaluation and posturography

The final, and most recently developed, area of testing undertaken in this field is that of postural control evaluation. Unlike the tests already described which have a focus on the location and extent of pathology within the vestibular system, postural control evaluation is used to assess functional capacity in the balance disorder patient (Furman, 1994; Shepard & Telian, 1996d). This includes analysis of control of body mass over base of support via response timings and patterns following perturbations, using kinematic techniques similar to those described in the previous section.

Table 4.1

CONDITION NUMBER	VISUAL CONDITION	SURFACE CONDITION
1	Normal	Normal
2	Blindfold	Normal
3	Dome	Normal
4	Normal	Foam
5	Blindfold	Foam
6	Dome	Foam

Six sensory conditions for the Clinical Test for Sensory Interaction in Balance (Shumway-Cook & Horak, 1986)

Increasingly, postural control is assessed in different sensory conditions using commercially developed technologies such as the EquiTest[9], based on the six sensory conditions first described by Shumway-Cook and Horak (1986) (see table 4.1). The EquiTest documents the position and movement of the centre of mass while standing under each sensory condition (the sensory organisation test) and following sudden perturbations (the motor control test) (Shepard & Telian, 1996d).

Additional vestibular rehabilitation assessment

Vestibular rehabilitation programmes may be delivered within otolaryngology (ENT) departments (Beyts, 1987), defined as a specific approach within physiotherapy (Horak, Jones-Rycdewicz, Black et al., 1992) or seen as a focus for collaboration across disciplines (Shepard & Telian, 1996g). Depending on the scope and approach to rehabilitation programmes, including the measures chosen to evaluate outcomes, a varied series of additional assessments are advocated. These may include the use of questionnaires, investigation of dizziness-provoking movements, tests of peripheral sensation, musculoskeletal examination and additional observations of motor control and functional movement (Borello-France, Whitney, & Herdman, 1994). Some authors include at least a limited evaluation of cognitive ability, for example, remembering and following instructions (Shepard & Telian, 1996g).

Applications

The traditional scope of neuro-otological assessment, combining symptomatic history with clinical examination and laboratory testing has the purposeful outcome of identifying the location of a lesion, achieving a pathological diagnosis or both. However, this is an inexact process and it is of particular note that the results of individual tests alone do not provide clarity of diagnosis.

It is also of note that results from the laboratory tests described above do not correlate directly with functional capacity in individual patients, whereas a relationship has been

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[9] NeuroCom International, Inc., Clackamas, Oregon

demonstrated with posturography and self assessment questionnaires (Shepard & Telian, 1996d). Except for the information that may be gleaned from some laboratory tests about the level of compensation to vestibular pathology (Shepard & Telian, 1996a), assessment and evaluation strategies associated with vestibular rehabilitation as they appear in the literature are strongly weighted towards clinical assessment, including the use of questionnaires (Borello-France et al., 1994; Shepard & Telian, 1996g). Formal vestibular rehabilitation programmes cannot, therefore, be appropriately designed and developed from the results of a traditional neuro-otolgical investigaton alone and by implication require cross disciplinary collaboration to ensure suitably personalised guidance.

4.2.4 Neurorehabilitation

Neurorehabilitaion is an area of healthcare practice concerned with re-enablement or prevention of functional deterioration in the presence of neurological injury or disease. Balance assessment within this context is usually undertaken by a neurophysiotherapist as part of a more global assessment of strengths and limitations, and as a basis from which to develop a therapeutic programme and/or detailed management advice.

Assessment is primarily focused on functional ability and safety as judged via the analysis of variation from normal motor performance. How that judgment is developed may be guided by the wider conceptualisation of motor control within which the therapist operates and any associated concept of balance or may be influenced by the use of available assessment tools.

Concepts of balance within neurophysiotherapy are in a state of flux but are inextricably linked with concepts of postural control (see 3.2.2). Postural control has been regarded both as a simple biomechanical process and as being under the control of a stereotypical, reflex-based central nervous system. Postural control is now increasingly viewed as a dynamic, multifactorial and purposeful process (Carr & Shepherd, 2000b; Shumway-Cook & Woollacott, 2001e). Assessment strategies reflect the current stage of development of these theories of postural control and vary in emphasis dependent on the strength of focus on individual factors within each theory.

Assessment strategies

Most authors focus on what De Weerdt and Spaepen (1999) term the mechanism of balance, analysing the ability to safely and efficiently perform various physical actions. The degree to which this is further analysed to identify reasons for functional limitations then varies. Standardised assessments, focused mainly on structured observation of functional movement, are also recommended and are sometimes suggested as outcome measures (Bennet & Karnes, 1998; Carr & Shepherd, 1998a).

The importance of biomechanical markers and task specific training is reflected in Carr and Shepherd's assessment guidance (Carr & Shepherd, 2000a). This guidance includes analysis of the muscle activity required to support body mass against gravity, observation of how body segments are controlled relative to each other and how body alignment relates to the task environment. Alignment is also considered with regards to the individual's limits of stability[10]. Finally, consideration is given to the nature of observed impairments, with particular emphasis on the impact on the ability to perform the required task, and increasingly complex tasks with reference to limits of stability.

The task orientated approach advocated by Shumway-Cook and Woollacott (2001b) defines an assessment process that examines postural control on three levels: function skills, motor and sensory strategies, and motor, sensory and cognitive impairments. Within this approach, standardised observational assessments may be used, but are recognised as giving an incomplete analysis of functional ability. Additional structured observations are advocated to allow observation of motor strategies used to accommodate a range of internal and externally induced perturbations. The Clinical Test for Sensory Integration in Balance (Shumway-Cook & Horak, 1986) is suggested as a method of assessing preferred sensory strategies. Finally, evaluation of potential underlying impairment, focused on key areas such as lower limb strength and mobility, is seen as essential to the completion of a comprehensive problem list and action plan (Shumway-Cook & Woollacott, 2001b).

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[10] the distance a person can move their centre of mass while standing before losing balance or taking a step

De Weerdt and Spaepen (1999) focus their description of balance assessment on a brief review of kinematic and kinetic analyses (as outlined in 4.2.2) and on a more comprehensive review of a series of clinically based tests under the heading of clinical evaluation theorem. The latter includes a range of tests drawn from neuro-otological traditions and a structured set of observations similar to those used by Shumway–Cook and Woollacott to identify motor strategies. More unusually for movement-based physiotherapy texts, De Weerdt and Spaepen deal, albeit briefly, with issues of sensory disorientation, advocating the importance of history taking, and in addition mention the need to assess for the presence of cervicogenic vertigo.

For all the examples given so far in this section, there is the implicit assumption that the specific tests or assessment strategies described can or will be undertaken by the therapist. Bennet and Karnes (1998), however, describe an assessment regime to be undertaken by the therapist and also introduce wider contextual information relating to tests that may be carried out by others as part of a process of identifying the origin of the impairment. The therapist's evaluation is structured around assessment of disability, via observation of functional movement, and partial assessment of impairment, via motor and sensory assessment as is possible within the non-specialist clinic. Additional information about the origin of impairment is seen as only potentially available, via laboratory or other specialist testing and there is a recognition that in some cases, for example, when assessing a person with multiple sclerosis, the absolute source of the impairment may not be easily defined (Bennet & Karnes, 1998). While this level of uncertainty may appear unsatisfactory in terms of the completeness of assessment (based on all available possibilities) it probably best reflects the realities of the majority of therapeutic practice at this time.

Standardised assessment tools

There is a range of published clinical assessment tools promoted for use within physiotherapy practice. One of the first and now most established tools is the Berg Balance Scale (Berg, 1989; Berg, Wood-Dauphinee, Williams et al., 1989), a structured observational tool with 14 separate physical performance observations each rated on a five point scale. This assessment tool has been the subject of extensive reliability and validity studies by its authors (Berg, Maki, Williams et al., 1992; Berg, Wood, &

Williams, 1995) and others (Steffen, Hacker, & Mollinger, 2002; Stevenson, 2001; Wee, Wong, & Palepu, 2003) and is often the assessment of choice against which to test the validity of new measures, for example (Whitney, Wrisley, & Furman, 2003). However, while it has proven to be a reliable instrument (Berg et al., 1992; Browne & O'Hare, 2001) and valid for use with older adults (Steffen et al., 2002; Thorban & Newton, 1996) and some stroke patients (Mao, Hsueh, Tang et al., 2002; Wee et al., 2003), limitations for use with a range of neurological conditions, including stroke, have now been reported (Cattaneo, Regola, & Meotti, 2006; Gustavsen, Aamodt, & Mengshoel, 2006; Inness, Niechwiej, Jagal et al., 2005; Stevenson, 2001). Primarily, these are ceiling effects and issues of sensitivity including the lack of ability to predict fallers. Similar problems are also reported for those with peripheral arthritis (Noren, Bogren, Bolin et al., 2001).

Another well established tool is the Timed Up and Go Test, which requires the subject to stand up from a chair, walk three metres and then return to the seat. Originally a graded observer-rated assessment (Mathias, Nayak, & Isaacs, 1986), the method of assessment was changed to that of timing the completed activity (Podsiadlo & Richardson, 1991) to improve reliability and increase sensitivity to change. Construct validity has been established and reliability for use with frail older adults (Hughes, Osman, & Woods, 1998; Podsiadlo & Richardson, 1991; Shumway-Cook, Brauer, & Woollacott, 2000), those with Parkinson's disease (Morris & Iansek, 2001) and those with lower limb amputations (Schoppen, Boonstra, Groothoff et al., 1999). It has been found to be highly predictive of elderly fallers (Shumway-Cook et al., 2000). However, although it has been shown to be sensitive to change in performance for patients with multiple sclerosis (Smedal, Lygren, Myhr et al., 2006), it does not discriminate between those who do and do not fall (Cattaneo et al., 2006). This may well be because it measures only a narrow aspect of balance function (Whitney, 1998) insufficient to address the range of potential impairments associated with diffuse neurological disease.

Both the Berg Balance Scale (BBS) and the Timed Up and Go Test (TUG) focus on physical performance, the BBS covering a range of individual everyday physical tasks and the TUG a proxy activity thought to be indicative of balance function. The Tinneti Balance Test is another tool that assesses a range of physical tasks, including aspects of gait, but was developed specifically to identify those (older adults) at risk of falling

(Tinetti, 1986). There is some early evidence of reliability and validity (Tinetti & Ginter, 1988) and two more recent studies demonstrating fair to good reliability across clinicians with a range of experience (Cipriany-Dacko, Johannsen, & Rude, 1997) and some predictive ability in identifying elderly fallers (Raîche, Hébert, Prince et al., 2000). There are no published studies with reference to younger adults with neurological disease.

The Functional Reach test for balance(Duncan, Weiner, Chandler et al., 1990) is another tool that uses a proxy activity, the excursion of forward reach in standing, to draw inference about balance function and risk of falls. The validity of the measure hinges on there being a positive correlation between forward reach and displacement of centre of pressure and there is conflicting evidence of how pure a measure this (Duncan et al., 1990; Jonsson, Henriksson, & Hirschfeld, 2003) and whether it is a good proxy for dynamic balance (Wernick-Robinson, Krebs, & Giorgetti, 1999). Its predictive value is also modest (Eagle, Salamara, Whitman et al., 1999) and questions have been raised about its feasibility of use for the general elderly population and in particular those with cognitive impairment (Rockwood, Awalt, Carver et al., 2000) and with Altzheimer's disease (Goodgold, Kiami, Ule et al., 2001). There is conflicting evidence of concurrent validity with the Berg Balance Scale when used across a broad adult population, including within neurological rehabilitation (Bennie, Bruner, Dizon et al., 2003), and in an acute stroke population (Smith, Hembree, & Thompson, 2004) and it is of limited value in predicting fallers in those with Parkinson's disease (Behrman, Light, Flynn et al., 2002).

The Rivermead Mobility Index (RMI), unlike all of the measures mentioned so far, was developed specifically with a neurological patient group in mind, but as a measure of functional mobility rather than a measure of balance per se (Collen, Wade, Robb et al., 1991). Initial reliability for a cohort of inpatient stroke and head injury patients was found to be high and there was a moderate correlation with standing balance (Collen et al., 1991). A review paper published in 1999 found that the RMI had been used in seven subsequent studies, primarily relating to stroke and multiple sclerosis (Forlander & Bohannon, 1999). Evidence from these studies was mixed in terms of the RMI's ability to document change associated with therapy but on balance the authors thought the combination of the positive findings and the simplicity of the measure indicated that it should be more widely used (Forlander & Bohannon, 1999). However, a survey of practice amongst physiotherapist involved in stoke care published in 1996 reported that only four out of 91 therapists used the RMI (Sackley & Lincoln, 1996). A recent study involving a stroke population demonstrates good concurrent validity and sensitivity to change over time (Hsieh, Hsueh, & Mao, 2000) and one involving patients with myotonic dystorophy concluded that fallers had on average lower RMI score than those who did not (Wiles, Busse, Sampson et al., 2006).

Some assessment tools focus not on physical performance but on the individuals own report of their symptoms, such as the Dizziness Handicap Inventory (DHI)(Jacobson & Newman, 1990) or perception of their risk of falling, such as the Falls Efficacy Scale (FES) (Tinetti, Richman, & Powell, 1990) and the Activities-specific Balance Confidence (ABC) Scale (Powell & Mys, 1995). Most of the reliability testing on the DHI has been carried out patients with vestibular dysfunction and the tool is used widely with patients reporting dizziness from various pathologies affecting the vestibular system (Kammerlind et al., 2005). The FES (Tinetti et al., 1990) and ABC (Powell & Mys, 1995) were developed for use with older adults, the latter focusing on a slightly higher functioning population. Both have high levels of reliability and validity for their target populations (Jørstad, Hauer, Becker et al., 2005) and there is some support for the use of the FES in the stroke population (Hellström & Lindmark, 1999; Hellstrom, Lindmark, & Fugl-Meyer, 2002) but since this is at the level of possessing similar sensitivity to the BBS, for which there is conflicting evidence, it remains of dubious value.

Not withstanding the limitations of all of these measures for adults with neurodisability in terms of their ability to detect change in performance or predict those at risk of falling, they are not generating assessment data at the level that would strongly influence the design of programmes of intervention. They are not set in the context of any particular theory of motor control nor are they overtly linked with a particular concept of balance. Most measures focus on physical performance, while a few acknowledge the impact of self-perception and confidence. None of these measures address sensory factors.

The Clinical Test for Sensory Interaction in Balance (Shumway-Cook & Horak, 1986) (see 4.2.3) was designed to test the influence of visual, proprioceptive and vestibular information on balance and has been shown to discriminate between those with vestibular function and those without (Cohen, Blatchly, & Gombash, 1993). The reliability of conditions three and six, designed to stabilise the visual field, has been called into question for this clinical test (Shumway-Cook, 2000) and the associated computerised version (Sensory Organisation Test) (Di Fabio et al., 1998) and a modified version with these two conditions removed is now in use (Shumway-Cook, 2000). The clinical and computerised versions have been shown to correlate (El-Kashlan, Shephard, Asher et al., 1998) with increased sensitivity of the clinical test, and increased correlation, when subjects are instructed to place the feet close together (Wrisley & Whitney, 2004). Interestingly, findings remain consistent whether or not footwear is worn (Whitney & Wrisley, 2004).

The limitations of current measures, the need to better understand the nature of specific conditions underlying balance and mobility disorders and the need to understand the context of clincal practice within which reliable and valid measures should sit are now recognised. For example Tyson and De Souza (2003) developed a clinical model for the assessment of posture and balance following stroke by UK physiotherapists via a series of focus groups. They have gone on to develop and validate a new scale based on this model (Tyson & DeSouza, 2004a, 2004b). Within TBI provision a similar approach to the assessment of balance and high-level community mobility has been undertaken by a Canadian group, resulting in the Community Balance and Mobility Scale (Howe, Inness, Venturini et al., 2006; Inness et al., 2005). With reference to Parkinson's disease Jacobs and colleagues are promoting the use of a multiple assessment approach to improve assessment and predictive abilities (Jacobs, Horak, Tran et al., 2006). Only the Community Balance and Mobility Scale, with its "crouch and walk", "walking and looking" and "walk, look and carry" dimensions begins to address one of the major criticisms of balance assessment levied by Huxham and colleagues (Huxham et al., 2001), the lack of testing proactive balance function.

Additional vestibular rehabilitation assessment

There is an increasing level of recognition of the impact of vestibular system dysfunction on functional movement (de Weerdt & Spaepen, 1999; Shumway-Cook & Woollacott, 2001a) and the need to develop core skills related to vestibular system dysfunction and assessment skills within neurophysiotherapy practice (Campbell, 2004; Meldrum & McConn Walsh, 2004). However, even where the need has been recognised, vestibular rehabilitation is still seen essentially as a programme additional to core neurorehabilitation practice (Shumway-Cook, 2000). This seems to be particularly the case when pathology or other circumstances bring about an awareness of balance sensations, resulting in dizziness or other forms of sensory disorientation. Professional awareness, competencies and the scope of clinical practice within neurorehabilitation have yet to develop to a level at which comprehensive assessment of balance dysfunction, inclusive of specific assessment of the vestibular system, is regarded as routine.

Applications

Balance assessment as currently developed in neurophysiotherapy practice remains focused on the mechanism of balance (or postural control) and at least partly excludes consideration of the sense of balance within standard practice. However within developing assessment strategies, attention is paid (in varying degrees within various approaches) to a wide range of underlying factors that have the potential to contribute to problems of postural control, including the analysis of body systems and compensatory strategies. Where there is a clear theory base that stresses a task/environment focus, it may be considered that there is also an implicit need to explore the effects of complex environments or demanding tasks on functional performance, but this is not explicitly stated. Similarly there is only limited reference to the impact of visual and cognitive dysfunction. Standardised measures, though recommended as being of potential use as outcome measures, are not prominent in their use and very few have proven validity for younger adults with neurodisability. However, the commonly adopted structured approach of functional and impairment focused observation followed by the formulation of explanatory hypotheses derived from the assessment findings seems appropriate as a basis for the development of remedial or management programmes. Success, in terms of developing the correct hypothesis around which to develop intervention plans, is obviously limited by the scope of factors included for consideration. In terms of the individual person being assessed, there would be clear advantages to having the full range of potential factors taken into account at a single point of contact within healthcare provision (see 11.3).

Summary

Balance assessment and analysis is undertaken across a range of disciplines and for a variety of purposes:

- to contribute to the knowledge base
- to aid medical or biomechanical diagnoses
- to identify the site of a lesion
- to identify those who may benefit from rehabilitation
- to develop the content of a rehabilitation programme or management plan
- to understand functional capacity, and
- to monitor changes in function.

Some assessment strategies have been developed to serve a specific purpose, but there are many examples of assessments developed for one purpose being used in a different context or applied to a different population, sometimes without a clear rationale. Beyond the strategies used to answer specific questions within clear research paradigms, the search for diagnostic precision and measurable outcomes following remedial interventions has resulted in the use of an expanding (and as yet imperfect) range of measures addressing both specific domains and holistic function. While a wide analysis of potential factors based on a range of tests and evaluations would seem in itself a laudable approach, this has to be balanced by considering other factors such as the demands on time, individual test validity, cost effectiveness, and discomfort and distress caused to those being assessed. Each researcher, service or individual practitioner needs to develop an assessment strategy that is appropriate for purpose in each case. The context within which practitioners operate varies as practice is not standardised across or within disciplines. Appropriate assessment strategies need to reflect the local context of available resource and will require a clear understanding of balance disorder as it occurs in the population of interest.

5 TRAUMATIC BRAIN INJURY[11]

> 'The brain, more than any other part of us, defines our individuality. It is the repository of our particular and unique memories, the controller of our defining skills and abilities, the moderator of our characteristic moods and feelings, the facilitator of our interactions with our environment and our communications with our fellow human beings.' (Rose & Johnson, 1996) p1

5.1 Definitions

Traumatic brain injury (TBI) has become the standard title used to describe what is actually a wide spectrum of sub-pathologies and an almost infinite variety of deficit profiles (van Balen, Mulder, & Keyser, 1996). The term brain injury has been adopted increasingly in preference to head injury as the importance of the site and extent of the actual brain damage has come more into focus. That is, in terms of long term outcome, it has been recognised that there is a marked difference between injuries with predominantly extracranial features and those injuries producing intracranial disturbance. The prefix traumatic is added to provide a distinction from other forms of acquired brain injury such as would occur, for example, from a ruptured aneurysm.

There is still no universally agreed definition of TBI. However, in an effort to emphasise TBI as a distinct entity, separate from stroke and other causes of acquired brain injury, the 1988 working party of the Medical Disability Society in the UK defined TBI as:

> 'Brain injury caused by trauma to the head (including the effects upon the brain of other possible complications of injury notably hypoxaemia and hypotension, and intracerebral haematoma).' (Medical Disability Society, 1988) p3

The content in parenthesis refers to the importance of recognising the functional impact of secondary damage, the mechanisms and results of which will be discussed later in this chapter.

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[11] Some material reproduced in this chapter was first published in:

Campbell, M. (2000). Understanding traumatic brain injury. In M. Campbell (Ed.), *Rehabilitation for traumatic brain injury: physical therapy practice in context* (1st ed., pp. 17-44). Edinburgh: Churchill Livingstone.

Campbell, M. (2004). Acquired brain injury: trauma and pathology. In M. Stokes (Ed.), *Physical Management in Neurological Rehabilitation* (2nd ed., pp. 103-124). Edinburgh: Elsevier Mosby.

The National Head Injury Foundation (NHIF) in the USA produced a rather more detailed definition that includes a description of resultant effects as follows:

> 'Traumatic head injury is an insult to the brain, not of a degenerative or congenital nature but caused by an external physical force, that may produce a diminished or altered state of consciousness, which results in impairment of cognitive abilities or physical functioning. It can also result in the disturbance of behaviour or emotional functioning. These impairments may be either temporary or permanent and cause partial or total functional disability or psychosocial maladjustment.' (Harrison & Dijkers, 1992) p206

The NHIF definition is comprehensive and in language that is easily understood. It is inclusive of those individuals whose injuries produce only transient symptoms, encouraging the event to be recorded as a TBI and thus aiding clinical decision making should a second injury occur. This is important given the cumulative effect of repeated minor injuries (Gronwall & Wrightson, 1975). However the NHIF definition does not include any system for grading the severity of an injury and if used needs to be combined with other measures.

5.1.2 Severity

The severity of TBI ranges from mild concussion with transient symptoms to very severe injury resulting in death. In injuries that do not result in death the two domains most frequently taken as indicators of injury severity are coma (depth and duration) and post-traumatic amnesia (PTA).

Coma

Coma is defined as 'not obeying commands, not uttering words and not opening eyes' (Teasdale & Jennett, 1974). The Glasgow Coma Scale (GCS) (Teasdale & Jennett, 1974, 1976) is the most widely used measure of depth and duration of coma. The GCS has three subscales, giving a summated score of 3 to 15:

- eye opening (rated from 1 to 4)
- best motor response (rated 1 to 6)
- verbal response (rated 1 to 5).

Although a general impression of a person's conscious level can be gleaned from a summated score, retaining the scores at subscale level gives a more accurate clinical picture. For example, knowledge of the lowest motor response rating and the pattern of improvement over time can provide physiotherapists with a valuable insight into the initial severity of damage to brain tissue associated with physical performance. Regarding summated GCS scores the convention is to categorise injuries into mild, moderate or severe (see table 5.1) using the lowest score in the first 24 hours.

Table 5.1

GRADE	SUMMATED GCS SCORE
Mild	13-15
Moderate	9-12
Severe	3-8

TBI severity: lowest summated Glasgow Coma Score (GCS) in the first 24 hours post-injury (Bond, 1986)

Duration of coma is also used as an indicator of severity, where coma is generally numerically defined as a GCS score of 8 or less (Bond, 1990). This convention introduces a further grading of very severe (see table 5.2) reflecting the increasing knowledge that may be gained from longitudinal review.

Table 5.2

GRADE	DURATION OF COMA (GCS ≤8)
Mild	<15 minutes
Moderate	>15 minutes, <6 hours
Severe	>6 hours, <48 hours
Very severe	>48 hours

TBI severity: duration of coma (Bond, 1986)

Reliability and predictive validity of the Glasgow Coma Scale

The GCS was developed initially to aid communication between clinicians and assist in the definition of duration of prolonged coma in the presence of brain injury (Teasdale & Jennett, 1974). The content was derived from observational studies, primarily of those with severe brain injury, and relates strongly to indicators of diminishing levels of consciousness associated with increasing levels of cerebral oedema or other mass effect such as large haematomas. Initial reliability was reported as good (Teasdale & Jennett, 1974; Teasdale, Knill-Jones, & Van der Sande, 1978)and moderate for a less impaired population following subarachnoid haemorrhage (Lindsay, Teasdale, & Knill-Jones, 1983). More recent studies focused on neurological inpatients continue to report high levels of inter-rater reliability (Juarez & Lyons, 1995; Rowley & Fielding, 1991), especially with experienced nursing staff who maintain a high level of consistency across severity of patients (Rowley & Fielding, 1991). Reliability for less experienced staff is better when assessing the more severe patients (Rowley & Fielding, 1991).

The GCS is now used far beyond this initial target group as an aid to triage in trauma care (Gill, Windemuth, Steele et al., 2005) and for wider functions, such as outcome prediction (Gabbe, Cameron, & Finch, 2003). One study involving two 'trained' medical staff in the emergency department reported only moderate reliability (Gill, Reiley, & Green, 2004). There is some suggestion that this is a factor of the pressurised environment and the over complicated nature of the GCS for the function it is being used for in this setting. The same authors subsequently report the development of a simplified scoring system focused on only the verbal and motor dimensions with similar (but lesser) predictive abilities for four key clinical outcomes they define as intubation, neurosurgical intervention, clinically significant brain injury and mortality (Gill et al., 2005). They accept the limitations of their study in developing the consensus on key clinical outcomes without reference to other practice areas and that the new scoring system remains untested in terms of reliability and validity. They do not discuss the limitations of an approach that excludes concussion and skull fracture without evidence of intracranial injury from the clinically significant brain injury category. The thrust of the argument for further development of this limited version of the GCS seems to relate to limiting the time required for training and for scoring in each case, rather than deriving a more valid measure.

The true picture of the predictive abilities of the GCS when used in the pre-hospital or emergency care phase is clouded by issues of missing data, for example, due to the inability to score verbal response in intubated patients or the complete absence of recordings in significant numbers of subjects included in retrospective studies (Gabbe et al., 2003). It has been shown that verbal scores can be accurately predicted from eye and motor scores using linear regression (Meredith, Rutledge, Fakhry et al., 1998) and that the motor score alone, mathematically transformed, behaves better than total scores in a statistical sense, offering improved predictive modelling (Healey, Osler, Rogers et al., 2003). These findings are likely to be of value in designing future studies.

There is a body of literature supporting the predictive ability of the GCS with reference to mortality, for example, (Bouillon, Lefering, Vorweg et al., 1997; Davis, Serrano, Vilke et al., 2006; Dunham, Ransom, Flowers et al., 2004; Moore, Lavoie, Camden et al., 2006) and some evidence of correlation with objective methods of measuring severity (Dunham et al., 2004; Hattori, Huan, Wu et al., 2003). Moore and colleagues also illustrate that this predictive ability is further enhanced by statistically transforming the clinical scores (Moore et al., 2006). Several mortality outcome studies have used logistic regression in this way and concluded that the GCS has positive predictive ability (Gabbe et al., 2003).

Studies looking at the ability of the GCS to predict functional outcome in survivors have focused on different populations and have regarded outcome in different ways. The GCS has been shown to be able to predict gross functional outcome in elderly closed head injury patients (Kilaru, Garb, Emhoff et al., 1996; Ritchie, Cameron, Ugoni et al., 2000)but only to have moderate predictive abilities in a population with acquired brain injury from mixed traumatic and pathological geneses (Diringer & Edwards, 1997). Wagner and colleagues (2000) found GCS to be predictive of outcome in a adult TBI population at 12 month follow-up, but nearly half of those eligible to be included could not be traced. Another study focusing on a TBI population, logged on the National Institute on Disability and Rehabilitation Research TBI Model Systems database, found modest but statistically significant correlations between initial and lowest GCS scores and various outcome variables and concluded that the GCS on its own has limited value as a predictor of functional outcome (Zafonte, Hammond, Mann et al., 1996).

While the GCS is routinely recorded before hospital admission there is some dispute about the ability of the GCS to assist triage or predict the need for an intensive pre-hospitalisation response. Part of the issue is that of adequate training of sufficient personnel as raised by Gill (2004). Meredith and colleagues (1995), in a study of nearly 30 000 patients concluded that the motor score of the GCS alone, and in particular the distinction between whether or not patients were able to follow commands, was a rapid and simple pre-hospital method of identifying those at risk of dying and thus those who require urgent trauma centre care. A smaller study of 412 patients using the total GCS, but only looking at those with GCS 3 to 8, concluded that other factors should be considered in screening those for rapid sequence intubation (Davis, Vadeboncoeur, Ochs et al., 2005). This was based on the subsequent outcomes, including the speed at which patients were able to be extubated, and an apparently implicit assertion that those who were able to be extubated and discharged from intensive care within 48hours did not benefit from the early intervention of the paramedics. In contrast Norwood and colleagues (2002) concluded that a full GCS score of 14 or less was an appropriate predictor of the need for full trauma care activation and admission to hospital.

In attempting to assess the validity of using the GCS for a range of functions far removed from its initial purpose, researchers often demonstrate the same confused thinking that initially resulted in widespread clinical use without due regard to fitness for purpose. The apparent simplicity of the scale has probably contributed to some of the issues of inter-rater reliability. Drift from initial assessment use and procedure has been recognised and clear and specific guidance have recently been represented in the literature (Waterhouse, 2005).

Use of the GCS for the original purpose of monitoring and communicating the status of those with reduced levels of consciousness or at risk of deterioration due to mass effect in the presence of significant brain injury remains valid, and reliability is improved via practice of accurate assessment adhering to clear guidelines. The GCS, used properly, can be predictive of mortality but insufficient attention has been given to the role of intervention (and changes in management) in confounding that predictive ability. One retrospective study does address this issue in relation to outcomes over 10 years in one clinical service and concludes that for these patients undergoing intensive interventions the GCS lost its predictive ability from 1997 onwards (Balestreri, Czosnyka, Chatfield et al., 2006). This conclusion is based on group statistics per annum and GCS scores are not mathematically transformed prior to analysis. Use beyond the original purpose, whether in full or in part, remains fraught with pitfalls though there is some evidence to support use in some circumstances and for some purposes. It is essential in each case to consider fitness for purpose.

Post coma states

Coma may be short lived or may extend over weeks, months or years. However, coma rarely lasts longer than a month; the severely injured person either dies or emerges into the vegetative state.

The V*egetative State* (Jennett & Plum, 1972) is defined as "a clinical condition of complete unawareness of the self and the environment, accompanied by sleep-wake cycles with either complete or partial preservation of hypothalamic and brain-stem automatic functions" (Multi-Society Task Force, 1994) p 1500.

The *Minimally Conscious State (MCS)* is a condition that has been described more recently. This is "a condition of severely altered consciousness in which minimal but definite behavioural evidence of self or environmental awareness is demonstrated" (Giacino, Ashwal, Childs et al., 2002)p 350-351. One or more of four diagnostic criteria confirm MCS and include: following simple commands; yes/no responses; intelligible verbalisation; and purposeful behaviour. Such meaningful interaction with the environment is not consistent but is reproducible or sustained enough to distinguish from reflexive behaviour.

Coma, Vegetative State and Minimally Conscious State are parts of a potential continuum from coma through to emergence of awareness that an individual may pass through as a transient phase or may remain at a particular level permanently.

Post-traumatic amnesia (PTA)

The definition and assessment of PTA remains controversial. The original concept was developed by Russell and taken to be the period from injury until the return of day to day memory on a continuous basis (Russell, 1932). Most analyses now identify disturbances in three domains: orientation, memory and behaviour. For example, "the patient is confused, amnesic for ongoing events and likely to evidence behavioural disturbance" (Levin, O'Donnell, & Grossman, 1979). However, Russell's categorisation of levels of severity is still used today (see table 5.3).

Table 5.3

GRADE	DURATION OF PTA
Mild	< 1 hour
Moderate	> 1 hour, < 24 hours
Severe	> 1 day, < 7 days
Very severe	> 7 days

TBI severity: duration of post-traumatic amnesia (Russell, 1932)

Tate and colleagues (2000) discuss the relative merits of currently available scales for prospective assessment of duration of PTA, addressing issues of orientation and memory, and highlighting in particular the difficulties in assessing the memory component. Retrospective assessment of PTA duration has been shown to be as reliable as prospective assessment in a severe population (McMillan, Jongen, & Greenwood, 1996), although Gronwall and Wrightson (1980) found that one quarter of mildly injured patients changed their estimation at a second interview after three months.

In practice, severity, particularly after the acute period, is currently assessed with reference to all three factors discussed above (coma depth and duration, and PTA) and with additional consideration given to early CT scans and later MRI scans when available.

5.2 Pathophysiology

TBI occurs when there is a direct high energy blow to the head or when the brain comes into contact with the inside of the skull as a result of a sudden acceleration or deceleration of the body as a whole. The brain is predisposed to certain types of injury by virtue of its structure and design, and because of irregularities on the inside of the skull. The type of brain injury sustained is a product of the circumstances generating the external force that reacts with the brain tissue, the amount of energy involved and how that energy is dissipated throughout the brain substance.

The brain has most of its mass in two large cerebral hemispheres, above the narrower brainstem and spinal cord (Nolte, 1999d). The brain and spinal cord are suspended within three layers of membranes known as the meninges and are further protected by a layer of cerebrospinal fluid between the inner two layers, the arachnoid and pia mater. The outer layer, the dura mater, is the most substantial layer and provides most of the mechanical strength of the meninges (Nolte, 1999e). The dura mater is attached to the inner surface of the skull. During normal activities the brain is constrained to move with the head but as it is not directly anchored within the skull this does not apply during sudden, swift movements or high-energy impacts. The brain substance is composed of cells and axonal connections forming areas of different densities that move and respond to force in different ways. Thus, the brain is free to move independent of the skull and in the presence of high energy it does so in an irregular manner, causing stretching and shearing of brain tissue. Further damage is inflicted on the soft brain structure as it moves across the irregularities on the internal surface of the skull (Jennett & Teasdale, 1981).

5.2.1 Types of injury and associated damage

Primary damage

External forces are expressed via three main mechanisms of primary brain injury:

- direct impact on the skull
- penetration through the skull into the brain substance
- collision between the brain substance and the internal skull structure.

TBI can occur without disruption of the skull and this is described as a closed injury (Currie, 1993). Alternatively, the skull may crack in a simple linear fracture, be depressed into the brain tissue or be pierced by a sharp or high velocity missile. Such penetrating injuries may be complicated by fragments of bone, skin and hair being pushed into the brain tissue, increasing the damage and raising the risk of infection. In the case of high velocity injuries, such as gunshot wounds, damage also occurs wide of the tract created by the course of the missile, as energy is dissipated within the brain substance (Currie, 1993).

Closed injuries can result in local impact, polar impact, shearing, laceration, axonal or blood vessel damage (Hooper, 1969). Local impact damage occurs immediately below the site of impact and can affect the scalp and meninges, as well as the brain substance in different measure, depending on the velocity of the impact and the flexibility of the skull. The brain may collide with the skull at the opposite pole to the site of primary impact and oscillate between the two, producing additional shearing damage (Hooper, 1969). Where shearing forces affect the long axonal tracts, such as in hyperextension or rotational injuries, axons may be stretched or severed within their myelin sheaths (Adams, Mitchell, Graham et al., 1977). This is known as diffuse axonal injury (DAI). When DAI is widespread it is associated with severe injury but has also been shown to occur in mild injuries (Povlishock, Becker, Cheng et al., 1983; Yokota, Kurokawa, Otsuka et al., 1991).

Lacerations most commonly occur adjacent to the internal areas of the skull that are irregular, producing damage to the frontal and temporal lobes of the brain (Currie, 1993). Hyperextension injuries can cause damage to the carotid or vertebral arteries interrupting blood flow as a result of dissection or occlusion. Cerebral vessels can also be torn or ruptured and result in a local collection of blood (Hooper, 1969). When this occurs in the immediate aftermath of an injury it is known as an acute haematoma. A slower accumulation of blood known as a chronic haematoma is most frequently found in the very young or in older adults.

Secondary damage

Secondary damage results from biochemical and mechanical factors. As soon as the injury occurs, the tissue damage and cell death that result spark a pathological process leading to chemical damage to adjacent but previously uninjured brain tissue and the development of oedema. The presence of oedema or a significant haematoma will result in displacement and distortion of other brain tissue (Hooper, 1969). There is little internal capacity within the skull to accommodate the swelling or distorted brain and further damage occurs as the brain is pressed against the skull or pushed into adjacent intracranial compartments. As well as compression of brain substance, this can also result in occlusion of major arteries.

Secondary damage may be aggravated by infection or complications associated with systemic dysfunction, which may result from the effects of the brain injury or be caused by co-existing injuries. Around 40% of severely injured patients will have other significant injuries (Gentleman, Teasdale, & Murray, 1986). The incidence of co-existing fractures in an American study of 325 subjects admitted to trauma facilities with a range of severities of TBI was 62% (Bontke, Don Lehmkuhl, Englander et al., 1993).

5.3 Incidence and prevalence

Studies reporting the incidence of TBI in Western developed countries produce a range of values of around 200-300 new cases presenting for medical evaluation per 100,000 population each year; for example, in the USA (Sorenson & Kraus, 1991), the UK (Jennett & MacMillan, 1981) and Australia (Hillier, Hiller, & Metzer, 1997). Published studies focusing on large urban areas generally produce higher incidence rates, with internal variance in causal factors related to cultural and lifestyle differences, for example high rates of assault in certain American inner city studies. A recent English study found a variance in incidence rates of 4.6 across health districts, associated with a range of lifestyle and socio-economic factors, including use of public transport, levels of unemployment and other markers of deprivation (Tennant, 2005).

Much of the data relating to prevalence in TBI is estimated from incidence data, taking the population age and survival rates into account. This has led to estimations of up to 439 per 100 000 (Kalsbeek, McLaurin, Harris et al., 1980). However, a national household survey in Canada (Moscato, Trevisan, & Willer, 1994) produced a self reported prevalence of disability from TBI lasting more than six months of only 54 per 100 000. Bryden (1989), in an interview-based household survey of three Scottish districts, recorded a prevalence of 100 per 100 000 for those whose everyday life was affected after sustaining a TBI. Given the population mix within these three districts Bryden goes on to argue that there is no reason why these figures should not be applicable to the rest of the UK, giving a national total of 55 000 in the late 1980's. In 1998 the number of people living in the UK with significant disability after TBI was estimated to be between 50 000 and 75 000 (Centre for Health Service Studies, 1998). This estimate has more recently been significantly revised upward to a level of 420 000 for those up to the age of 65 (DH Long-term Conditions NSF Team, 2005).

5.3.1 Population characteristics

Age and gender

Whatever the overall incidence rates, certain characteristics of the adult TBI population at time of injury have proven to be consistent over many studies. The review by Sorenson and Kraus (1991) of several selected US studies is typical in showing that the highest risk of injury is between the ages of 16 and 25, declining until late middle age and beginning to increase again about age 60 or 65. A later study by van Balen and colleagues (1996) records the highest statistical risk for individuals older than 85, followed closely by those aged between 14 and 25. The pattern of occurrence is comparable between the two sexes although it varies in magnitude. Kraus and McArthur (1996) describe the incidence ratio between men and women as ranging between 2:1 and 2.8:1. They also go on to make the point that the mortality rate ratio is 3.5:1 comparing men to women, this being strongly indicative of more severe injuries among men. Taking these two figures together it can be seen that in terms of TBI survivors, the male to female ratio can be expected to nearer to 2:1. In the Canadian prevalence survey mentioned previously, the gender ratio is recorded as 1.8:1 (Moscato et al., 1994).

Cause of injury

In the majority of studies, transport accidents are implicated as the major cause of TBI. For example, Hillier and colleagues (1997) in South Australia report 57% of hospital admissions with TBI in 1989 resulting from transport accidents. The same study attributes 29% of cases to falls and 9% to assaults. There are no subdivisions given for the falls category within this study, nor are figures broken down to relate causal factors to age. However, males involved in transport accidents were much more likely to be the car driver (29%) than the passenger (8%) in comparison to the same figures for females at 24% and 22% respectively. Other studies imply trends towards an increased rate of sporting accidents and falls in the younger (< 20 years) age group and towards simple falls in the older (> 60 years) age group. For example, a study focusing on an adolescent sample (Body & Leatham, 1996) reports sport as the primary causal factor in males (52%) and females (76%) between 15 and 19 with transport accidents accounting for only 15% and 10% respectively. Miller and Jones (1990) report a 77% incidence of falls in a population aged 65 and over and also indicate that within this population the male to female ratio is much closer to 1:1.

5.4 Impairments and their functional impact

In terms of observable deficits or ongoing impairments post TBI, few are clearly apparent in the acute stage, particularly in those who are in coma or sedated to allow elective ventilation as an early management strategy. Some difficulties can only be confirmed by specific testing or via structured observation in a functional setting and this can prove difficult during the period of emergence from coma. Formal assessment of underlying impairments can be an ongoing challenge with regard to those who remain in a minimally conscious state or those who experience problems of awareness, agitation or other challenging behaviours. Ongoing evaluation, appropriate to the stage of recovery, is essential to obtain an accurate assessment of the level of impairment, and its functional impact, as the extent and severity of deficits affecting each individual can vary significantly.

5.4.1 Early observations

Other than the changes in conscious level already described, the most obvious consequences of TBI in the initial post injury period are those of motor behaviour. In addition to the best (motor) scores recorded via the use of the GCS, the behaviour or responses of the other limbs, the trunk and eyes can give an indication of the extent of the damage and, in some cases, the likelihood of continuing motor deficit. While severe injuries are commonly accompanied by raised muscle tone, flaccid limbs may indicate additional sites of injury, for example spinal cord, brachial plexus or peripheral nerve injury. Spinal cord injury is said to occur in 4% of severe TBI's, while spinal cord injury has been reported as having associated mild TBI in between 25% and 50% of cases (Narayan, Gokaslan, Bontke et al., 1990). Imbalances in muscle activity or absence of activity can quickly lead to secondary soft tissue changes. Antigravity muscles appear to be most at risk and a number of other factors such as disuse, resting muscle length and the frequency of stretch have been identified as important parameters in preventative management (Goldspink & Williams, 1990).

5.4.2 Secondary observations

As the period of acute illness or depressed consciousness comes to an end, more accurate assessment of a number of potential deficits becomes possible. Deficits in cranial nerve function and more specific limitations of sensory-motor function may become evident at this stage. Continuing cognitive limitations and associated behavioural difficulties can still limit formal evaluation (Campbell, 2000a).

The sense of smell is frequently lost or impaired following TBI and this can be at a primary detection level or at the level of perception or discrimination of aromas. Olfactory nerve damage is often the result of shearing damage at the cribiform plate or found in association with anterior fossa fractures (Roberts, 1979).

The visual system can be affected via direct or ischaemic damage to the optic nerve or via damage to other cerebral structures involved in the processing or interpretation of visual stimuli (Narayan et al., 1990). Eye movements can be disrupted by damage to the oculomotor, trochlear or abducens nerves and be observed by the assessor as strabismus (malalignment) or reported by the patient as diploplia (double vision). Damage to the oculomotor nerve can also lead to difficulties with pupilary control and light accommodation.

Trigeminal nerve damage occurs with facial fractures and can lead to facial numbness or hypersensitivity (Currie, 1993). The facial nerve may be damaged extracranially in the pre-auricular area or in association with temporal fracture (Narayan et al., 1990). The latter may present as a delayed palsy from pressure associated with swelling in the restrictive bony canal and this type carries a more positive recovery outcome. Damage to the vestibulo-cochlear nerve and its functional apparatus is also associated with temporal impact and fracture. Neural deafness as a result of nerve damage and conduction deafness as a result of dislocation of the bony chain or bleeding into the middle ear may occur (Currie, 1993). Vestibular function may also be disrupted by local damage to the vestibular apparatus, by the creation of a perilymph fistula or by an occurrence known as labyrinthine concussion which may also occur with some occipital impacts (Shumway-Cook, 2000).

The incidence of lower cranial nerve trauma, as opposed to dysfunction associated with brain stem damage, is said to be minimal, although it is acknowledged that some injuries may occur with occipital/basal fracture or in association with neck trauma.

The question of the contribution of neck trauma to TBI symptomologies, especially in mild TBI or in the presence of suspected posttraumatic stress disorder is beginning to be addressed in the literature (Couch, 1995; Gerber & Schraa, 1995; Parker, 1996; Taylor, Cox, & Mailis, 1996) although it is far from clear what, if any, relationship will be identified in either direction. There is no doubt, however that the mechanical forces involved in TBI are related to those causing bony spinal trauma and it can be assumed that there are cases where the forces involved fall short of producing fracture but do cause damage to other tissues. It is accepted that traumatic transection of the carotid or vertebral arteries, though infrequent, does occur (Auer, Krcek, & Butt, 1994). Zasler (1996) reported a 38% incidence of abnormal cervical examination in a series of 300 TBI outpatients, including 4 with previously undiagnosed disc herniation.

Depending on the site of injury a variety of distinct or combined motor disorders may begin to be recognised during this secondary stage. As well as the more common hypertonicity and ataxias, dyskinesias, tremors or other involuntary movements may also develop (Krauss, Trankle, & Kopp, 1996). However, these less common movement disorders appear, in some cases, to have a latent period before they are clearly recognisable.

As well as the sensory deficits discussed in relation to cranial nerve damage, a variety of central and peripheral sensory impairments may be present. These can include difficulties with the perception or interpretation of visual, tactile or proprioceptive information or disturbance within the sensory-motor loop, for example, dyspraxia (Garner, 1990).

Communication problems may be expected in the early recovery phase. This may be as a secondary result of cognitive blunting, due to linguistic failure as a direct result of focal or vascular injury, or due to difficulties in speech production associated with other motor deficits including dysphagia (Cherney & Halper, 1996).

5.4.3 Emerging cognitive and behavioural issues

Motor deficits may be clearly evident from the point of injury or soon thereafter but other consequences, most notably continuing cognitive and behavioural sequelae, may not begin to be quantified for some weeks or months after moderate or severe injury and the full extent of their functional impact, even after minor injury, cannot be ascertained until a full return to pre-injury activities is attempted.

Ongoing cognitive, social and psychological problems have been documented by a series of authors, for example, Oddy and colleagues (1978b), Lezak (1978), Brooks and Aughton (1979), Levin and co-workers (1979) and many others. The longer term effects reported in the literature are not limited to those directly affecting the injured person but also describe the impact on family units and wider social networks (Brooks, 1984; Brooks, Campsie, Symington et al., 1987; Kreutzer, Gervasio, & Camplair, 1994; Novack, Bergquist, Bennett et al., 1991; Oddy, Humphrey, & Uttley, 1978a; Perlesz, Kinsella, & Crowe, 1996).

Complaints of mental fatigue and limitations of concentration are extremely common, even years after injury (Hillier, Sharpe, & Metzer, 1997; Ponsford, Olver, & Curran, 1995). Attentional disorders and limitations of information processing may persist even following mild injury (van der Naalt, van Zomeran, Sluiter et al., 1999). A range of deficits of memory and learning continue beyond the period of posttraumatic amnesia and often represent the most commonly reported ongoing cognitive complaint (van Balen et al., 1996).

A whole range of advanced cognitive and mature behavioural functions associated with frontal lobe damage may also be present, affecting the ability to think in a reasoned or creative way, plan or act with due regard to past experience or likely future consequences or behave in a socially appropriate or sensitive way (Hart & Jacobs, 1993; Mattson & Levin, 1990). Not all people who sustain TBI have all of these difficulties but the frequency of frontal and temporal lobe damage makes the occurrence of impairment of these and other functions dependent on the integrity of these areas of the brain, such as motivation, commonplace in the TBI population. Specific behavioural syndromes, for example, episodic dyscontrol, which is sometime associated with temporal lobe epilepsy and frontal lobe damage, may also occur as well as a number of reactive disturbances of mood and behaviour (Brower & Price, 2001).

Posttraumatic epilepsy is an accepted potential consequence of TBI. Incidence of late epilepsy, that is, after the first week post trauma, has been reported at being between 2.5% and 5 % (Jennett, 1990) and although more than half will begin having seizures within the first year, around one quarter begin their epilepsy after more than four years post injury. Individuals may develop any form of epilepsy including full grand mal seizures or a variety of forms of temporal lobe epilepsy such as absences, so called psychic phenomena, such as olfactory hallucinations, déjà vu or physical nausea, or repetitive ritualistic behaviours known as automatisms. Temporal lobe seizures may not be initially recognised as epilepsy and not all cases are accompanied by positive EEG recordings. However, suspected cases may respond well to a trial of anticonvulsant therapy.

Other medical complications may develop as a direct consequence of brain damage. For example, a variety of hormonal imbalances can result from damage to the hypothalamus or pituitary stalk and these may only present as problems a substantial time after injury (Horn & Garland, 1990).

Longer term effects

The wider functional effects of a range of common impairments experienced by individuals after TBI have long been recognised. Outcome studies using formal measures of global disability have been published from the early days of improved medical management, for example, (Hall & Cope, 1985; Jennett & Bond, 1975). However, by nature of their simplicity and in contrast to the range of potential impairments already highlighted above, the knowledge generated from these studies was clearly limited to broad brush functional outcome. Other authors have chosen to present outcomes in a more focused way, either with reference to specific functional domains, such as vocation or relationship status, (Ben-Yishay, Silver, Paisetsky et al., 1987; van der Naalt et al., 1999; Wood & Yurdakul, 1997) or specific deficits domains, such as cognitive or psychosocial skills (Brooks & Aughton, 1979; Levin, 1998; Oddy et al., 1978b; Perlesz, 1996). Knowledge of the occurrence and detail of any particular impairment or its functional impact is therefore a function of the level of research attention it has attracted and the manner in which it has been addressed.

Balance disorder following TBI

Residual balance problems after TBI are consistently reported within the literature. How problems are reported, and in what detail, varies across studies. Carer and self-reported rates are distilled from semi-structured questionnaires while more focused studies report objective measures, often related to aspects of postural control, that are indicative of balance disorder.

59% of relatives of those with a severe TBI interviewed by Brooks and colleagues in the West of Scotland (n=134) (Brooks et al., 1987) reported balance and co-ordination difficulties up to seven years post injury. Self-reported levels in the same study were significantly less, at 23%. 45% of a group with mixed severities in South Australia (n=67) reported problems with balance at five year follow-up (Hillier, Sharpe et al., 1997) and 26% of a mostly severe group of 175 interviewed at two years post injury reported ongoing dizziness (Ponsford et al., 1995).

Several studies report increased levels of postural sway (Newton, 1995; Wade, Canning, Fowler et al., 1997; Wober, Oder, Kolleger et al., 1993), or other abnormalities of postural control or gait parameters (Basford, Chou, Kaufman et al., 2003; Shumway-Cook & Olmscheid, 1990). However, while there are significant levels of self-reported residual difficulties and increasing evidence of functional deficits, little attention has been given to describing associated factors or impairments underlying balance disorder. Guerts and colleagues did not find any significant impact of the introduction of an arithmetic task on weight shifting abilities in a small group with postural instability post TBI (Geurts, Ribbers, Knoop et al., 1996). The participants recruited for this study had 'no detectable neurological impairments' and therefore represent only a small section of the population of interest. The same authors in a later study report the presence of both cognitive dysfunction and postural instability in a small group with post-concussion syndrome (Geurts, Knoop, & van Limbeek, 1999), but do not discuss any causal relationship.

This lack of knowledge as to what constitutes balance disorder after TBI presents a significant challenge to the development of effective therapeutic intervention or management programmes for individuals experiencing sensory disorientation or functional limitations of balance.

Summary

Traumatic brain injury (TBI) is a comprehensive term that covers injuries resulting in brain damage, commonly of a diffuse nature. TBI includes a range of injury severities and may result in both transient and longer term impairments and functional effects. Around 50% of those who sustain a TBI will also sustain additional injuries. Many sustain their injuries as young adults and consequently have to live with any residual problems for the rest of their lives. Twice as many males as females are affected in this young group of peak incidence, although gender differences are less apparent in older adults. Residual problems are likely to affect a range of functions across physical, cognitive, emotional and socio-behavioural domains and the impact of the changes associated with TBI is felt beyond the individual, within the family unit and in the wider social network. Not all impairments are identifiable in the early recovery period and the functional impact of lasting impairments may not be fully appreciated for a substantial period after injury or until return to a full pre-injury lifestyle is attempted. Balance disorder is a recognised post injury problem in a general sense but is poorly described.

6 BALANCE DISORDER AFTER TBI: THE CLINICAL PROBLEM

6.1 Balance disorder and clinical practice

The foregoing chapters describe the uncertain and potentially confusing context within which clinical practice sits. The combined impact of uncertainty, disagreement or lack of knowledge across what should be core foundations of practice is significant. This is easily seen in areas such as balance disorder after TBI where the nature of disorder is not understood and the question of how to develop an adequate service response is current. It is also evident when current patterns of service response for those with suspected balance disorder are examined. This is important to acknowledge in order to answer the question of how services for those with suspected balance disorder after TBI should sit in relation to generic balance disorder service provision.

For the majority of people experiencing disorders of balance in the UK, their first point of contact will be the general practitioner (GP). First line management for most cases will be taken forward by the GP alone and treatment (by medication) will focus on the pathology believed to underlie the symptoms. This approach assumes that symptoms are a result of a transient disease process and that there will be no lasting effect on the postural control system or on functional ability. In cases where onward referral is considered by the GP to be necessary, referral will almost certainly be to a fellow medical practitioner, commonly an ENT consultant or occasionally a Neurologist. Service response within these specialities will depend on the unique approach of the consultant and any links with specialist balance disorder services. The range, applications and limitations of assessment processes potentially available within specialist balance disorder services are outlined in 4.2.3. The service response received by any individual will be dependent on the tradition of the healthcare profession they consult or are referred to, the knowledge and skill base of the individual practitioner they see and whether their service remit extends beyond diagnostic assessment. Service response is not governed by a common framework.

Some individuals who experience balance disorder after TBI may consult their GP in the first instance and be dealt with in a similar way to those with disease-based balance disorders. The limitations of this service response for those with suspected balance disorder after TBI could be usefully explored but this population is not the current focus of study.

Current awareness of the need to better understand the nature of balance disorder after TBI has been raised via the recognition of a population within specialist neurorehabilitation services who complain of, or are suspected to have, balance disorder. It is the specific clinical problem of developing an appropriate service response for this population that will now be explored, with reference to the context outlined in the previous chapters.

6.1.1 Current rehabilitation practice

Current rehabilitation practice is not standardised. The scope and content of assessment and the type and extent of intervention offered will vary depending on the discipline and individual skill base of the practitioner that is consulted (see chapters 3 and 4). It will also be influenced by the remit of the service within which an individual is seen. The level of assessment, and so the identification of problematic issues, will be derived from within the service context, for example, whether the focus of service provision relates to the individual at impairment, function or participatory levels.

6.1.2 Current neurophysiotherapy practice

Neurophysiotherapy practice is in the process of change. Progressive practice looks for an evidence or theory base and attempts a comprehensive consideration of evidence sources (see 3.2.3 and 4.2.4). The framework of contributory sources still varies as does the relative emphasis on individual sources within a given framework. There are, however, common areas of focus. Two such areas are the importance of understanding the role of postural control systems in achieving functional movement and the need to incorporate environment and purpose in the development of understanding of motor control. However the full implications of these key factors have yet to be translated into defined clinical practice, where the influence of prior treatment approaches remains. This is seen in relation to balance in the continuing dominant focus on the *mechanisms* *of balance* and the relative lack of emphasis on the *sense of balance* (see 3.2.3 and 4.2.4).

6.1.3 Systems underpinning human balance

Human balance in the context of purposeful movement is a complex topic requiring comprehensive analysis. Nashner has analysed and described the range of subcomponents of the postural control system required to achieve dynamic equilibrium in normal subjects (Nashner, 1982). This analysis includes musculoskeletal and neurological components, inclusive of neurological systems and processes that monitor the environment and facilitate adaptation to intra and extra personal change (see table 6.1). It also recognises the structural, behavioural and environmental domains identified in Chapter 2 as necessary for inclusion in comprehensive modelling of motor control. The postural control system as described by Nashner is clearly complex and extensive and dependent on many factors for optimum performance.

Table 6.1

MUSCULOSKELETAL	NEURAL
Range of motion	Motor processes that generate and co-ordinate forces for controlling the centre of body mass within the defined limits
Flexibility & alignment of skeletal segments	Sensory processes (including visual, vestibular and somatosensory systems)
Passive elastic properties of the muscular system	Central integrative mechanisms essential for perceiving orientation relative to gravity and surrounding objects
	Adaptive processes that modify sensory and motor systems in response to changing environment and task demands

Components of postural control (Nashner 1982)

6.2 Pathophysiology of TBI

TBI is characterised by diffuse brain injury, which results in a complex mix of residual neural deficits. TBI is also associated with a high incidence of concurrent injuries. Secondary musculoskeletal problems can develop as a result of both sets of injuries. The individual who sustains a TBI therefore has the potential to experience a wide range of primary and secondary impairments affecting a whole range of body systems and life functions (see 5.5).

6.2.1 Potential for multi-system dysfunction in TBI balance disorder

If Nashner's analysis of the postural control system is considered alongside the patterns of injury and range of resultant impairments associated with TBI then the theoretical possibility of multi-system dysfunction underpinning balance disorder after TBI can be clearly seen.

6.2.2 Balance disorder after TBI as described in the research literature

The majority of the literature with reference to balance disorder after TBI reflects the same limitations to comprehensive understanding as is apparent from the forgoing review of concepts, approaches and use of language. Studies tend to focus on one aspect of the subject without setting the wider context or assume consensus in the use of language. In general there is an assumption that balance is a clearly defined and well understood entity requiring neither explanation nor definition.

Outcome studies in the main rely on the report of those who have sustained TBI and/or their carers in terms of limitations of functional balance or the experience of dizziness (Brooks et al., 1987; Ponsford et al., 1995). One outcome study adds objective evidence of physical impairment and limitations of functional balance via physical examination using standardised observational assessments (Hillier, Sharpe et al., 1997).

Several balance-specific studies focus on measures of postural sway or motor strategies during postural control (Shumway-Cook & Olmscheid, 1990; Wade et al., 1997; Wober et al., 1993). One recent study reports performance on standard vestibular science assessment, augmented by motion analysis during gait (Basford et al., 2003). Some authors have focused on the relationship between postural instability and cognitive functioning (Geurts et al., 1999; Geurts et al., 1996) but these studies represent only early observations and focus on those without detectable sensorimotor impairments.

An additional perspective on balance disorder after TBI can be gleaned from papers reporting the outcome of specific interventions (Godbout, 1997; Gurr & Moffat, 2001; Herdman, 1990), but these almost entirely focus on vestibular dysfunction and reduction in the experience of dizziness. Finally, references are made to sub populations of those with TBI in larger studies of vestibular rehabilitation (Shepard, Smith-Wheelock, Telian et al., 1993; Shepard & Telian, 1995) because of their less favourable response to generic programmes.

In all of these papers, only Shumway-Cook and Olmschied (1990) set a context in terms of an overview of the subcomponents of postural control as described by Nashner (Nashner, 1982). These authors compare postural control strategies seen in a small group of people post TBI across a range of severities with those expected from preceding balance studies. They include a theoretical discussion covering a number of additional factors that may be contributing to, or limiting recovery from, balance disorder after TBI with reference to the known pathophysiology. What they do not do is describe the deficit profiles of the TBI subjects and so the presence or otherwise of factors with the potential to affect balance control is not directly addressed.

The question, as postulated, of whether balance disorder after TBI is a multifactorial entity and, if so, what kind of impairment profile might be associated with TBI balance disorder remains unanswered.

6.3 Limitations of current knowledge and practice

Neurophysiotherapeutic practice in relation to balance disorder is biased towards assessment and interventions focused on the mechanism of balance, commonly referred to as postural control. Awareness of developments in vestibular rehabilitation has begun to focus attention on the sense of balance but without a robust theoretical framework it is not clear how this is to be incorporated into practice. Indeed there is not yet a clear acceptance that this area of impairment or dysfunction should be incorporated into neurophysiotherapy practice.

Interdisciplinary team working within TBI rehabilitation has identified that service delivery and efficacy of interventions is optimised when therapy and adjustment programmes are delivered holistically and with due regard to confounding factors. For this population, comprehensive, prioritised and paced service delivery within a single programme is the gold standard. A primary limitation in advancing the discussion of the appropriate service response for individuals with suspected balance disorder after TBI at neurophysiotherapeutic, rehabilitation team and wider healthcare response levels is the lack of knowledge concerning the nature of balance disorder after TBI. It is essential that the nature of balance disorder after TBI is clearly defined.

Summary

Limitations in the development of an agreed theory of motor control and inconsistencies in the conceptualisation of balance, along with an evolutionary history in clinical practice strongly influenced by practical experience, have led to an inconsistent awareness of, and response to, TBI balance disorder. Clinical response in each case is influenced by the professional background and personal skill-base of individual clinicians as well as by the service context in terms of service remit and philosophy. In neurophysiotherapy, service response continues to be biased towards the mechanism of balance although there is increasing awareness of symptoms associated with malfunction of the sense of balance. Balance disorder is reported as a common problem after TBI but it is not clearly defined. Studies tend to focus on single aspects, commonly related to postural stability, and are rarely set in a wider context. The potential for TBI balance disorder to be a multifactorial entity has been raised with reference to the known complexity of achieving dynamic equilibrium and the wide range of potential impairments associated with diffuse TBI. The range and frequency of occurrence of the complex array of impairments with the potential to contribute to balance disorder has not been reported. Detailed knowledge of the characteristics of TBI balance disorder is an essential precursor to the development of an appropriate healthcare response for this population.

7 SECTION I: SUMMARY AND CONCLUSIONS

7.1 Summary

This section has addressed the first aim of the research programme, namely, to identify and describe factors that have shaped and influenced healthcare practice concerning balance and balance disorder and so to understand barriers to improved practice. Direct and wider healthcare contextual influences on physiotherapy practice have been explored by way of three focused subject reviews covering:

- Motor control
- Balance concepts and derivations
- Balance assessment and evaluation.

Diverse approaches to the study of the nature and control of movement were identified and to the categorisation and development of theoretical models. Observations derived from the examination of a range of approaches highlight the complexity of motor control and the importance of adopting a comprehensive analysis inclusive of personal, environmental and task-related influences. No clear and consistent link was found between individual theoretical models and approaches to clinical practice over time, although there was evidence of a relatively recent developing relationship that offers a positive basis for future development. The complexity of the subject, the variety of approaches to theory development and the absence of a mature relationship between theory and practice offer some explanation of the current lack of application of a clear theoretical framework for clinical practice.

Examination of how balance is conceptualised within healthcare practice revealed another complex picture of varying concepts and definitions and limitations of scope, largely dependant on the evolution of the discipline in focus and skewed in favour of dominant pathology groups. Development towards an increasingly holistic approach within neurophysiotherapy practice could be discerned but also continuing barriers in the form of a failure to address issues of definition and concept across healthcare practice and a failure to acknowledge the full implications of sensory dysfunction within clinical practice.

Differences in concept and derivation could also be seen to impact on approaches to, and methods of, assessment and evaluation of balance and balance disorder. Some assessment strategies are evidently derived from a clear conceptualisation and related to purpose but others lacked an obvious theoretical basis and some assessments are being applied in areas with no proven validity. This is a significant issue in the area of clinical practice affecting the reliability of diagnoses and management decisions. The lack of a comprehensive and agreed theoretical working model precludes even the discussion of areas of disparity within or across disciplines and ultimately results in a substandard response to those with balance disorder issues that do not fit directly the traditional understanding of balance (of whatever discipline). Without recourse to a comprehensive theoretical model, populations with suspected balance disorder, or those with balance disorder the underlying factors of which are not currently known, require the development of individual frameworks of understanding appropriate to known pathology or deficit outcome.

Current knowledge concerning the pathophysiology of TBI and how severity and outcome is determined in broad terms within clinical practice has also been reviewed. TBI is seen to be a common cause of death and injury in a predominantly young population. Successful developments in medical and surgical care have led to an increased survival rate and increased prevalence of those with disability. While the potential for individual survivors to experience impairments across a wide range of domains is now clear, and for those impairments to result in functional limitations, there remains significant limitations of knowledge with respect to much of the detail. Dizziness and limitations of functional balance are known to result from TBI but the nature of balance disorder has not been described beyond gross postural instability.

Individuals with dizziness or loss of balance following TBI who seek healthcare advice will meet with a variety of limited responses, dependent on the traditions, knowledge and experience of the clinician they consult. All responses will, in addition, be limited by the lack of an established cohesive and comprehensive approach and the pervasive influence of established approaches developed to meet the needs of those with other forms of balance disorder.

7.2 Conclusions

Current physiotherapy practice has evolved in the context of:

- limited understanding of motor control
- an inconsistent relationship between theory and practice
- (unacknowledged) inconsistencies in the conceptualisation of balance and balance disorder
- the absence of a theoretical working model.

The physiotherapy and wider healthcare response to those with suspected balance disorder following TBI is further limited by the incomplete understanding of the nature of balance disorder in this specific population and of that response being set within the context of services developed for balance disorders resultant from markedly different pathologies.

There is a clear need to establish a detailed understanding of the nature of balance disorder after TBI and to use that understanding to develop proposals for an improved healthcare response.

SECTION II

8 RESEARCH DESIGN AND METHODOLOGY

8.1 Research programme aims

The first aim of the research programme:

- to identify and describe factors that have shaped and influenced healthcare practice concerning balance and balance disorder and so to understand barriers to improved practice

has been addressed in Section I of this thesis. The two remaining aims of the research programme are:

- to develop a better understanding of the nature of TBI balance disorder
- to establish proposals for an improved healthcare response for those with suspected balance disorder following TBI.

8.1.1 Current understanding of TBI balance disorder

Balance disorder is an apparently common problem after TBI, as is evidenced by the reports of survivors and carers in general outcome studies (see 6.2.2). There is evidence from a series of small experimental studies that balance disorder affects postural stability and postural control strategies. There is also limited evidence of a sensory component affecting balance function in that postural control has been seen to vary in a small number of individuals tested under different sensory conditions. People with balance disorder after TBI have been recognised as a subpopulation within generic balance services and participants have been included in vestibular rehabilitation studies. The TBI participants have less positive outcomes compared to the studied group as a whole and their limited success has been attributed to likely co-existing deficits, without those deficits being defined.

There is evidence, therefore, that balance disorder is associated with TBI but there is no clear understanding of what constitutes TBI balance disorder. Without this understanding, and in the absence of an established theoretical model, significant barriers to the development of appropriated assessment and management strategies remain.

8.1.2 Research questions

While the nature of balance disorder following TBI has not been documented, hypotheses concerning the potential nature can be derived from examination of the primary literature. If factors with the potential to contribute to balance control are considered in tandem with knowledge of the pathophysiology of TBI it can be seen that TBI balance disorder has the potential to be significantly more complex than the predominant focus on physical performance within clinical practice would suggest (see 6.2.1). There is already an indirect acknowledgement of a level of inadequately understood complexity affecting those with balance disorder after TBI in the recognition that there are (some assumed but yet to be confirmed) barriers to success in applying standard vestibular rehabilitation programmes to address the needs of this client group (Shepard, 1997).

The primary questions to be addressed at this time are:

- Is TBI balance disorder associated with complex underlying causes, and if so
- Can the factors underlying TBI balance disorder be described?

8.2 Influences on research design

8.2.1 Context and clinical applicability

The context within which this whole enquiry sits is the need to develop an appropriate clinical response within neurophysiotherapy practice. This applies initially to the scope of clinical assessment and ultimately to intervention and management strategies. Neurophysiotherapy practice within TBI rehabilitation sits within an interdisciplinary, cross-agency context. The enquiry should therefore be appropriate to the context of integrated care and be consistent with the role of the neurophysiotherapist within the wider team. It should be feasible to replicate methods chosen to examine the nature of TBI balance disorder within a standard (specialist) TBI rehabilitation programme.

8.2.2 Characteristics and context of research participants

Individuals who have sustained a TBI are vulnerable as a result of the traumatic incident in which they sustain their injuries and the medical, physical, cognitive and emotional sequelae of those injuries. At the time of engagement with rehabilitation services there is a relationship of trust between the injured person and the clinical team. Life after TBI is full of challenges, with often even the achievement of basic tasks of day to day living being an ordeal. Recruitment of individuals in these circumstances onto a research study imposes a duty of care on the researcher. This is a particularly important factor for consideration given the possibility of provoking noxious sensations in the process of exploring this research area. The research design needs to minimise distress to the participant and if possible offer something of benefit in return.

8.2.3 Constraints

The absence of a working model or established theory of balance disorder precludes the use of an experimental or quasi-experimental research design and suggests that the chosen methodology should support a process of data collection and analysis sufficient to generate such a model or theory. Development of theory is generally approached via qualitative, observational research methods, typified by a process of observation, description, classification and interpretation.

Classic observational research involves extended periods of unstructured field study in naturalistic settings with subsequent data analysis. In order to apply the principles of observational research to vulnerable participants in a clinical context, adjustments have to be made. For studies involving TBI participants this translates into the need to reduce the period of observation and to maximise data collection within the constrained timeframe. Both of these objectives are achieved via the application of an observational framework to standardise the process and the data set. An observational framework ensures a specific focus of observation and allows comparative and summative analysis to be undertaken. The robustness of data generated from such a structured observational approach is increased if the structure that is applied is derived from existing data or established knowledge.

8.3 Materials and methods

A structured observational study was employed to record the occurrence of a predetermined range of deficits with the potential to compromise functional balance in a series of consecutive referrals to two adult TBI rehabilitation services. The study comprised the development of an inclusive assessment schedule, a test of clinical feasibility and intra-observer reliability (5 participants) and the application of the confirmed schedule to a further 22 participants. Analysis of the categorical data generated by this process was then undertaken to determine the frequency of the deficits reported and observed and to describe any emerging deficit profiles across the group. A secondary analysis of findings on a case by case basis was then undertaken to identify emergent issues in individual cases.

Participants were recruited from consecutive admissions to one inpatient TBI rehabilitation unit and from consecutive referrals to an unrelated outpatient TBI service. All persons with a TBI diagnosis referred for rehabilitation assessment were included and only those assessed as medically unfit or unable to tolerate the assessment process were excluded. All of those approached consented to participate. Ethical approval for the study was sought and obtained from the two local NHS Research Ethics Committees.

8.3.1 Standardisation

The process of observation was standardised by adherence to a predetermined assessment schedule by a single researcher, and by the inclusion in the schedule of standardised tests and methods of assessment wherever possible. Each assessment was progressed in a set order and each test or observation was operationalised in a consistent manner.

8.3.2 Assessment schedule development

In line with the objective of adding structure to the observation process, to ensure focus and maximise the productivity of the observation period, and to ensure the validity of the observational focus, Nashner's (Nashner, 1982) description of the components of normal postural control as summarised by Shumway-Cook and Olmscheid (Shumway-Cook & Olmscheid, 1990) was utilised to generate a series of core assessment domains. Each component was considered alongside known TBI injury patterns and post injury deficit profiles to generate broad areas of potential impairment (see table 8.1). Each of these potential areas was included in the assessment schedule whether or not deficits had been previously documented in the literature.

Table 8.1

<table>
<tr><th>Nashner's components</th><th>Applicability to TBI</th><th>Translation into broad domains of assessment</th></tr>
<tr><td>1. Range of motion</td><td rowspan="2">Range, flexibility and alignment of skeletal segments may be affected by weakness or other limitations of motor performance or by skeletal or soft tissue adaptation resulting from direct injury or secondary to changes in use</td><td rowspan="3">Biomechanical alignment, tissue extensibility and underlying factors</td></tr>
<tr><td>2. Flexibility & alignment of skeletal segments</td></tr>
<tr><td>3. Passive elastic properties of the muscular system</td><td>May be affected by primary motor control deficits or emerge secondary to changes in use</td></tr>
<tr><td>4. Motor processes that generate and co-ordinate forces for controlling the centre of body mass within the defined limits</td><td>Wide range of potential motor deficits across the TBI population</td><td>Motor control/performance:
• Trunk, limbs
• Isolated, global, dual tasks
• Contextual (positional/ reflex/ anticipatory)</td></tr>
<tr><td rowspan="3">5. Sensory processes (including visual, vestibular and somatosensory systems)</td><td rowspan="3">Wide range of potential sensory deficits affecting all the named systems and including associated motor control elements, such as eye movements</td><td>Vision & underlying motor processes</td></tr>
<tr><td>Vestibular system: peripheral & central</td></tr>
<tr><td>Peripheral sensation & pain</td></tr>
<tr><td>6. Central integrative mechanisms essential for perceiving orientation relative to gravity and surrounding objects</td><td>Wide range of potential deficits affecting speed and capacity to perceive, process and interpret sensory information</td><td rowspan="2">Integration and adaptability, i.e. the efficiency of 'on-line' processing and action, e.g
• Attention to and integration & interpretation of sensory information
• Functional performance & relationship to demand, e.g. dealing with concurrent and changing stimuli or avoidance behaviours</td></tr>
<tr><td>7. Adaptive processes that modify sensory and motor systems in response to changing environment and task demands</td><td>Potential limitations or absence of adaptive processes relevant to both immediate function and future progression. Failure to engage in the range of activities required to drive adaptive process may also impact.</td></tr>
</table>

Applying Nashner's postural control analysis to TBI

Assessment domains

1. Biomechanical alignment, tissue extensibility and underlying factors

This domain included observation of variance from normal biomechanical alignment, joint range and restrictions in soft tissue extensibility. It was recognised that influencing or underlying factors may be identifiable in some cases, for example a previous joint fusion or a co-existing pathological process. However, there may also be cases where the reason for any observed variance might not be immediately discernable or even be the subject of dispute. For example, apparently increased resting muscle tone might be explained by a hypothesis implicating primary spasticity or by an alternative hypothesis implicating changes in muscle structure and behaviour secondary to change in use. The question of primary effects and secondary compensations could be expected to apply to a range of potential observations, particularly in those seen at times distant from the index injury. The core data for this domain was restricted to what could be observed. The development of hypotheses concerning causal factors was restricted to the period of secondary individual case analysis which would take into account all the identified factors in each case.

2. Motor control / performance

This domain comprised observation of the performance and control of limb movement and postural orientation, appropriate for task. This included resting state, force generation, timing, execution and co-ordination during movement and success in achieving appropriate postural stability and adaptation. The knowledge and observational skills required to assess the factors outlined in this and the previous domain draw heavily on core skills of neurophysiotherapy practice.

3. Vision and underlying motor processes

This third domain included a basic but comprehensive screen of visual function, covering sensory and motor aspects, including visual acuity, visual fields and oculomotor function. Some of the knowledge and skills required to complete this set of observations are additional to core neurophysiotherapy practice but the recommended assessment processes call upon a similar set of principles and parallel observational skills. In addition to knowledge development by reading, guidance and instruction to develop appropriate skills was obtained from clinical and academic colleagues and by attendance at a specialist one day course on neurovisual rehabilitation.

4. Vestibular system: peripheral and central

Observations to address the focus of the fourth domain needed to target identifiable dysfunction in the vestibular system or subcomponents thereof. Methods used were taken directly from specialist areas of practice that focus on the balance organ as previously described. While use of these tests is relatively new within neurophysiotherapy practice they are commonly undertaken by physiotherapists working in specialist 'balance' services. Similarly to the additional knowledge and skill development for domain 3, guidance and instruction to develop appropriate skills for domain 4 was obtained from clinical and academic colleagues and by completion of a specialist three day course on vestibular rehabilitation.

5. Peripheral sensation and pain

Domain 5 included information gathering from individual self-report and direct testing to document limitations of, or changes in, the perception of peripheral sensation, including reports of pain. Essentially this is a core physiotherapy assessment focus but it was important to ensure that observations included a comprehensive evaluation of all the main elements with the potential to be affected in this population. For example, the testing of limb sensation was not restricted to accuracy but included elements of speed of response and ability to discriminate between competing stimuli.

6. Integration and adaptability

The final core assessment domain targeted functional motor behaviours, observing habitual strategies, the range and variety of strategies used and any limitations of functional movement seen in the context of changing task demands. Observation of functional movement is a key physiotherapy skill but, in a similar way to the last domain, the observational structure required to address the question of integration and adaptability needed to be contrived to include the opportunity to demand changes in habitual behaviour, for example to explore the impact of an enforced change in pace of gait or a request to scan the environment while walking.

Controlling for influencing factors

An additional assessment domain of influencing factors comprising pre-injury history and status and injury details, including severity, was also included to allow consideration of the impact of any pre-existing pathology, avoid misattribution of observed deficits and facilitate analysis of deficit patterns in relation to core demographics. Formal measures of concurrent post injury deficits (such as cognitive function) were not undertaken within this preliminary study.

Schedule content and choice of observations

In line with the long-term objective of developing an assessment schedule for use in clinical settings, laboratory-based measures or those dependent on complex technologies were excluded. Established clinical methods of assessment addressing all of the domains detailed above were identified from primary literature, clinical textbooks, personal experience and discussion with practitioners and academics across a range of disciplines. Final decisions on inclusion were based on reliability (where known), feasibility and comprehensive coverage without obvious repetition.

It is important to acknowledge that some components of the assessment schedule, although used regularly in clinical practice and often described in textbooks, have not been subject to the scrutiny of formal research. However, since the primary objective of this study was to understand the nature of balance disorder as seen in clinical practice, such measures were accepted as valid for the purposes of this study. It is also important to acknowledge that, although individual observations have target behaviours and for clarity of description are categorised under a single domain, there is a high level of interdependency because of the functional nature of some observations.

Pre-study clinical observations had highlighted a variety of semantic descriptions of dizziness and sensory disorientation that offered important insight into the patients' experience. The opportunity to freely describe any sensory disorientation was therefore considered to be an important assessment component. However, the TBI population has been found to be sometimes unreliable in terms of self-report because of co-existing cognitive deficits (Allen & Ruff, 1990; Fleming, Hassell, & Strong, 1996; Hillier &

Metzer, 1997; Newman, Garmoe, Beatty et al., 2000; Prigatano, 1991). The information gathering process was therefore designed to include cross-referencing of subjective report with observed findings and with additional corroborating evidence where possible. This included post assessment discussion with key staff and carers and review of clinical records. A summary of the components covered by the assessment schedule and assessment methods is given in table 8.2. A copy of the assessment schedule proforma can be found in appendix 1.

8.3.3 Pilot Study

An initial pilot study, involving five participants, was undertaken to examine feasibility of use, intra-observer reliability, and content validity of the newly designed assessment schedule.

Participant details

Five participants (three male, two female) were recruited and assessed on two occasions one week apart. Full details are given in table 8.3. The participants ranged in age from 20 to 29 (mean 26 years) and in severity from 3/15 to 14/15 (mean 7/15) on lowest summated Glasgow Coma Scale (Jennett & Bond, 1975) scores. On the date of the first assessment the participants were between 7 and 39 (mean 21) weeks post injury.

Protocol

Participants were seen in a physiotherapy treatment space and were always accompanied by a member of the rehabilitation team known to them. As part of the consent process they were warned that the assessment might induce sensory disorientation and that they could withdraw from the study at any time. Each participant was reminded at the beginning of the assessment that they could stop the assessment at any point. In addition to standard therapeutic equipment, the assessment employed the use of a Snellen chart, a hand-held optokinetic drum and an office swivel chair. The time allowed for completion of the assessment schedule was 40 to 60 minutes. There were 267 potential observations per participant per assessment.

Table 8.2

Assessment domains	Targeted component or behaviour	Detail	Information source: Self-report	Information source: Examination	Information source: Records /other reliable source
All	Reported symptoms	Structured interview, spontaneous report during examination, review of records, witness report.	✓		✓
Influencing factors	Pre-injury history & status	Relevant history including visual, vestibular & cervical pathology, pre-injury functional status	✓		✓
	Injury details & severity	Injury mechanism and severity, other injuries or complications			✓
Biomechanical alignment & tissue extensibility	Available range & influencing factors, limb and spinal joints	Limitations of, or other changes in, range of movement or changes in tissue extensibility		✓	
Motor control/ performance	Motor dysfunction	Resting state, force generation, timing and execution, co-ordination of purposeful movement		✓	
	Static & dynamic postural control	Symmetry & alignment, stability and maintenance of sitting and standing. Appropriate postural adaptation during positional change.		✓	
Peripheral sensation & pain	Light touch, proprioception & pain	Examined in supine, single and double stimuli, sharp and blunt discrimination, single and multi-joint proprioception, accuracy and speed of response	✓	✓	
Vision & underlying motor processes	Ocular motor function, visual acuity, visual fields	Gaze stability, occlusion and near point of convergence. Smooth pursuit and voluntary saccades. Optokinetic function. Acuity by Snellen chart. Visual fields by confrontation.		✓	
Vestibular system	Peripheral system dysfunction, vestibular reflex dysfunction	Dix-hallpike manoeuvre, Halmagyi head thrust, Fukuda stepping test. Vestibulo-ocular reflex, cervico-ocualr reflex.		✓	
Integration and adaptability	Monitoring behaviours	Visual scanning of the environment and recognition of changes therein		✓	
	Sensory disorientation and secondary response	Provoked symptoms and avoidance behaviours		✓	
	Movement strategies & habits	Restrictions and management strategies		✓	
	Success in functional movement and functional impact of combined limitations	Repertoire and quality of functional movement demonstrated during the assessment process.		✓	
		Corroborated report of home and community-based activity levels.	✓		✓

Assessment schedule contents

Table 8.3

Participant number	Gender	Age at injury	Lowest recorded summated GCS	Time since onset a t 1st assessment (weeks)
1	Female	20	14	11
2	Female	29	3	32
3	Male	23	3	14
4	Male	28	5	7
5	Male	29	11	39

Details of participants 1 to 5

Feasibility

All ten assessments were completed within the anticipated timeframe of less than one hour. However, additional time was required after the second assessment in most cases to allow discussion of issues raised by the assessment process. Testing of limb sensation was incomplete for participant 3 on the first assessment who was unwilling to close eyes in supine and unable to say why. The same participant was able to co-operate fully on the second assessment and reported a transient sensation of rotational dizziness.

Intra-rater reliability

The comparative data for the pilot study is given in table 8.4.

Table 8.4

	Number of recorded observations: assessment 1	Number of recorded observations: assessment 2	Number of disagreements
Participant 1	267	267	3
Participant 2	267	267	6
Participant 3	244	267	7
Participant 4	267	267	2
Participant 5	267	267	6
Total	1312	1335	24

Total recorded observations by participant

The level of agreement as calculated by Cohen's Kappa (Cohen, 1968) was 0.96. Disagreements related to the following factors:

- The participants' self-report of current difficulties, with a tendency not to contradict prior report but to report more on the second occasion.
- The observation of performance of the movement from sitting to standing. However this disagreement was consistent with another disagreement in the observation of preparation for standing.
- Two related observations differing on the second assessment in one case but being consistent with each other and therefore indicating a clinical change.

The last observation is also potentially important given that the second assessment was more symptomatic than the first, raising the possibility of fluctuating levels of symptoms.

Amendments to the assessment schedule

The intra-observer study largely confirmed the content of the assessment schedule. One item was amended and one addition was made. The observation of sit to stand was expanded from one to three observations over the assessment and considered alongside preparatory behaviours. As a result of reviewing the clinical utility of the assessment schedule a potential limitation in the assessment of vestibular function was identified. It was not possible to perform the Halmagyi head thrust (Halmagyi & Curthoys, 1988) in some cases because of 'protective' neck muscle activity, leaving only the Dix-Hallpike manoeuvre as a consistent test of peripheral vestibular function. The Fukuda stepping test (Fukuda, 1959) was therefore added to the revised version of the assessment schedule in an attempt to gain further insights into vestibular system function.

8.3.4 Main study

The revised assessment schedule was applied, following the protocol developed for the pilot study, to a further 22 adults referred for rehabilitation at two separate centres within one English NHS Region. The study design allowed the collection of data for the research process and the provision of a clinical summary for use by the rehabilitation teams at the two participating sites.

8.3.5 Results

Original observations are reported in relation to the study group as a whole and in single case terms. A set of emergent topics is then discussed with reference to the literature and subsequently in terms of implications for clinical practice.

9 ORIGINAL OBSERVATONS: PRIMARY ANALYSIS

9.1 Whole group observations

Because the data is categorical and not grouped, observations are reported for all 27 participants assessed in both the pilot study and main study except in relation to the two amended items when comments relate only to the 22 participants recruited for the main study. Full participant details are given in table 9.1.

A data file was created within SPSS for Windows. Deficit frequencies were collated individually and with reference to the broad assessment category headings. The descriptive statistics function was used allowing visual inspection of trends and associations. This function was used to inspect individual variables in relation to injury severity, age and gender and similarly the number of deficits seen in each assessment category.

Analyses of trends or association in relation to severity of injury have to be interpreted with caution as six of the 27 participants did not have recorded GCS scores. However, the use of the explore action within the descriptive statistics function in SPSS allows relationships to be explored with full knowledge of where the missing values fall.

9.1.1 Confounding factors

A total of 14 pre injury factors with the potential to affect assessment observations were identified affecting 11 individuals. Six participants had a childhood history of eye injury, squint or early glasses prescription. One person had a previous neck injury and three a documented episode of low back pain. Three had a history of drug or alcohol abuse and one had had a Bell's Palsy.

9.1.2 Sample validity

The study sample reflected well the wider adult TBI rehabilitation population with a 3:1 male to female ratio and an age range of 16 to 58 (mean 34, median 29).

Table 9.1

Participant number	**Gender**	**Age at injury** (years)	**Severity:** (lowest summated Glasgow Coma Score)	**Time since onset at 1st assessment** (weeks)
1	Female	20	14	11
2	Female	29	3	32
3	Male	23	3	14
4	Male	28	5	7
5	Male	29	11	39
6	Female	41	3	14
7	Male	48	4	22
8	Male	16	8	58
9	Male	34	14	105
10	Female	27	15	224
11	Male	27	14	36
12	Male	47	15	70
13	Male	58	14	72
14	Male	27	13	140
15	Male	20	15	20
16	Female	47	Not recorded	69
17	Male	26	4	102
18	Male	26	13	98
19	Male	33	3	122
20	Male	30	Not recorded	151
21	Male	47	Not recorded	69
22	Female	52	15	21
23	Male	53	3	20
24	Male	53	13	62
25	Male	26	Not recorded	52
26	Male	28	Not recorded	160
27	Male	29	Not recorded	47

Details of participants 1 to 27

Summated Glasgow Coma Scale (GCS) (Jennett & Bond, 1975) scores were available for 21 of the 27 participants and ranged across all the potential ratings from 3 to 15 with a mean of 9.6, suggesting a bias toward the mild/moderate end of the spectrum. This bias is in keeping with the TBI population as a whole but could be regarded as unusual in the subset seeking or requiring rehabilitation support, where the perception is that there will be a bias towards those with documented severe injuries. Of the other six participants two were thought not to have lost consciousness but had posttraumatic amnesia of a few hours, three had preadmission witnessed loss of consciousness of between two and 10 minutes and one was (severely) injured abroad but records were not available.

Participants were between two months and four years four months post injury with a median value of one year. This timeframe is valuable in considering longitudinal outcome rather than just early symptomology.

9.1.3 Spread of deficits

Deficits were observed across a wide range of assessment domains at both an individual and group level. Of the six main domains targeted by examination (biomechanical, motor performance, peripheral sensation, vision, vestibular and integration/adaptability) 20 participants had deficits in all domains, six in all but one (peripheral sensation) and one in all but two (peripheral sensation and biomechanical). There was no consistent deficit pattern within the group as a whole, nor any obvious emerging subgroups.

9.1.4 Frequency of deficits

The frequency of pathological findings across the studied group is presented under summary headings in table 9.2 and key facts are described in the text.

Functional balance and dizziness

All 27 participants reported episodes of stumbling or falling and all described feeling to some degree physically unstable at the time of assessment. Classic rotational dizziness or other forms of sensory disorientation, such as pulling sensations or heavy/light-headedness where reported by 24 participants (all participants were medically stable with stable blood pressure).

Table 9.2

ASSESSMENT DOMAINS	COMPLAINTS OR OBSERVATIONS	NUMBER OF PARTICIPANTS AFFECTED
Pre-injury influencing factors	Vision Neck Balance Other	6 1 0 7
Biomechanical alignment & tissue extensibility	Neck stiffness (reported)	13
	Neck: reduced range of movement (observed)	24
	Other biomechanical factors	8
Motor control / performance	Neck: reduced speed or quality of movement	23
	Motor dysfunction (limbs)	19
	Abnormal postural alignment at rest, eyes open	17
	Postural loss, sway or drift, eyes open	11
	Postural loss, sway or drift, eyes closed	23
Peripheral sensation & pain	Tactile deficits, single stimuli	3
	Tactile deficits, discrimination	20
	Proprioceptive deficits, single joint	0
	Proprioceptive deficits, multi-joint	9
	Reduced speed of response	17
	Neck pain	8
	Headache	11
Vision & underlying motor processes	Double vision	8
	Blurred vision or visual degradation	18
	Vergence abnormalities	23
	Eye movement abnormalities	18
	Optokinetic abnormalities	20
	Visual field deficits	9
	Reduced visual acuity	13
Vestibular system	Vestibular signs (excluding VOR abnormalities)	15
	VOR abnormalities	26
Integration and adaptability	Dizziness / other description of disorientation	24
	Illusory postural movement, eyes open	3
	Illusory postural movement, eyes closed	8
	Abnormalities of functional movement, including gait	27
	Fatigue	12

Frequency of pathological findings

Physical signs

Although the incidence of documented neck injury (and of reported neck pain) was low, 24 participants presented with abnormal resting head positions and/or restricted cervical movements. Eighteen participants showed signs of cerebellar-type inco-ordination in the upper limbs, six severe, 12 minor. Only one participant had restricted movement associated with increased resting muscle tone. One participant could not be accurately assessed because of pain associated with healing fractures. All participants had limitations of functional gait, commonly difficulties in varying speed and abnormal fixation of trunk and head position in addition to asymmetry of weight distribution, duration of weight bearing and stride length.

Peripheral sensation

Only three participants had significant limitations of accuracy of sensory awareness at a single stimulus level. However, many more (17) had problems in terms of reduced speed of response and with the addition of cognitive load. Nine of these had difficulties in multijoint proprioception and 20 in discriminating between different or competing stimuli.

Visual signs

All participants had some degree of change in visual system function, commonly problems of vergence (23), smooth pursuit (17) or diminished acuity (13). Although only eight reported classic double vision, 18 described blurring or other forms of visual degradation. Optokinetic response to a hand-held drum was abnormal in 20.

Vestibular system signs

Fifteen participants were symptomatic on the Dix-Hallpike manoeuvre. Symptoms included classic nystagmus, dizziness and disorientation, pallor and a strong wish to avoid the position without the ability to articulate why. All but one participant had reduced gain, visual degradation or dizziness on clinical vestibulo-ocular reflex testing. While standing with eyes closed there was a clearly observable sway in 17 participants, three displayed other forms of postural drift and three were unable to maintain eye closure or lost balance immediately the eyes were closed. Three participants described movement sensations while standing with eyes open that were not seen by the assessor. There were 11 participants where a combination of observations suggested dysfunction of the otoliths or of the cerebral structures concerned with segmental alignment and vertical orientation.

Performance on the Fukuda Stepping Test, which was added to the revised assessment schedule in an attempt to add clarity to observations of vestibular system deficits, in the end raised more questions than it answered. The classic positive response of significant rotation or lateral deviation from the midline while stepping on the spot with eyes closed was displayed by only three participants. However eight participants combined rotation and forward progression and three produced significant forward progression on its own. The remaining eight participants of the 22 asked to perform this manoeuvre were unable to attempt the task.

Frequency and spread of deficits: summary findings

- There was a high incidence of balance disorder in the studied group.
- Deficits were consistently found across a wide range of the targeted contributory domains.

9.1.5 Trends and associations

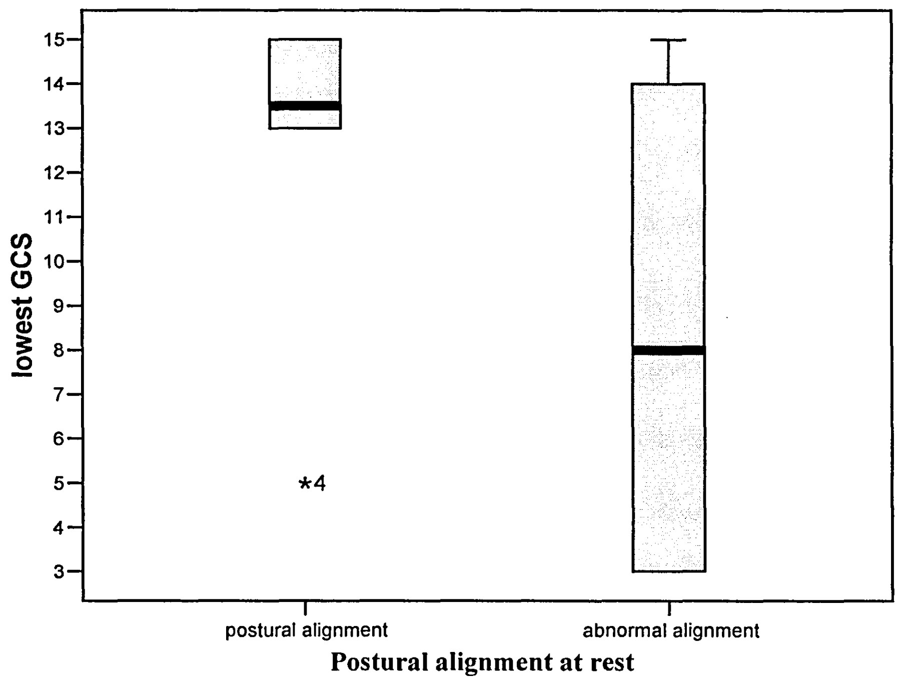
The deficits observed across the group were considered with respect to severity, age, gender and mechanism of injury.

Severity

Biomechanical alignment & tissue extensibility

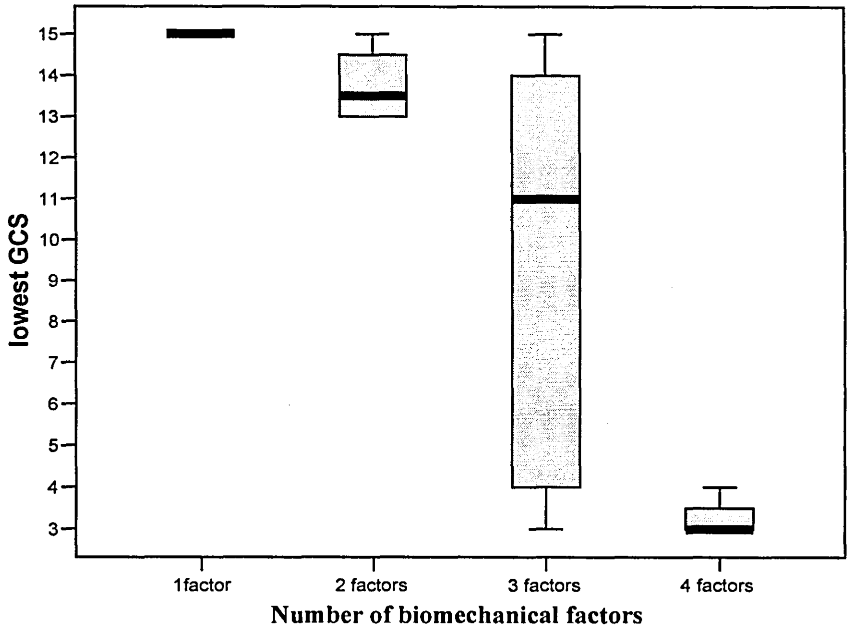
No clear relationship between severity of injury and individual biomechanical deficits were found, with only postural alignment at rest showing a tendency towards being associated with more severe injury (figure 9.1).

Figure 9.1



However, when severity was considered alongside the number of biomechanical factors identified for each participant, there was a trend for higher severity to be linked with multiple biomechanical deficits (figure 9.2).

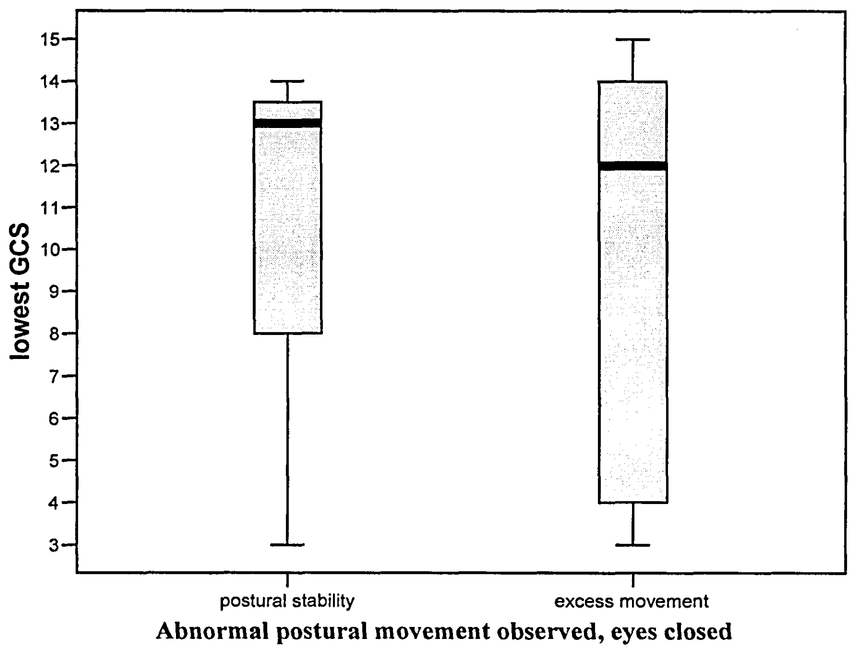
Figure 9.2



Motor control / performance

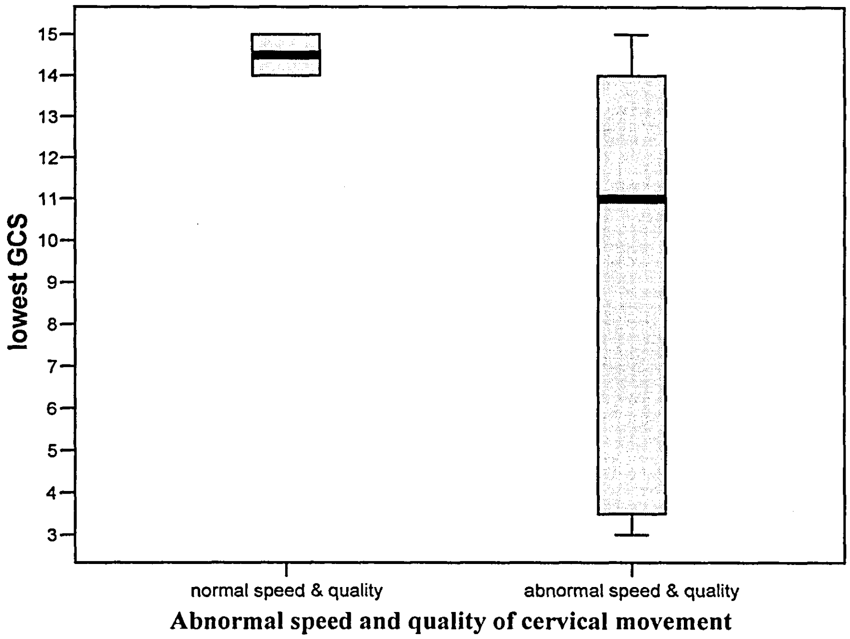
Postural instability in the eyes open condition was not linked to any specific range of severity but only one of the four participants who remained stable with eyes closed had a documented severe injury (figure 9.3).

Figure 9.3



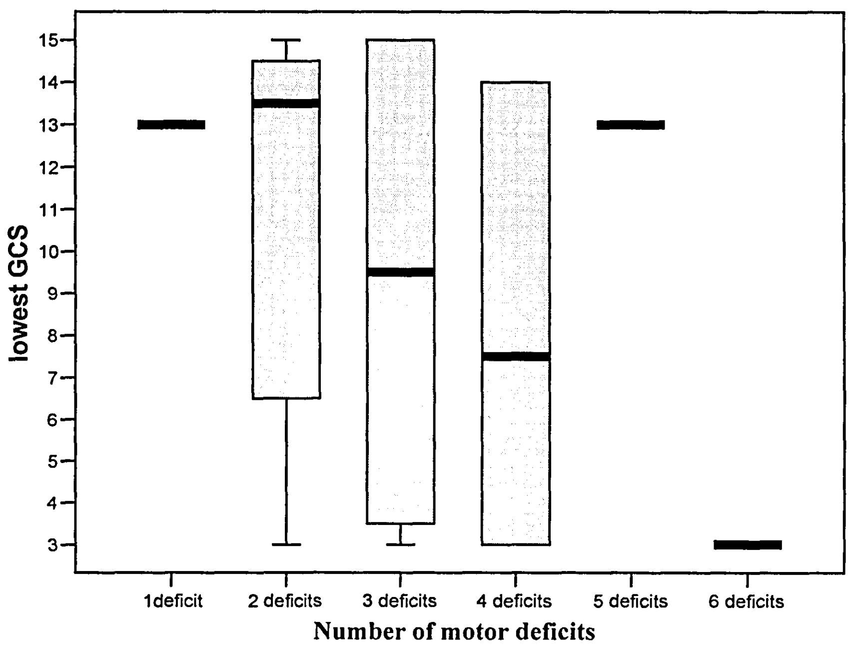
There was a similar relationship for those retaining normal speed and quality of cervical movement (figure 9.4), with all four having minor injuries. The median GCS score for those with minor upper limb ataxia was 13/15 as opposed to 11/15 (more severe) for those with significant upper limb ataxia, but the range was wide in both cases.

Figure 9.4



There was a trend for higher severity to be linked with increasing numbers of motor control deficits (figure 9.5). There was one participant only in each of the one, five or six deficit categories.

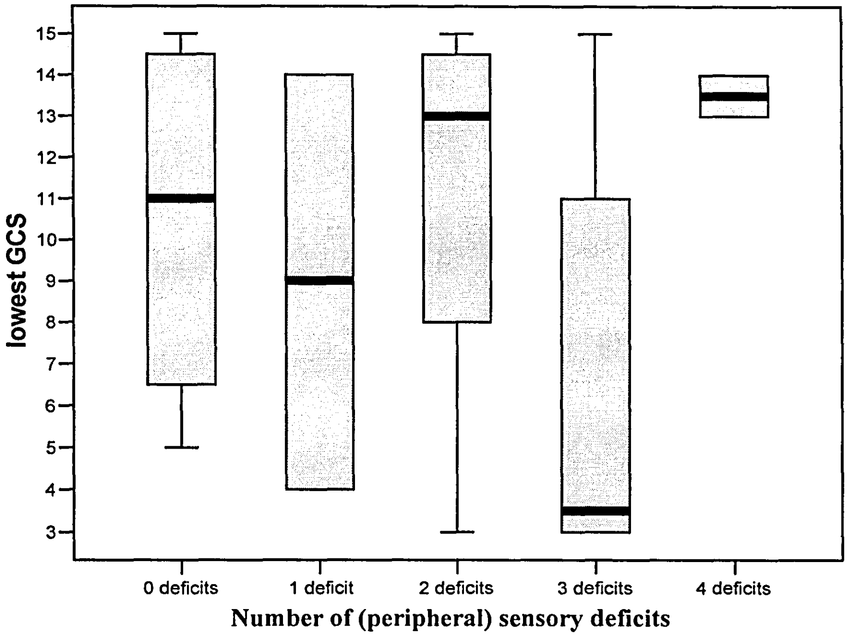
Figure 9.5



Peripheral sensation & pain

There was no link between severity and the occurrence of peripheral sensory deficits at individual or frequency level (figure 9.6) nor with the report of neck pain or headache.

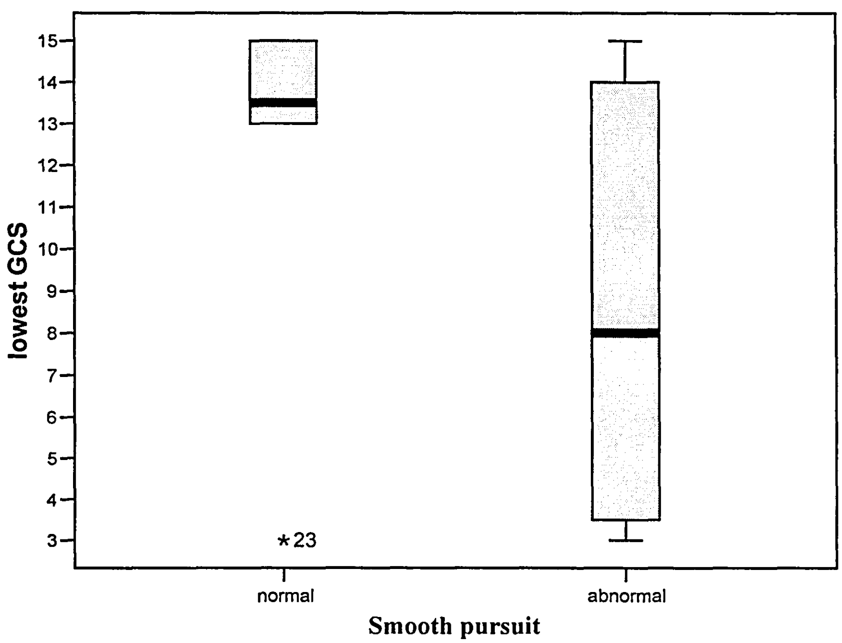
Figure 9.6



Vision & underlying motor processes

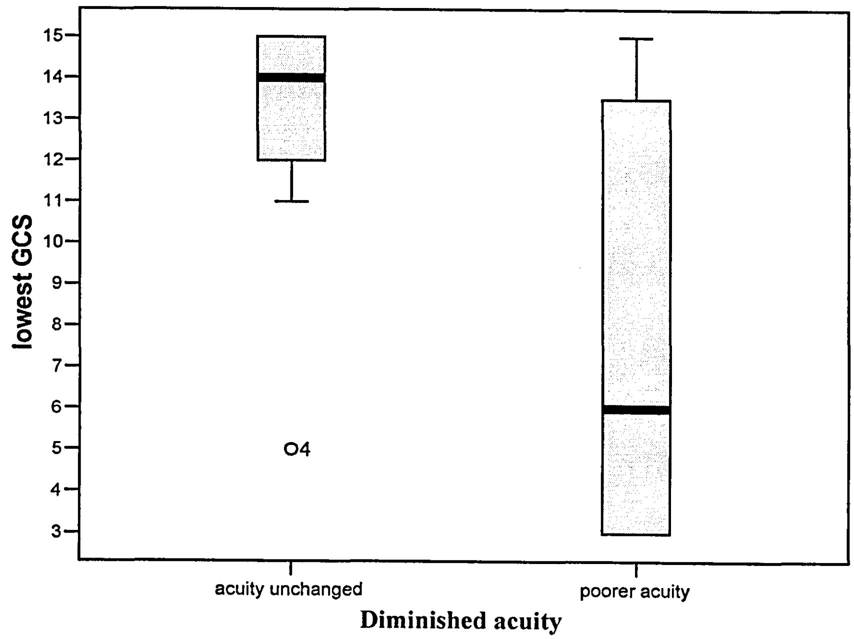
Oculomotor problems were found across severities but those who were problem free tended to have less severe injuries, for example smooth pursuit (figure 9.7).

Figure 9.7



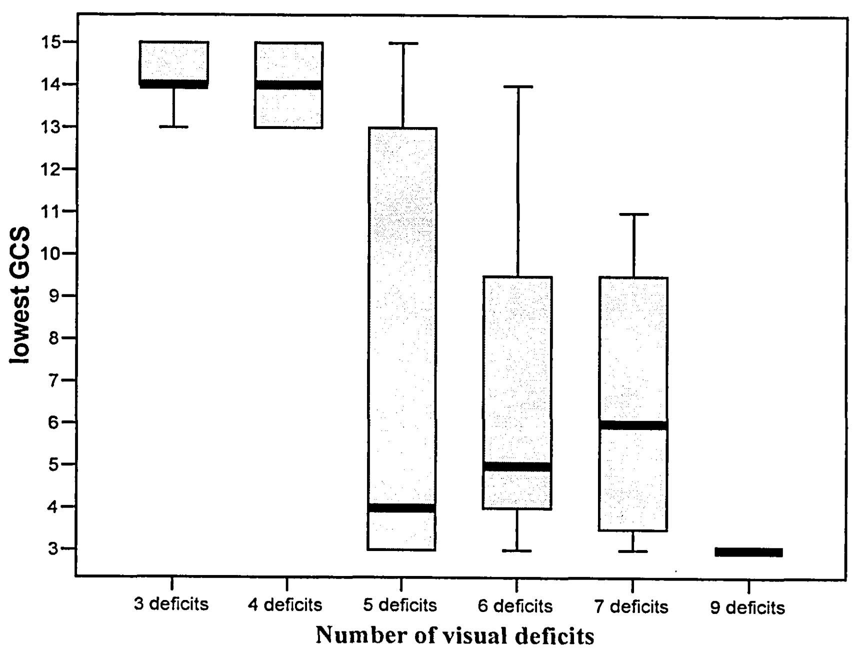
A similar tendency was found for acuity (figure 9.8).

Figure 9.8



There was also a tendency as before for those with severe injuries to have multiple deficits, the number increasing with the severity (figure 9.9).

Figure 9.9



Interestingly, while reports of double vision were more likely to occur with moderate/severe injuries (figure 9.10), visual blurring was more prevalent in the minor/moderate cases (figure 9.11).

Figure 9.10

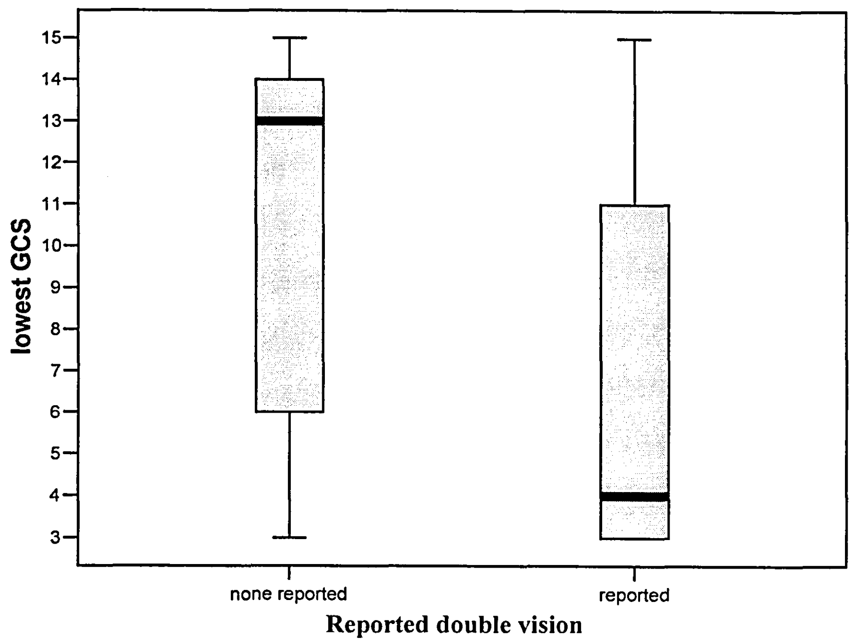
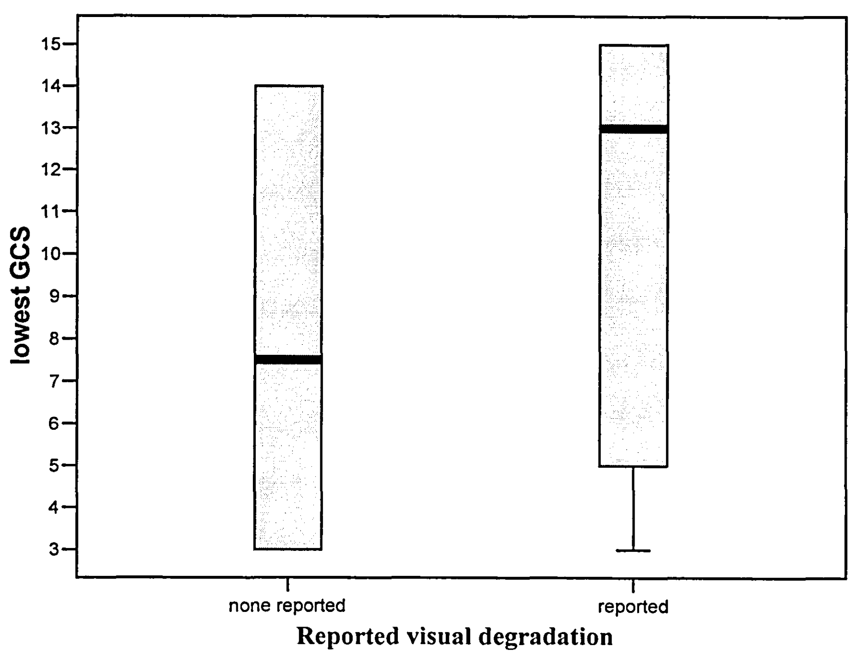


Figure 9.11



Vestibular system

As with visual blurring, individuals who were symptomatic on the Dix-Hallpike manoeuvre were more likely to have had a *less* severe injury (figure 9.12). This was also the case for those whose presentation was suggestive of otolith dysfunction (figure 9.13).

Figure 9.12

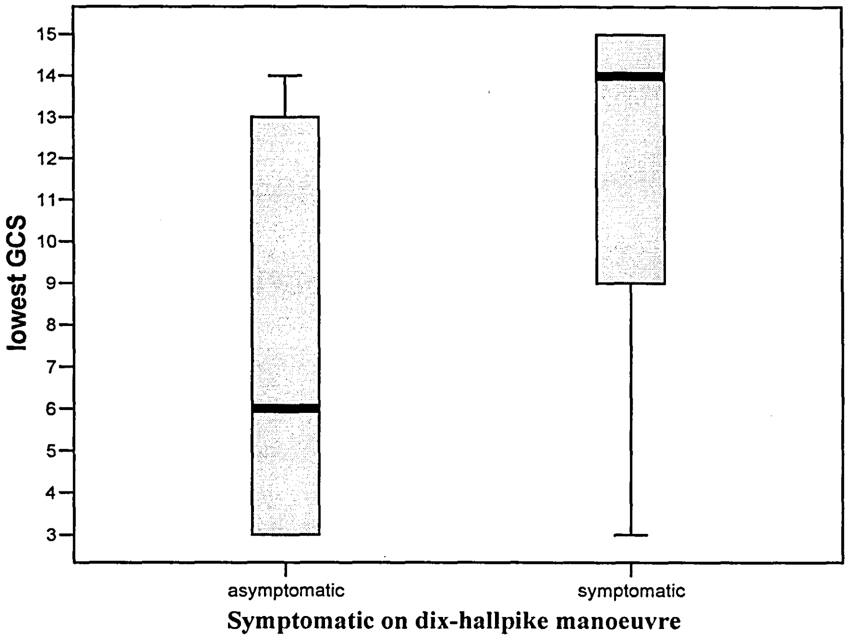
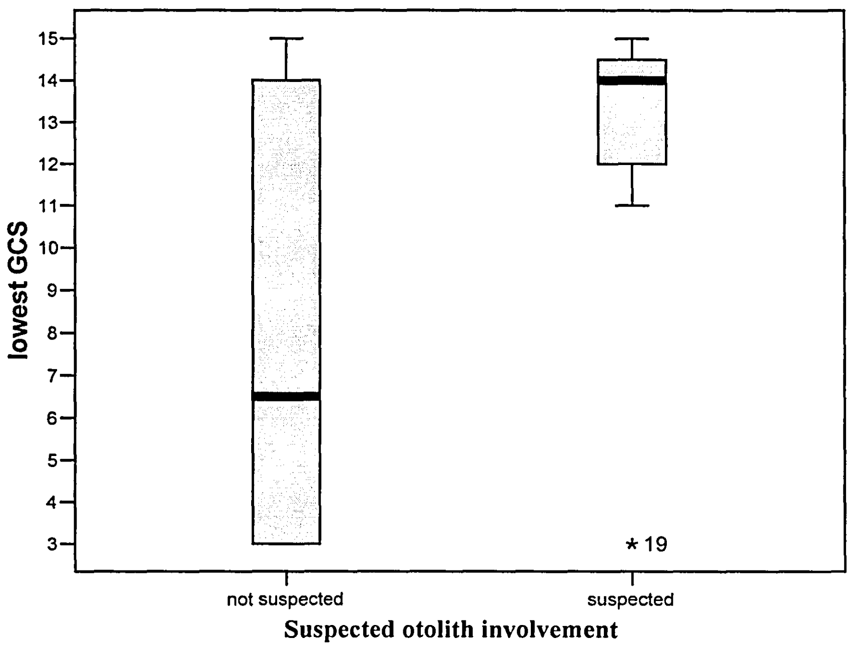


Figure 9.13



Finally, those with less severe injuries were also in the majority across the whole group when the number of positive vestibular signs was considered (figure 9.14) and for the smaller group (22) who were asked to complete the Fukuda Stepping Test (figure 9.15).

Figure 9.14

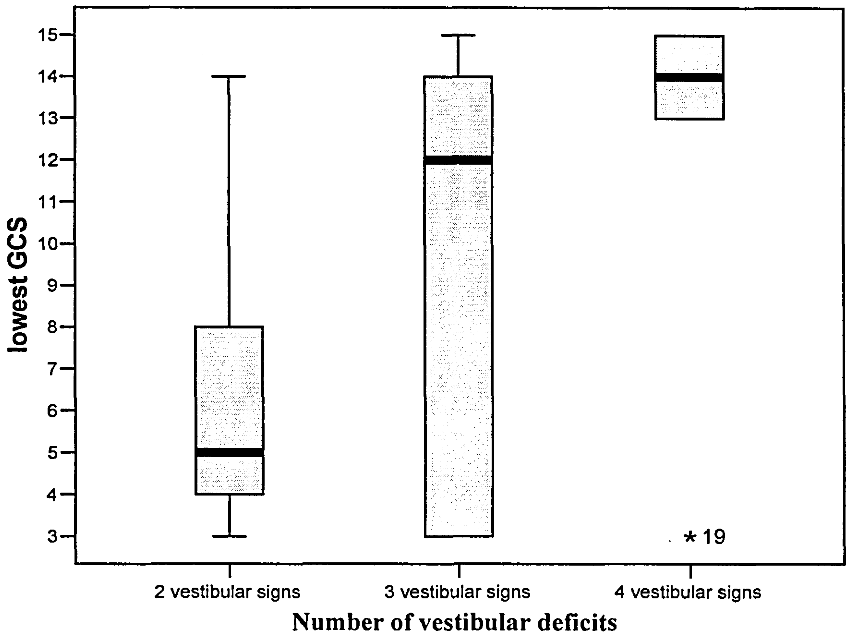
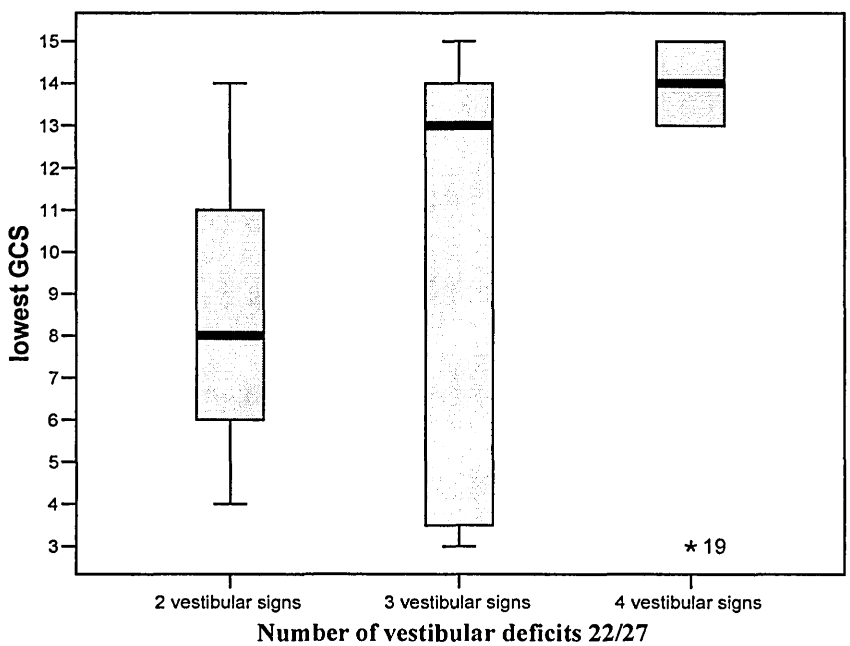


Figure 9.15



Integration and adaptability

The only notable observation with regard to signs associated with integrative function in terms of severity was that individuals who did not complain of dizziness or disorientation were those most severely injured.

Severity: emerging issues

- The data suggest an overall tendency for the number of deficits within each domain to increase with injury severity as measured by GCS scores.
- A clear exception to this trend was the signs and symptoms associated with vestibular system dysfunction which were more prevalent in those with less severe injuries.

Age

Biomechanical alignment & tissue extensibility

There was no clear association between age at the time of injury and the prevalence of individual or multiple biomechanical deficits (figure 9.16) except for a tendency for younger participants to have reduced range of cervical movement (figure 9.17).

Figure 9.16

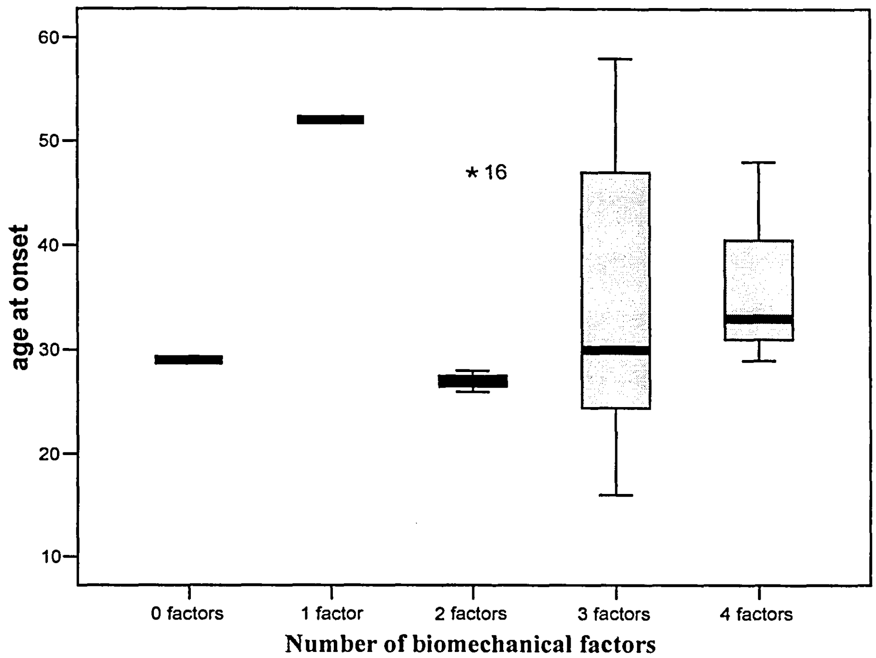
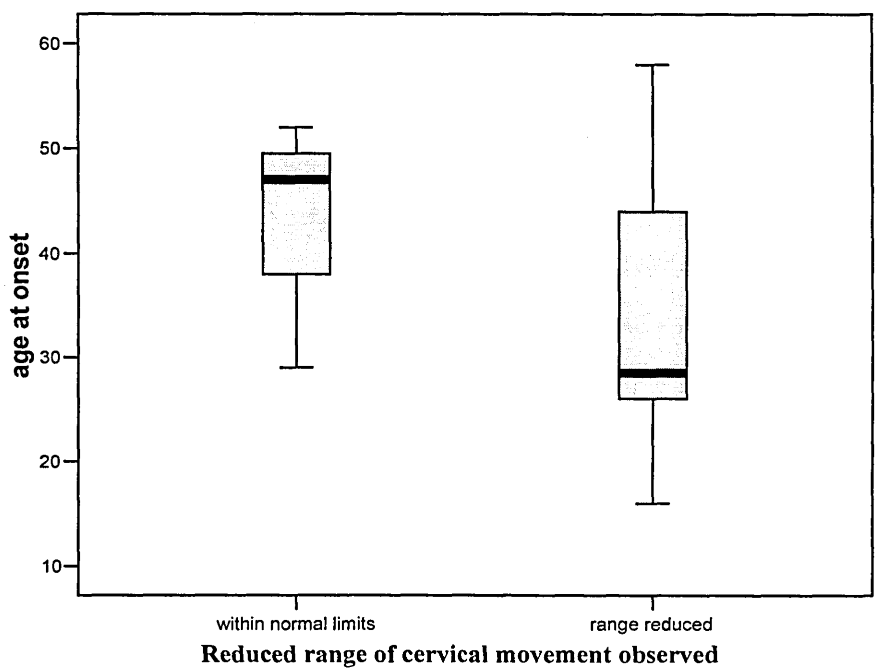


Figure 9.17



Motor control / performance

There was no relationship observed between age at injury and issues of motor control (figure 9.18). It is of note that this is the case in terms of observations of postural stability, where a tendency towards increased instability may have been anticipated in the older age group (figures 9.19 & 9.20).

Figure 9.18

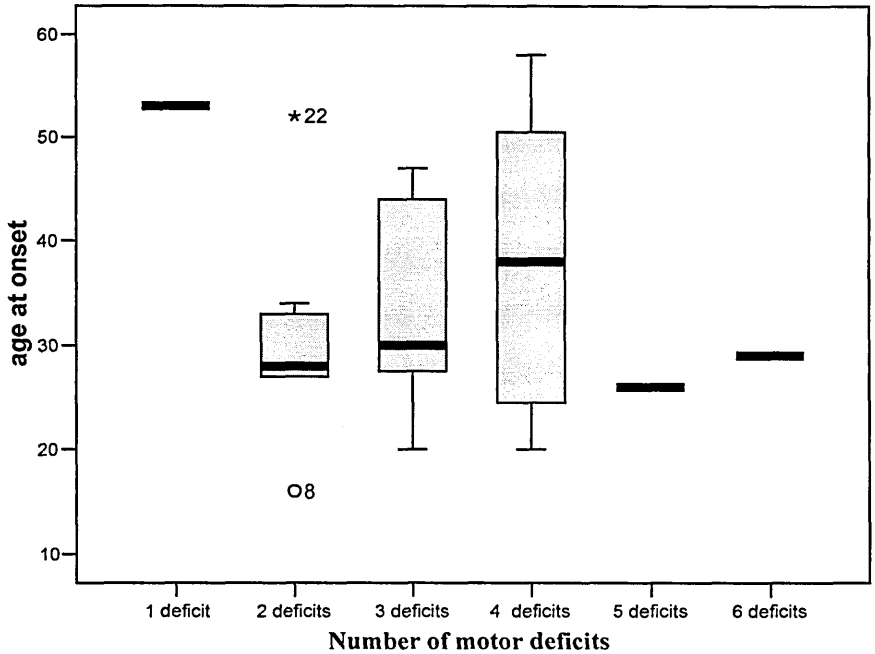


Figure 9.19

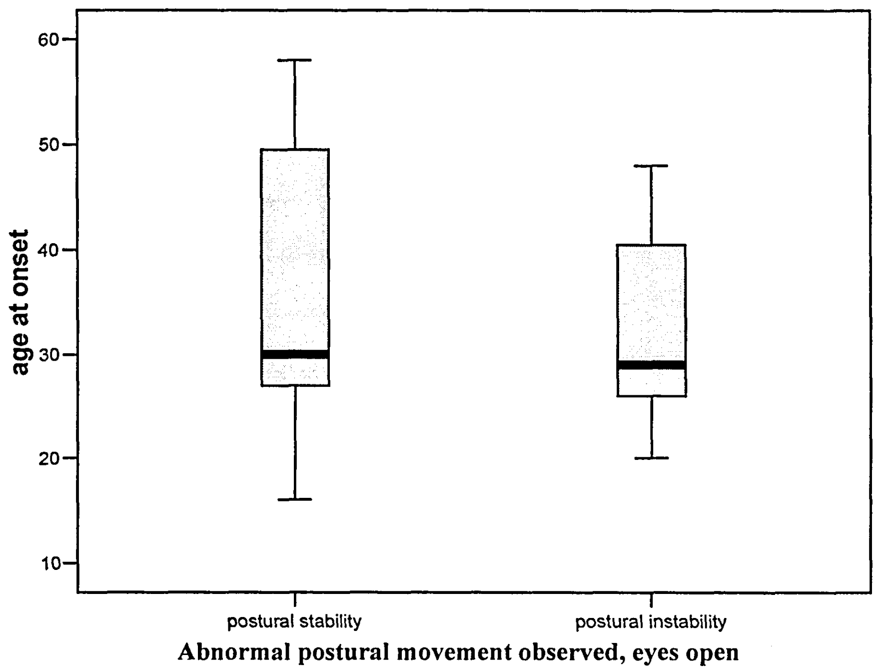
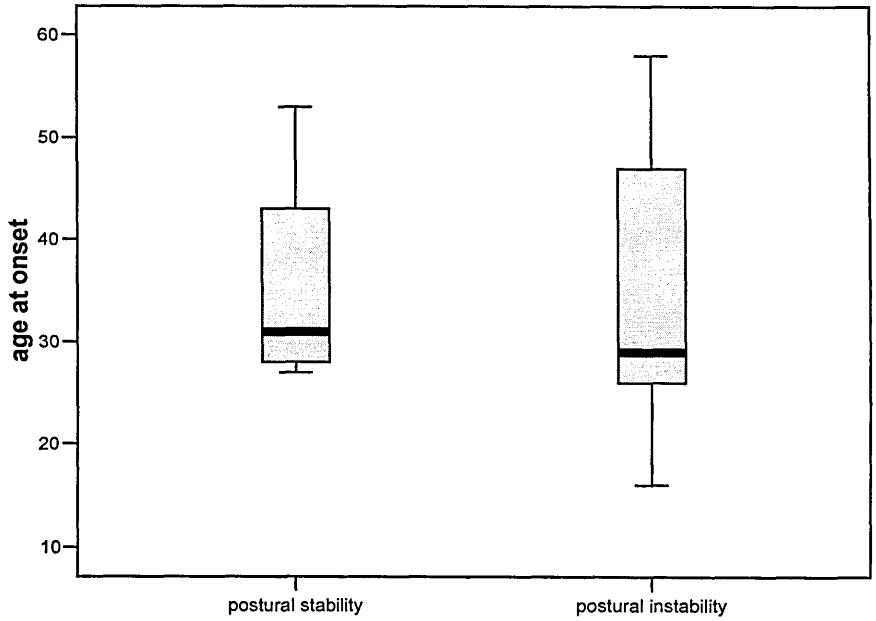


Figure 9.20

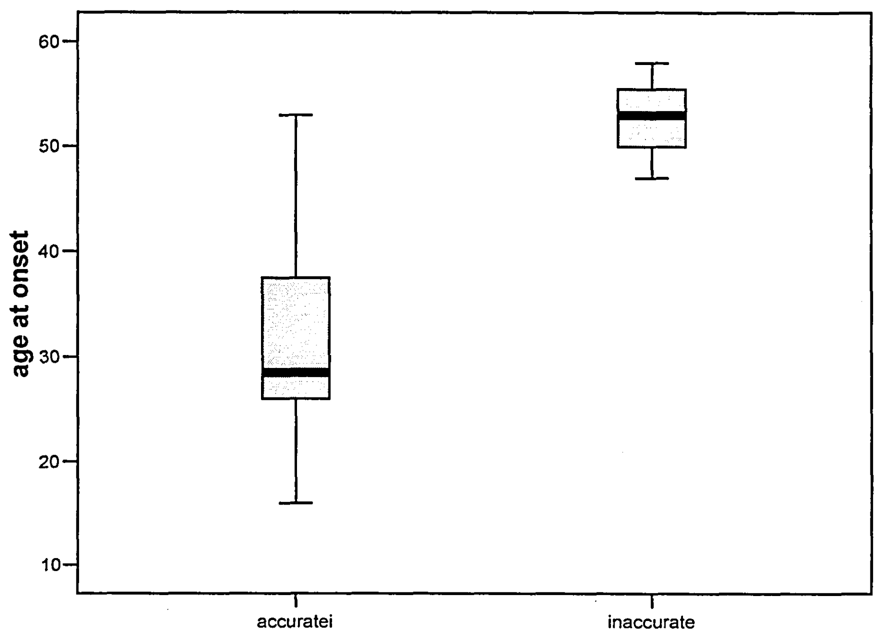


Abnormal postural movement observed, eyes closed

Peripheral sensation & pain

The data suggest a tendency towards increasing levels of peripheral sensory deficit with increasing age (figures 9.21, 9.22 & 9.23).

Figure 9.21



Single stimuli tactile deficit

Figure 9.22

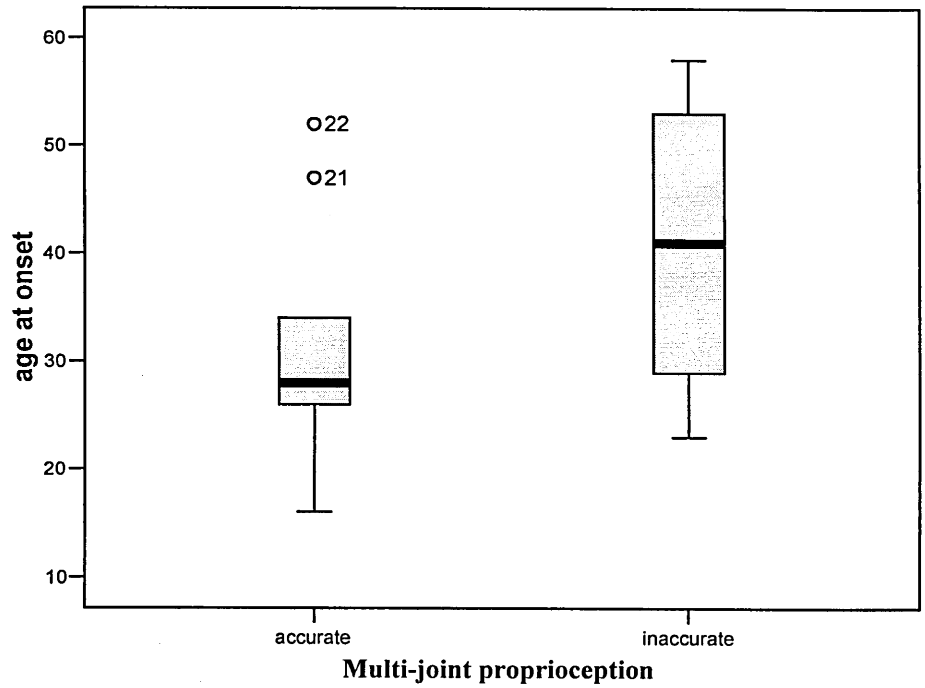
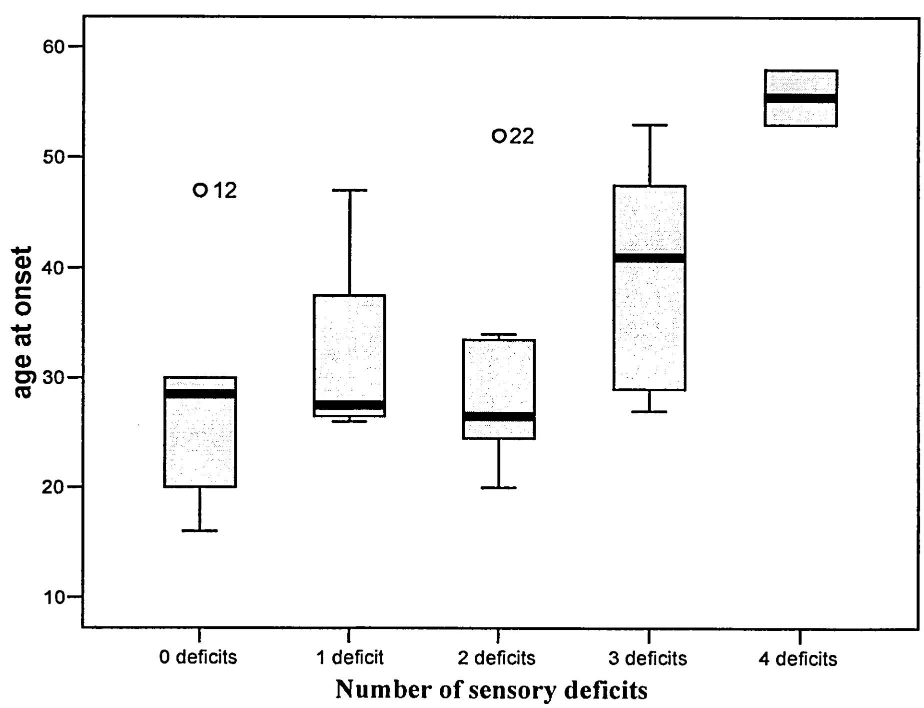
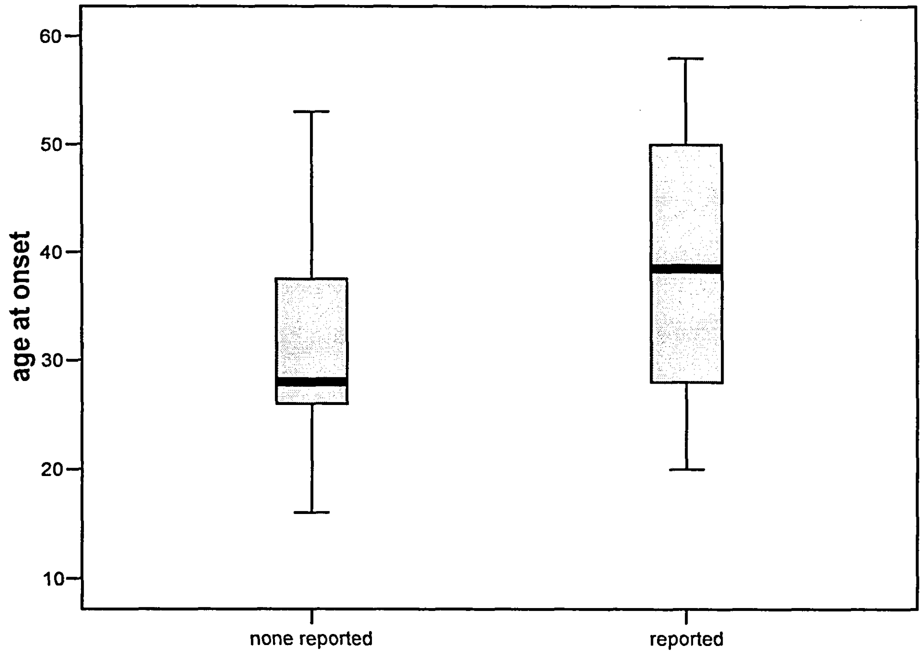


Figure 9.23



Neck pain was also more frequently reported with increasing age (figure 9.24).

Figure 9.24



Vision & underlying motor processes

There was no relationship observed between age and individual or multiple visual deficits.

Vestibular system

There was no relationship observed between age and vestibular system dysfunction.

Integration and adaptability

There was no relationship observed between age and integrative function.

Age: emerging issues

- The data suggest that the prevalence of peripheral sensory deficits increases with age.

- There are notable findings in terms of reduced cervical range in the younger age group and there being no difference in levels of observed postural stability across the age range.

Gender

There was no significant or consistent difference in self reported or observed deficits between the genders.

Mechanism of injury

Analysis of deficit trends with reference to the mechanism of injury was limited by lack of clear detailed documentation of this factor or patterns of resultant lesions in the clinical notes. Four broad categories derived from the information available (RTA motor cycle, RTA other, assault/hit by falling object, fall) were used to explore a range of possible relationships, with no clear trends emerging.

Primary analysis: summary of findings and emerging issues

- There was a high incidence of reported and observed balance disorder in the studied group.
- Deficits were consistently found across a wide range of the targeted contributory domains.
- Deficits in some domains were found at a very high frequency: reduced range of cervical movement (89%), postural loss, sway or drift with eye closure (85%), vergence abnormalities (85%), VOR abnormalities (96%), reports of dizziness or other sensory disorientation (89%), gait abnormalities (100%).
- There was an overall tendency for the number of deficits within each domain to increase with injury severity as measured by GCS scores, however
- A clear exception to the trend linking injury severity and increased frequency of deficit was seen within the vestibular system domain where the signs and symptoms associated with vestibular system dysfunction were more prevalent in those with less severe injuries.
- The prevalence of peripheral sensory deficits appears to increase with age.
- There was a higher incidence of reduced cervical range in the younger age group.
- There was no difference in levels of observed postural stability across the age range.
- There were no differences between the genders.
- Lack of detail in relation to the documentation of injury mechanism or cerebral lesions limited further analysis of emerging differences in patterns of injury associated with severity as detailed above.

10 ORIGINAL OBSERVATONS: SECONDARY ANALYSIS

10.1 Single case analyses

During the data collection period a summary of findings and clinical opinion was produced in respect of each participant as a basis for feedback to the host clinical teams. The structure and content of the summary was derived from pre-study discussions and was initially intended to be biased towards those aspects of assessment or onward referral not undertaken as routine with standard clinical practice. However, as it transpired that practice was not necessarily standardised across clinicians within teams and that practice was also influenced by the discourse that developed as a result of the research focus, the summaries also developed over the period of data collection into a basis for dialogue and exploration on a case by case basis. At the end of the data collection period, and subsequent to the examination of the whole group data, further consideration was given to the deficit profile of each participant in turn. An anonymised copy of each of the clinical summaries together with the secondary review narrative can be found in appendix 2. A brief summary of salient points and emerging issues in each case is presented here.

Participant 1:

This 20 year old female was initially assessed as a minor injury (GCS 14) and only admitted for observation because of a sluggish right pupillary response and the history of high energy injury (side impact RTA). She presented with a range of impairments with high functional impact following an apparently minor injury raising the question of whether her presentation (significant injury with limited impact on conscious level) was influenced by the mechanism of her injury. The impairments included abnormal postural orientation with respect to gravity, possibly influenced by visual deficits. There was also an asymmetrical postural drift with limited awareness and poor corrective response. There was apparently 'reflex' increase in neck muscle tone associated with reports of noxious sensation (dizziness), including dizziness associated with visual demands. Fatigue was reported associated with walking and with sudden loud noise. There were questions in relation to the robustness of her self-report, including her description of her pre-injury status.

Participant 2:

This 29 year old female had an unwitnessed fall at home resulting in severe injury with occipital fracture and right hemisphere contusions. There was observable cognitive clouding at the time of assessment and a discrepancy between verbal self-report and observed behaviours, particularly in relation to avoidance behaviours (movements provoking distress), highlighting the need for skilled exploration of behaviours observed in assessment. There were a number of co-existing deficits with the potential to inter-relate in different causal directions indicating the need for a pragmatic approach to diagnosis and management strategies. There was poor performance on sensory testing with a cognitive load, the impact of which on functional success and risk analysis required careful consideration. There was also an issue of 'corrective' behaviours in response to illusory movements adding to risk.

Participant 3:

This 23 year old male sustained a severe injury in an RTA resulting in an occipital fracture and bilateral frontal contusions. While each of his deficits were individually minor their combined functional impact was significant. He had visual, vestibular and subtle inattention issues, poor midline judgement, gradual loss of postural tone (unilateral) and bilateral minor upper limb ataxia. He also demonstrated 'reflex' increase in neck muscle tone associated with reports of noxious sensation, which included dizziness and nausea.

Participant 4:

This 28 year old male sustained his severe injury while on a motorcycle resulting in basal skull fracture and multiple facial, trunk and limb fractures. There was significant cognitive clouding at the time of assessment with under reporting. His self report was clearly at odds with his functional ability. Assessment was also limited by healing fractures. Both of these factors highlight the limitations of single assessments in deriving definitive assessment findings and the need to skilfully explore avoidance behaviours within the assessment process.

Participant 5:

This 29 year old male sustained a moderate injury (GCS 11/15) as a pedestrian in an RTA resulting in a frontal fracture with frontal contusions, temporal swelling, and thoracic and limb injuries. He had a rotated and tilted resting head position that seemed to relate at least in part to achieving binocular single vision but the position was further accentuated when vision was removed and the postural drift extended to include the trunk. There was an early history of hyperacusis and rotational dizziness but although these were now reported as resolved he presented with ongoing significant functional imbalance with limb ataxia and a narrow and laterally drifting base. Cervical range of movement was reduced in range and quality, freer when body moved on neck but this was also associated with loss of single vision.

Participant 6:

This 41 year old female sustained a severe injury as a passenger in an RTA resulting in a traumatic right temporal subarachnoid bleed with intraventricular blood, cerebral oedema and upper limb fractures. She presented with multiple impairments across all domains affecting primary sensory and motor (including oculomotor) skills, possible inattention, absence of anticipatory postural adjustments and reduced speed of processing. Estimation of straight ahead varied with sensory condition with preponderance to the right with eyes open and left with eyes closed. She walked with a stiff style of gait and resisted rotatory movements between body segments.

Participant 7:

This 48 year old male sustained a severe injury probably in a fall or possibly via an assault resulting in a right temporal fracture with bilateral temporo-frontal contusions and limb fractures. His postural orientation was significantly removed from the line of gravity (postero-lateral) and he had problems monitoring postural drift in trunk and limbs and in maintaining extensor postural tone. He reported being aware of postural instability during routine tasks and used limb fixation to increase feelings of safety in static postures. He demonstrated central vestibular signs with 'reflex' co-contraction of neck musculature, but did not report dizziness. He denied visual difficulties although oculomotor and attentional deficits were apparent on examination. There appeared to be an attentional component in responding to sensory stimuli, with improvement in accuracy but continuing problems of speed and discrimination.

Participant 8:

This 16 year old male sustained a moderate/severe (GCS 8) injury in an assault resulting in a traumatic subarachnoid haemorrhage with left parietal contusions. His resting posture was orientated away from the line of gravity (postero-lateral right). The head posture was potentially explained by longstanding unilateral low vision in one eye but there was also a similar inclination of the trunk. He reported a tendency to fall to the left and was observed correcting leftward drift during activity. There were signs of left vestibular hypofunction. The postural deviation to the right at rest was potentially a secondary corrective behaviour. His peripheral sensory system was intact with good accuracy and speed of response and this appeared to be offering protection from overall loss of postural control.

Participant 9:

This 34 year old male sustained an apparently minor injury (GCS 14) in a motorcycle RTA but also experienced posttraumatic amnesia of up to one week and had two previously documented minor TBI's. He also sustained a fractured talus in the injury which, although surgically repaired, continued to cause debilitating pain preventing full weight-bearing. Pain, dizziness and fatigue were the dominant complaints and associated with low mood. The dizziness was associated with nausea and controlled by anti-emetic medication (which is known to retard normal compensatory processes). He was also taking a significant amount of pain medication. There were right-sided vestibulo-visual signs and postural instability on assessment. He was slow to respond to sensory testing and had difficulty discriminating between stimuli, especially on the right. The extent of his disability would not normally be expected of an apparent minor injury and could be the cumulative effect of repeated injuries. However, the diminished speed and capacity of information processing could also be associated with the presence of pain, the use of medication or the co-existing low mood.

Participant 10:

This 27 year old female sustained an apparently minor injury in an RTA in Ireland and was not admitted to hospital. Post traumatic amnesia is estimated at one week. She was involved in a second side impact RTA one year after the first. Her main complaints relate to difficulty dealing with moving environments (physical and visual) and although there was a suggestion of vestibular system involvement (including significant postural instability and fear with vision removed), the symptoms did not fit with horizontal semicircular canal problems. There was a significant history of post injury cervical spine problems with headache, assisted to some degree by manipulative physiotherapy though requiring monthly maintenance. There was 'reflex' increase in neck musculature during right leaning postures. There was also an established link between her sensory disorientation and severe autonomic symptoms including vomiting and very regular 'preventative' use of anti-emetic medication. Again this case raised concerns about the level of disability associated with an apparently minor injury and the long term use of medication that limits compensatory processes. She was hesitant on peripheral sensory testing. Cervical spine pathology seemed to be central in the continuation of symptoms and possibly a primary factor.

Participant 11:

This 27 year old male sustained a minor injury in a motorcycle RTA resulting in a depressed skull fracture and a diffuse traumatic subarachnoid haemorrhage, facial fracture and eventual removal of the right eye. He demonstrated right sided attentional issues on visual and peripheral sensory testing, left sided ataxia and subtle but consistent left-sided vestibular signs. Resting head position was rotated to the right. He reported dizziness (feeling like his head was being left behind) and loss of balance but demonstrated no perceptible movement in static sitting and standing. He was previously a martial arts enthusiast. Dizziness and postural instability was elicited on dynamic testing. His gait was stilted and lacked rotation, even at speed. Again there is a significant level of impairment following an apparently minor injury and symptoms suggesting vestibular involvement that are not obviously attributable to (horizontal) semi-circular canal dysfunction.

Participant 12:

This 47 year old male sustained a minor injury in a motorcycle RTA resulting in a burst fracture of L4 and upper limb fractures. There were reports of right tinnitus early in the recovery phase. There were visual and vestibular signs on examination, several significant witnessed falls and many reports of stumbling. Some of his errors appeared to occur when he was using his (unreliable) vision to substitute for vestibular function. He experienced dizziness on cervical motion and on VOR testing and had a clear postural drift, worse with eyes closed. He also experienced illusory movement. He was, however, determined to continue to pursue demanding activities, such as using ladders. There were also reports of headache associated with periods of concentration and with a stiff upper thorax and neck on rising in the morning. This is another example of apparently excessive signs and symptoms following a minor injury (as measured by GCS) and illustrative of the risks of 'corrective' behaviours associated with visual substitution for vestibular loss in the presence of visual dysfunction and postural correction following illusory movement.

Participant 13:

This 58 year old male sustained a minor injury in an assault resulting in a fractured base of skull and fractured nose. His report of symptoms highlighted some unusual descriptions such as eye watering, sensations of eye itchiness when trying to concentrate, misreading words but always getting the first letter right, feeling like a puppet on a string, feeling like he had a cork bobbing from side to side in his head, occasional whooshes of dizziness. He presented with a series of subtle mainly left-sided signs, consistent with each other. As well as avoiding movement into the left visual field, there was a left-sided head tilt, he required extra saccades to find left placed targets and there was an apparent rebound. There was a sensation of falling to the left on eye closure in sitting and immediate unease and a subsequent dramatic fall back in standing. There was also diminished sensory awareness on the left and a large rotation to the left on the Fukuda Stepping Test. However, while passive VOR testing produced dysmetric eye movements active VOR within his chosen small range was asymptomatic. He had difficulty with VOR cancellation, especially to the left. Cervical range was very restricted with virtually no extension. His gait was very slow, with generalised co-contraction and limited respiratory excursion (he reported breathlessness). In contrast to the co-contraction, there was upper limb ataxia. This is yet another set of significant findings in an apparently minor injury. However, it is not easy to differentiate between primary symptoms and secondary compensations.

Participant 14:

This 27 year old male insulin dependent diabetic sustained a minor (GCS 13) injury. Injury mechanism and acute management issues were not recorded in the clinical record. He had had laser treatment for a pre-injury right retinopathy and his acuity was stable. There was a deviation in postural alignment with respect to the line of gravity in a postero-lateral (left) direction, affecting head and trunk and increasing, along with a side to side sway, on eye closure. There were clear indicators of bilateral peripheral vestibular involvement including fatigable dizziness. He was slow to recognise stimuli in the left visual field and there was nasal drift on occulomotor testing, abnormal optokinetic response in vertical and dizziness on apparently normal responding horizontal. He reported fluctuating levels of visual blurring and difficulty dealing with bright lights and surroundings. His gait was rigid with visible instability during directional change. Instability and feelings of instability were reduced with increased speed of gait although this was something that he could not sustain. This case is a good example of inter-related signs and symptoms requiring pragmatic prioritisation in planning management strategies and interventions.

Participant 15:

This 20 year old male sustained a minor injury when he fell from a moving van. Although the ambulance service was called they took this young man home rather that to A&E. He subsequently took to bed for several days complaining of headache, dizziness and nausea. He was subsequently found to have a fractured right occiput.

Aspects of his reported symptoms and assessment findings were consistent with vestibular system dysfunction, but not attributable to horizontal semi-circular canals. There was postural malalignment of head and trunk with a left bias and resistance to correction of left head rotation in static postures. There was postural instability, and difficulty stabilising gaze in the primary position. In contrast there was a right of centre bias during gait when he used a ground reference point and tilted to the right from the waist. His base of support was narrow with the left leg often crossing the midline consistent with his report of veering to the right in day to day functioning. He also rotated to the right and travelled forward during the Fukuda stepping test. There was significant upper limb ataxia on testing, especially on the left. He was aware of and clearly described difficulties in assessing environment horizontal and vertical and in successfully interpreting his visual impressions.

Participant 16:

This 47 year old female sustained her injury in an RTA. The severity was not recorded. She was initially treated for clavicular and malleolar fractures and whiplash type symptoms. She presented with mixed vestibular and cervical symptoms, predominantly right sided and associated with autonomic response. There were also limitations and abnormalities of eye movements to the right and limitations of right neck rotation. There was postural drift, partially corrected in sitting but overwhelming in standing to the extent of preventing the maintenance of eye closure. Peripheral sensory (tactile) awareness was reduced in the right limbs although proprioception was fine. She felt in control in sitting because she could feel increasing pressure on the ischial tuberosity but had no similar reference point in standing. There was right upper limb ataxia. There were some core similarities between this participant and participant 13, including the dramatic way they lost balance and the slow creeping nature of their gait. This case again demonstrates the cumulative functional effect of co-existing impairments.

Participant 17:

This 26 year old male sustained a severe injury driving a car involved in an RTA. He had significantly high muscle tone in the early period of recovery and underwent surgery to lengthen both tendo-achilles. His movement pattern was characterised by high levels of co-contraction and minimal rotation or fractionalisation within functional movement. Co-contraction was also evident in supine lying. There was a global lack of extensibility in the soft tissues. Although conversation was superficially normal it became apparent through comparing his report and assessment findings that he both under-reported and denied difficulties. There was a range of visual problems including limitations of awareness in the left visual field. He experienced after motion during the assessment and described this as a diminishing problem. There was postural drift and instability which increased with eye closure but tests of peripheral vestibular function were not symptomatic. He did, however, rotate a full 180° to the right during the Fukuda Stepping Test. He was unable to maintain a static eye position when the head or body was passively rotated. His chosen upright orientation and his trunk inclination during gait was posterior to the line of gravity. There was a clear impact on his overall presentation of the early high tonal state and a range of symptoms that might be described as central vestibular dysfunction.

Participant 18:

This 26 year old male sustained a minor (GCS 13) injury in an RTA. His dominant symptoms were difficulties of gaze fixation and increasing levels of visible fine nystagmus (and associated dizziness) observed during the assessment, particularly associated with rotational (head on body, body on head) movements, significant levels of illusory movement with eyes open and increased with eye closure. There was postural instability (but not in the direction perceived by the participant) and reduced speed of response for sensory testing with cognitive load. There was also a sway-back orientation of the trunk during walking and increasing instability with decreased speed. Slight ataxia was observable in both right limbs. This participant preferred to keep a degree of movement going at all times, apparently using active movement as a form of sensory substitution.

Participant 19:

This 33 year old male sustained a severe injury in a RTA resulting in a fractured base of skull, left extradural haematoma, left carotid cavernous fistula and pulmonary contusions. He had corrective eye surgery (details unknown) while with another service. However, he was still having problems achieving binocular single vision (still having two images in the vertical plane) and apparently adopting an abnormal head posture (in extension) to bring the stronger of the two images into central vision. This abnormal head position was associated with soft tissue adaptation and limitations of neck movement. He had a right-sided hemiplegic type gait with mixed resting muscle tone and hyperaesthesia, often verging on pain, throughout the right side. There were also problems of sensory discrimination on this side. Postural drift to the left, increased on eye closure and rotation to the left during the Fukuda Stepping Test was observed in contrast to reports of fear of falling to the right and sometimes feelings of being pulled backwards. Fusion problems here were contributing to biomechanical problems and to postural vulnerability. There also seemed to be two possible issues of imbalance, one relating to vestibular system tone and one to hemisensory loss and muscular dyscontrol, particularly proximal instability for weight bearing.

Participant 20:

This 30 year old male sustained his injury in an RTA abroad resulting in a fracture dislocation of C6/7 diagnosed and surgically stabilised *after* transfer to the UK. He had corrective eye surgery as a child and there were some visual findings probably related to this. He had an abnormal resting head position and very significant limitations of all cervical movements. Headache was elicited during the assessment and along with posterior eye pain was reported as an ongoing problem. He reported dizziness following quick or rotational movement and regular stumbling and falls, mostly backward, and dizziness with nausea was provoked by vertical VOR testing. He perceived an illusory diagonal rocking motion in sitting and a strong sensation of 'waves of bobbing' in standing. During attempts to maintain static standing there were repeated sudden upper limb balance reactions in a fairly dramatic manner, similar to the characteristics seen in participants 13 and 16. An eyes-open trial of the Fukuda stepping Test produced a sensation of seasickness and he preferred not to proceed with the full test. Tactile and proprioceptive testing was grossly intact, though interpretation of multi-joint movements was slow. He reported experiencing juddering sensations and intermittent paraesthesia in both left limbs. He also described disturbing episodes of offensive olfactory illusions. He was slow to turn while walking and reported the room as spinning (had to sit to recover) after a few directional changes. The primary debilitating factor here appeared to be sensory disorientation and postural dyscontrol of cervical origin.

Participant 21:

This 47 year old male was hit on the head by scaffolding at work. He attended A&E and was not admitted but returned two weeks later complaining of headaches and had a failed attempt at work return within the first month. Although he did return to work he continued to have difficulties and, indeed, was more symptomatic in terms of provocation of dizziness and disorientation on the study assessment than when seen earlier by the treating team. Dizziness was induced by movement, by optokinetic stimulus and VOR testing. Postural alignment was to the left and behind the line of gravity affecting head and trunk with both illusory sensations of movement and increasing postural drift with eyes closed. He reported sometimes feeling he was being pulled over. Anticipatory postural adjustments appeared to be absent and he reported regular stumbling and continuing falls particularly attempting night visits to the toilet. There was diminished sensory awareness in the left limbs and a degree of ataxia, clearly observable during gait. In this case there was a clear reliance on vision for self-assessment of postural stability and possibly both vestibular and cervical contributions to disorientation. Importantly, his attempts to maintain work performance seemed to be resulting in fatigue related increase in symptoms.

Participant 22:

This 52 year old female sustained a minor injury in an assault resulting in a small right temporal subdural haematoma. She had visual signs on the right and bilateral but predominantly left-sided mixed vestibular signs, with 'reflex' increase in neck muscle tone on VOR testing. There was postural instability, deviation to the left and she adopted a narrow base at rest and during gait. There was reduced sensory awareness and ataxia in the left upper limb. This participant presented with mixed peripheral vestibular and central signs following an apparently mild injury. Her injury was relatively recent (21 weeks) and her strategy for maintaining safety and preventing noxious sensation was to limit all but necessary activity.

Participant 23:

This 53 year old male sustained a severe injury in an RTA and his recovery was complicated by a pulmonary embolism. He presented with visual signs, including extinction of right stimuli on bilateral presentation and had difficulty moving his eyes independent of head movement and in inhibiting a reflex right head rotation when his body was rotated left. There was a range of sensorimotor deficits, more severe on the right, and difficulties of body alignment, even in supine. Cervical range was diminished and associated with pain. Gait was initially slow with right sided balance reactions, improved at increased speed but this speed was not sustainable with any directional change. He adopted a wide base and there was postural instability (visible sway) but this was not increased by eye closure. This case is illustrative of accepted complex patterns of movement disruption associated with severe injury and in this case complicated by loss of volitional control and ability to fractionate movements between body segments and functional components, essential for safe function.

Participant 24:

This 53 year old male sustained a minor (GCS 13) injury of which he has no recall. There was no fracture and a negative CT scan with only a left side head laceration as evidence of injury. He presented with an abnormal head posture (extended with left tilt) and restricted cervical range. There were subtle visual signs, worse on the left and more apparent in the vertical plane. He denied hearing loss but appeared to respond more to auditory input from the right. He reported frequent stumbling and problems during night visits to the toilet, including episodes of passing out. Postural instability was dramatically increased in standing when eyes closed and quickly resulted in a full autonomic response, including excess sweating and hyperventilation. He described the sensation on eye closure as feeling like being in a vacuum. There was 'reflex' neck muscle tone increase and breath holding on passive VOR testing but no problems with body on head rotation. He adopted a narrow based gait with backward inclination and breath holding was again evident when asked to increase pace. He avoided forward leaning throughout the assessment. However, he responded well to explanations of the impact of breath holding and was able later to walk at a reasonable pace without provocation of noxious sensation. This case is illustrative of the combined impact of learned avoidance, anxiety and hyperventilation.

Participant 25:

This 26 year old male sustained an occipital impact injury and left-sided facial bruising in an assault. He presented with subtle left sided visual problems and described problems of spatial judgement and maintaining orientation to the midline while in motion. His resting head position in sitting was in extension with a left tilt and there was a perception of self movement not seen. In standing there was a visible A-P sway and a gradual postural drift to the left with eventual correction when eyes opened. The sway transformed into an erratic side to side movement when eyes closed. He described his right side as feeling weightless although sensory awareness, including proprioception, was grossly intact except for some hesitation on discrimination. The right hemiface was hypersensitive and there was right upper limb ataxia. He was unable to maintain focus on VOR testing and vertical testing of this and during optokinetic stimulus was perceived as odd and seen to be limited in excursion. The unusual description of weightlessness and particular vestibulo-visual problems in the vertical plane suggested involvement of the otolith and graviceptive pathways.

Participant 26:

This 28 year old male sustained his injury in a fall from scaffolding resulting in left sided injuries to the head, hand and pelvis. He presented with a range of visuo-vestibular signs more predominant in the vertical plane. There was postural instability which increased with eye closure and a 135° rotation to the left on the Fukuda Stepping Test. Dix-Hallpike testing was, however, negative. Gait was slow with visual reference to the ground and with increased fixation, including eyes, when asked to walk with forward facing gaze. There was reduced speed of response for sensory testing with cognitive load. Symptoms were under-reported when compared to assessment findings and he was self-chastising about his levels of inactivity and feelings of fatigue, labelling himself as lazy. Dizziness and nausea were elicited during the assessment. This case is again illustrative of vestibular system dysfunction not attributable to the horizontal canal and linked with subtle brainstem/cerebellar signs. It also raises issues of the misattribution of reasons for inactivity.

Participant 27:

This 29 year old male sustained his injury in a motorcycle RTA resulting in left facial bruising and mid thoracic fractures. He reported only intermittent problems with dizziness (an upward and backward sensation) and physical instability when feeling dizzy. Postural instability, postural drift and perception of illusory movement were all elicited during the assessment as well as dizziness. He vacillated slightly to the left (rotation) then significantly to the right (rotation) and finally to the left (deviation) while all the time moving forward on the Fukuda stepping test. On Dix-Hallpike to the right he reported a momentary "whoosh" sensation and his eyes filled up and blink rate increased, he reported feeling slightly dizzy on return to sitting from the left. Blink rate also increased in right side lying. He reported the visual target as dipping on left rotation when trying to increase the speed on VOR testing. There was an abnormal slow phase on left going and upward movements on optokinetic testing and difficulties with the visual near reflex. The trunk was 'fixed' in backward inclination and slight right shoulder retraction during gait and a sensation of continuing motion was reported on stopping after walking at increased pace. Slight ataxia was noted in the left upper limb. After initially denying any problems with hearing or added noise he mentioned that he had been sent for and ENT opinion because of popping noises in his ear. He reported that no problems were found but referral had not been made known to the treating team and relevant notes were not available. Even given the number of easily elicited symptoms, he did not consider himself to be in a particularly dizzy period, raising questions about his self-report and related issues of risk. Risk was also a consideration in the fact that part of his postural instability was related to his 'corrective' behaviours for illusory movements.

Secondary analysis: summary of findings and emergent issues

From an analysis of the findings across the single cases a number of recurrent issues emerge. These issues fall into three broad categories:

- Observations relating to the nature of balance disorder after TBI, including
  - Postural orientation
  - Postural drift
  - Illusory movement
  - Muscular co-contraction and reflex motor responses
  - Dizziness and disorientation
  - Central and other ill-defined balance system disorders
  - Functional signs of balance system dysfunction
- Challenges to commonly held views on the outcome of apparently minor injury.
- Evidence of the need for both structure and flexibility in the assessment process and the need to consider findings as a whole in order to predict their combined functional impact.

The emergent issues identified via the primary and secondary analyses will now be considered as whole.

11 SUMMARY OF OVERALL FINDINGS

11.1 Comparison of primary and secondary analyses

The findings of the primary and secondary analyses are consistent and complementary. The primary analysis provided a baseline description of the nature of TBI balance disorder as observed across the studied group, which can be summarised as:

- Highly prevalent
- Multifactorial
- Often characterised by neck stiffness, postural instability, vergence and VOR deficits, reports of sensory disorientation and gait abnormalities, and
- With increasing frequency of deficits associated with increasing severity, except for vestibular signs which were observed in greater frequency in minor injuries.

Further investigation of trends and associations within the primary analysis was limited by the nature of assessment of initial injury severity and by limited documentation of injury mechanisms.

The secondary analysis confirmed a high prevalence of perceived and observed impairments. It also confirmed balance disorder as multifactorial in nature at the level of individual. It further highlighted that the highly prevalent deficits identified by the primary analysis could be accompanied by a range of other deficits, giving a more varied picture than might be suggested by considering the most prevalent deficits alone.

The secondary analysis generated additional information relating to recurrent characteristics across the population such as the internal consistency of abnormal postural orientation within individual participants and the prevalence of co-contracting behaviours associated with lack of intersegmental movement. It also raised questions in relation to symptomatic apparently minor injury and identified the importance of examining the deficit profile as a whole in order to understand the likely functional impact on individuals, rather than assuming minimal impact of subtle deficits. Finally, the value gained from screening the range of domains consistently *and* being able to explore in more detail in individual cases suggested the need for both structure and flexibility in the assessment process.

11.2 Topics for further discussion

Through both the primary and secondary analyses, a range of observable characteristics associated with TBI balance disorder have been described. Although some of the identified characteristics are highly prevalent they have also been found to occur with a varied range of other deficits, raising questions about the mechanisms that underlie. Similarly, some of the observed characteristics and reported sensations are unusual and not immediately understandable. Finally, some of the findings directly challenge current beliefs or practice. Each of these areas require examination and discussion in order to distil greater clarity and, where possible, improve understanding.

The topics identified for examination following a thematic analysis fall into three broad categories relating to:

- the nature of balance disorder after TBI, including
    - Postural orientation
    - Postural drift
    - Illusory movement
    - Muscular co-contraction
    - Dizziness and disorientation
    - Central and ill-defined balance system disorders
    - Functional signs of balance system dysfunction
- symptomatic minor injury
- assessment structure and interpretation of findings.

12 DISCUSSION OF EMERGENT TOPICS

This discussion covers the issues identified as emergent themes from the data analyses and is structured around three primary topics, namely:

- the nature of balance disorder after TBI
- symptomatic minor injury, and
- assessment structure and interpretation of findings.

Recurrent and novel observations are explored with reference to a wide literature and potential links between observations are also discussed.

12.1 The nature of balance disorder after TBI

12.1.1 Postural orientation

Orientation within the environment

One of the most recurrent observations seen within the studied group was abnormal postural orientation, that is, head, body and limb postures that do not conform to the general expectations of symmetry and alignment with respect to common environmental markers such as the line of gravity or the visual horizon. Seventeen of the 27 participants had observable abnormalities of alignment and the issue was highlighted as a significant factor in 14 of the single case reviews.

Within physiotherapy practice a traditional analysis of factors that may underlie postural asymmetry or malalignment would certainly include considerations of muscle weakness or imbalance and biomechanical factors, for example, relating to restrictions of joint movement. There are also other specifically recognised syndromes relating to neuropathology that are known to impact on postural symmetry and motor behaviour, for example, the Pusher Syndrome seen after certain forms of stroke (Davies, 1985). There are no such syndromes currently described for TBI. There are, however, findings reported in the wider literature that may offer a context within which to understand and describe aspects of the core problems of alignment observed in the studied group.

Orientation with respect to gravity

Brandt and Dieterich, in an extensive series of publications, describe characteristic eye, head and trunk tilts, inaccurate estimations of subjective visual vertical (in the direction of the spontaneous head tilt) and directional postural imbalance associated with a range of peripheral and central vestibular disorders (Brandt & Dieterich, 1987, 1994, 1995; Dietrich & Brandt, 1992, 1993).

In the first paper Brandt and Dietrich (1987) present a series of clinical cases with identified brainstem and midbrain lesions and discuss their signs and symptoms with reference to a review of animal experimentation literature and previously described single human case studies. The literature review reveals reports from as early as 1926 (Brain, 1926) suggesting evidence to link head-trunk tilt, skew deviation of the eyes (malalignment) and ocular cyclodeviation (orbit rotation) with disorders of the afferent otolith and vertical semicircular canal pathways and/or the associated 'graviceptive' pathways passing through the pontomedullary vestibular nuclei to the midbrain tegmentum.

Brandt and Dieterich focus their attention primarily on *lateral* head tilt and associated visual signs and perceptual symptoms but importantly in considering the application of this paper and its findings to the studied TBI group, with their range of directional tilts, the literature review also includes reports of other forms of postural malalignment. This includes observations by Sano et al (Sano, Sekino, Tsukamoto et al., 1972) of *head extension* tilt induced by stereotaxic electrical stimulation of the interstitial nucleus of Cajal (INC) or adjacent areas of the medial longitudinal fasciculus, and of isolated lateral head tilt (without visual signs) following stimulation of an area adjacent and caudal to the INC.

Similarly, although examination of the new human cases reported by Brandt and Deitrich (Brandt & Dieterich, 1987)in this paper focuses on head tilt, eye deviation and estimation of visual vertical, it also reports that there was commonly a trunk tilt in line with characteristics of the head tilt. This combination of head and trunk tilt similarly inclined away from the vertical was also seen in the studied TBI group, sometimes clearly observable in quiet sitting and more often in standing.

In a later summative paper Brandt and Dieterich (1995) present clinical classifications of what they term Central Vestibular Disorders, developed from their own studies and those of others. The classifications are described in relation to the three major planes of action of the vestibulo-ocular reflex: yaw (horizontal), pitch (sagittal) and roll (frontal) planes. They link detailed clinical signs (oculomotor, postural and perceptual) with a range of circumscribed central lesions based on studies primarily focused on humans with acute brainstem or midbrain infarcts. Of particular note with reference to the studied TBI group is the recognition in this paper and in later textbooks (Brandt, 1999e; Brandt & Dieterich, 2000) of head and body tilts in lateral, anterior and posterior directions, and of combinations of all of these, linked to unilateral and bilateral lesions in specific regions of the brainstem and midbrain.

In the light of this work it seems important to consider the possibility that the consistent postural deviations observed in a significant number of the studied TBI group could be associated with injury to brainstem and/or midbrain centres.

In terms of direct evidence of brainstem or midbrain lesions in individual cases, detailed imaging was not available for analysis for the participants included in this study. In some cases there were other neurological signs, such as cranial nerve damage or eye movement abnormalities, that would suggest lesions in or near the appropriate brain areas.

In terms of known patterns of injury in the wider TBI population, brainstem and midbrain damage after TBI has been strongly associated historically with severe and very severe injury and regarded as a poor prognostic indicator (Adams et al., 1977; Firsching, Woischneck, Klein et al., 2001; Rosenblum, Greenberg, Seelig et al., 1981). The prevalence and outcome of brainstem and midbrain damage associated with minor or moderate injury (as would relate to many of the participants in this study) has not been a significant focus for study nor for discussion within clinical practice. However, there is some emerging evidence from perfusion studies of thalamic/midbrain insults occurring at least as frequently as in the accepted areas of vulnerability in minor and moderate injuries, the frontal and temporal lobes (Abdel-Dayem, Abu-Judeh, Kumar et al., 1998; Abu-Judeh, Parker, Singh et al., 1999). There are also individual case reports of circumscribed midbrain and brainstem lesions producing specific impairment, often in the context of otherwise preserved function.

For example, deafness has been reported associated with bilateral lesions of the inferior colliculi (Howe & Miller, 1975; Jani, Laureno, Mark et al., 1991), internal opthalmoplegia associated with ponto-mesencephalic contusion (Beck & Meckler, 1981; Bonilha, Barbosa Fernadez, de Vasconcelos Mattos et al., 2002; Catalano, Sax, & Krohel, 1986), hemihypaesthesia associated with posterolateral midbrain contusion (Saeki, Higuchi, Sunami et al., 2000) and hemiparesis with disturbance of consciousness associated with a lesion between the cerebellar peduncle and the reticular formation (Wong, 1993). The last two cases are reported to have made a good recovery.

The primary, isolated, brainstem and midbrain lesions described in these papers differ from the extensive primary lesions described at autopsy by Adams and colleagues (1977) as diffuse axonal injury and from secondary damage to brain stem and midbrain centres caused by tentorial herniation as a result of uncontrolled gross cerebral oedema, both of which are associated with very severe injury and high morbidity.

Meyer and colleagues, having retrospectively reviewed a series of traumatic midbrain haemorrhages, commented on an unexpectedly high survival rate and suggested a more focused review of the site and extent of lesions in advance of predicting morbidity (Meyer, Mirvis, Wolf et al., 1991). Sganzerla and colleagues (1992) also described isolated midbrain lesions associated with head hyperextension injuries and highlighted the possibility of a more positive outcome in comparison to the poor prognosis previously associated with damage in this area following TBI. Primary brainstem lesions have since been differentiated by Shibata and colleagues via the use of early MRI scanning into two categories (deep and superficial), with different longitudinal outcomes (Shibata, Matsumura, Meguro et al., 2000).

The findings of all of these studies taken together clearly challenge the received wisdom that brainstem and midbrain injuries are associated only with severe injuries and high levels of morbidity. They also require a different explanation of injury mechanism beyond diffuse axonal injury or compression secondary to gross oedema.

Shibata and co-workers suggest that the superficial injuries in their study may have been caused by impact of the brain against the tentorial edge (a fold in the dura between the cerebral and cerebellar hemispheres). A similar mechanism for injury has been postulated by pathologists Adler and Milhorat (2002), with a recognition that the significant variations seen in the size and shape of the tentorial notch (the open space within the dura through which the midbrain and brainstem pass) would impact on how and what might be damaged in individual cases.

The series of circumscribed midbrain and brain stem lesions described in the case reports listed previously also suggest the existence of injury mechanisms capable of concentrating impact energy in a specific central manner. For example, there would need to be a concentration of energy to produce focal bilateral contusions of the inferior colliculi (Jani et al., 1991) or a fractured clivus (the basal edges of the occipital bone at the very centre of the skull), as reported in the case of an isolated bilateral internuclear ophthalmoplegia (Bonilha et al., 2002). Saeki and colleagues (2000) in their description of the case with isolated hemihypaesthesia report a discrete lesion "at the level of the lower midbrain coinciding with the tentorium level", in the appropriate topological area of the spinothalamic and trigeminothalamic tracts. Wong (1993) implicated the clivus as the likely point of impact in the case of the hemiparesis.

There is a strong case to support the possibility of a range of brainstem and midbrain lesions occurring as part of a TBI even in the absence of severe or very severe injury. These lesions may well result in disruption of normal perceptions of verticality with respect to gravity, as detailed by Brandt and Deitrich (1999f; 1999g; 1999h).

In terms of the data collected in this study there is a good fit across several participants with respect to trunk and head tilt and in some cases with abnormal resting eye positions. The question of fit with inaccurate estimation of subjective visual vertical cannot be explored since this was not part of the data collection. It would be important to factor this question into subsequent studies, particularly in the light of the work of Karnath and colleagues (2000a; 2000b; 2005) in relation to thalamic haemorrhage and the "Pusher Syndrome" and Bronstein and colleagues (2003) in relation to vestibular nucleus lesions that would seem to indicate the presence of two 'graviceptive' systems in humans dealing separately with postural (haptic) and visual vertical.

Orientation with respect to other points of reference

While gravity is clearly a dominant reference point with respect to upright posture there are additional, mainly visually mediated, factors with the potential to contribute to the abnormal resting postures observed in the studied group. These include adaptations to postural alignment to achieve visual clarity and influences on motor behaviour of abnormal estimation of the orientation of the horizon or the position of midline.

Visual clarity

Problems of visual clarity in the studied TBI group comprised double vision associated with oculomotor disorders and visual blurring associated with limitations of the vestibulo-ocular reflex (VOR), nystagmus and accommodation disorders. Observed compensatory or secondary behaviours included head tilting and rotation, repetitive blinking and, in relation to VOR, static co-contraction of neck (and sometimes trunk and limb) musculature.

Acquired anomalous head postures are well recognised effects of double vision, nystagmus and loss of vision in one eye in ophthalmological practice. Remediation of abnormal head postures is an identified target, alongside the promotion of optimal vision, of surgical intervention in children and adults with congenital and acquired visual problems of this nature (Arroyo-Yllanes, Fonte-Vazquez, & Perez-Perez, 2002; Hertle & Zhu, 2000; Kubota, Takahashi, Hayashi et al., 2001; Nucci & Rosenbaum, 2002; Velez, Foster, & Rosenbaum, 2001). Head tilts and rotations to achieve binocular single vision, gaze stabilisation or centralisation of the available visual field in monocular vision are common place in untreated cases, but postural tilts are not described beyond the head and neck.

Three of the studied participants had sufficiently reduced vision in one eye to explain head rotation to centralise the useful vision as described above.

Several other participants had limitations of excursion of both eyes to one side on both voluntary and reflex movements. There was not a consistent pattern of compensatory head rotation observed in these cases. Some adopted a head rotation consistent with centralising the available visual field, others held an essentially midline position at rest or were rotated in the opposite direction. Some demonstrated *limitations* of rotation in the same direction of the reduced eye movements and a few even blocked trunk rotation in the opposite direction, that is, movement that would result in a head position that was rotated with respect to the trunk, even though no active head rotation was required. These variances indicate a level of complexity in primary responses and secondary adaptations to superficially similar deficits and make it difficult to directly relate postural malalignment to visual deficits beyond those described in the ophthalmology literature without further consideration of what may underlie the observed deficits.

Limitation of eye movements following brain damage is found not only with cranial nerve and central eye movement generator damage but can also be associated with attention and perceptual disorders, for example, spatial neglect. This is commonly, but not exclusively, associated with lesions of the right cerebral hemisphere. While the detailed mechanisms that result in neglect are still the subject of much research and debate, most neuropsychological accounts describe the condition as a set of attentional disorders, although there are aspects of the neglect syndrome that are better described as disorders of action (Robertson & Halligan, 1999).

The neglect syndrome as described by Heilman and colleagues (2003) comprises hemi-inattention, hemispatial neglect, extinction, allesthesia, anosognosia, and hemiakinesia, the latter being in part a disorder of action. Not all patients present with all aspects of the syndrome and there is some evidence that the disorders of action are associated with more frontal and mid brain lesions rather than those restricted to the post central somatosensory areas (Bisiach, Geminiani, Berti et al., 1990). Hemiakinesia and associated directional bradykinesia and hypometria do not only apply to limb actions but can also apply to eye and head movements (Robertson & Halligan, 1999).

The behavioural presentation of a subsection of the studied group in respect of their inability to scan or explore sections of their spatial environment was reminiscent of aspects of behavioural presentation seen in patients post stroke with the larger neglect syndrome except that it was mainly limited to lack of movement of the eyes and head.

Formal estimation of extrapersonal midline or visual straight ahead was not a core assessment question but some participants reported errors in negotiating limited spaces such as doorways, a common functional difficulty associated with difficulties of midline orientation (Heilman, Jeong, & Finney, 2004). In some cases additional signs were noted as a result of exploring unusual behavioural observations. For example, participant six who with eyes open consistently estimated straight ahead as right of the true midline (there was lack of excursion of the eyes to the left and some subtle signs of inattention) but also consistently estimated straight ahead as left of the true midline with vision removed.

Appreciating this inconsistency is clearly important for risk management in day to day life but is also illustrative of the different mechanisms that contribute to the perception of orientation within the environment. Cases such as this are worthy of further investigation and discussion since there is evidence in the literature of left visual field deficits being associated with left deviations on line bisection tests while left neglect deficits are associated with right deviations (Barton & Black, 1998). However there is also some evidence from healthy participants of a tendency towards a left bias (Jewell & McCourt, 2000), possibly explained by the suggestion that spatial computation activates the right hemisphere, and a linked hypothesis that given an associated increase in attention to the left (and the left therefore appearing larger), a left sided deviation is induced in the estimation of midline (Heilman et al., 2004). A similar hypothesis is advanced for left-sided deviation associated with spatial imagery (Heilman et al., 2004), that is, the right hemisphere is activated during this process. There is clearly more work to be undertaken to understand performance in healthy participants, the phenomena associated with discrete lesions affecting vision and visuoperception, and the interaction between multiple lesions.

Of course visual image and the position of the eyes relative to the rest of the head are only parts of the overall system that governs orientation to the midline. Important contributions are also provided by vestibular and cervical information. It is thought that all of this information is transformed and integrated into an egocentric, body-centred frame of reference, that informs subsequent motor behaviour (Karnath, 1994). There is also evidence that functional inaccuracies in determining the midline can be reduced on at least a temporary basis by manipulation of other components of the overall system (Karnath, 1994), including the action (Robertson, Nico, & Hood, 1995; Robertson & North, 1994; Robertson, North, & Geggie, 1992) and attention systems (Robertson, Mattingley, Rorden et al., 1998). The judgement of straight ahead within this theoretical framework involves complex neural computations dependent on the accuracy of the primary sensory information available, an intact transformation and reference framework and the absence of confounding influences.

While subjective judgement of straight ahead was not directly addressed within the assessment protocol applied to the study participants, eye and head positions that did not conform to midline, motor behaviours associated with visuospatial deficits and a range of underlying deficits in the primary visual, vestibular and cervical systems were recorded. Although only a small number of participants could be said with confidence to have problems with midline orientation, the importance of acknowledging the complex neural computations associated with the judgement of spatial orientation and the impact of multiple, even if minor, deficits occurring in one individual is worthy of consideration. The importance of this wider inter-relationship is further illustrated by Marendaz and colleagues who demonstrated the influence of different postural conditions (lying, sitting and standing) on the time taken to search for and identify visual targets (Marendaz, Stivalet, Barraclough et al., 1993).

Unreliable horizon

Similar issues of visual stability and estimation of orientation apply in relation to the horizon. Estimation of subjective visual horizon was not directly assessed within the protocol but there was spontaneous reporting by a few participants of functional difficulties such as being unable to align wall hangings (to the satisfaction of other family members) or of perceptions of a tilted environment.

In terms of visual stability, several participants reported a moving horizon during gait or this was found to be an issue when they were asked to correct abnormal head positions (often eyes to floor fixations) during the assessment of gait. This oscillopsia, especially when associated with head movement, is a recognised symptom of vestibular dysfunction, particularly bilateral peripheral dysfunction (Herdman & Clendaniel, 2000) or centrally mediated disorders (Leigh, 2000). It can also occur in the presence of eye muscle weakness or with nystagmus, when it may be present at rest (Leigh, 2000).

In terms of the studied group there were a few participants whose resting head position (rotated right or left or forward flexed) might be attributable to avoidance of the eye position producing resting nystagmus. In the majority, where oscillopsia was associated with head movement, the impact on postural orientation was only seen during dynamic activities and was commonly associated with the adoption of a forward flexed head position.

12.1.2 Postural drift

As well as abnormalities of postural alignment at rest there was also a recurrent theme of postural instability, observed in differing degrees across four primary conditions, in sitting and standing with eyes opened and with eyes closed.

Sway

Many of the participants exhibited abnormal levels of postural sway. Increased levels of postural sway is a documented outcome associated with balance disorder after TBI (Basford et al., 2003; Geurts et al., 1996; Newton, 1995; Wade et al., 1997; Wober et al., 1993). Increased sway is already regarded as an indicator of functional balance disorder (Lehmann, Boswell, Price et al., 1990) and reduction in sway as an indicator of successful therapeutic intervention (Wade et al., 1997). However, there are some apparently conflicting findings described in the literature in relation to excess sway and injury severity and there has been little exploration of what underlies this form of postural instability.

The earliest studies either focused on moderate and severe injuries (Newton, 1995) or found a relationship, even within a severe population, between lowest initial GCS scores and severe postural imbalance (Wober et al., 1993). A more recent study, however, included 20 participants experiencing instability at six months or more after TBI across a range of severities (predominantly minor) and found an increase of over 50% in antero-posterior and lateral sway as compared to matched controls (Geurts et al., 1996). Another controlled study that employed motion analysis and standard measures of vestibular dysfunction found abnormalities on caloric irrigation testing in eight out of 10 TBI participants, seven with unilateral vestibular impairment and one bilateral (Basford et al., 2003). This study recruited TBI participants who felt unstable but excluded those with neuromuscular deficits, documented skull fractures, rotational dizziness or those taking medication known to affect balance function.

The earlier studies that focused on those with moderate or severe injuries did not include assessment of the peripheral vestibular system and therefore contributions from vestibular damage cannot be excluded as a causal factor in the postural instability seen in these cases. However, in considering the findings across studies and in light of the group observations reported for the current study that indicate a higher preponderance of vestibular system dysfunction in less severe injuries it can be postulated that postural instability following traumatic brain injury does not have a single causal factor. It is certainly clear that injury severity is in itself not a predictor of postural instability.

Rotational drift and loss of antigravity activity

Three of the studied participants did not present with oscillating instability but exhibited a form of postural drift best described as rotational, that is, a gradual drift from their best approximation of symmetrical standing involving twisting of the upper trunk. In one case this was accompanied by a spreading loss of extensor tone. In the other two cases it could be postulated that the drift was influenced by the 'resting' biomechanical alignment, with one having a significantly extended and rotated head and the other a degree of shoulder girdle retraction. Of course it could be argued that the abnormal resting positions in themselves may have their basis in the same factor that causes the postural drift over time. Either way, these factors appeared inter-related.

Several participants demonstrated difficulty in maintaining activity in the antigravity muscles over one minute in standing, in the absence of gross motor weakness. In one case this was a dominant feature, apparently relating to the lower limbs, in another, the participant had obvious problems of motor impersistence across a range of motor acts including eye movements as well as the maintenance of postural tone at rest.

Motor impersistence is a recognised symptom relating to the inability to sustain motor actions in pathologies as different as Attention Deficit Hyperactivity Disorder (Corbett & Glidden, 2000; Tantillo, Kesick, Hynd et al., 2002), Huntingdon's Chorea (Kipps, Duggins, Mahant et al., 2005) and Cerebrovascular Disease (Sakai, Nakamura, Sakurai et al., 2000). It has been variously regarded as a right hemisphere syndrome related to mechanisms of directed attention involving frontal and midbrain lesions (Kertesz, Nicholson, Cancelliere et al., 1985) and as being more directly related to abnormalities of the midbrain (Bhidayasiri & Truong, 2004) particularly the caudate nucleus (Hynd, Hern, Novey et al., 1993). In much of the literature the term motor impersistence has been applied exclusively to movements of the eyes, mouth and head but in terms of the neglect syndrome it has also been applied to limb and whole body postures (Robertson & Halligan, 1999).

The lack of clarity of definition and scope in the literature makes it is difficult to discuss the contribution of motor impersistence to the postural drift observed.

12.1.3 Illusory movement

Participants described illusory movement sensations (self-motion) in both the eyes open and eyes closed conditions. All three participants who experienced illusory movement sensations in standing with the eyes open continued to experience these sensations on eye closure and all required significant verbal feedback to maintain eye closure for any period. A larger number who did not experience illusory movement while vision was available experienced illusory movement when vision was removed. In a few cases the movement that was seen differed from that described by the participant, for example, participant 18 who perceived side to side movement in standing with eyes closed while antero-posterior sway was observed.

There were a number of participants who described movements in sitting which could not be observed but then became visible (oscillating in the direction of the previously described illusory movement) in standing. It is interesting to consider whether the movement seen in standing resulted from postural instability or whether it was generated as a corrective response to a perception of movement.

There were some cases where participants clearly made apparent saving responses (to illusory movements) which resulted in significant threat to stability and in one case to a full loss of balance.

Brandt includes the perception of illusory environmental or self motion (along with any unpleasant distortion of static gravitational orientation) as a constituent part of a multifactorial syndrome he terms vertigo (Brandt, 1999e). While the word vertigo is more casually used interchangeably with the word dizziness, vertigo, as conceptualised by Brandt, is an umbrella term describing a multisensory, sensorimotor syndrome, with perceptual, postural, ocular motor and autonomic manifestations. These manifestations may be induced by unusual stimulation of intact sensory systems or by pathological dysfunction. Pathological dysfunction as cited by Brandt extends beyond peripheral and central vestibular disorders to include vascular and traumatic disorders, hereditary and age related disorders, drug induced vertigo, sensory vertigo syndromes and psychogenic and phobic syndromes.

The use of vertigo as an overarching term in this context firmly identifies the vertigo syndrome as sensory (potentially multisensory) in origin and characterises the associated perceptual experiences and physical and autonomic manifestations as secondary effects. This is in almost direct contrast to the starting point of physiotherapeutic practice as previously described, which has primarily seen balance disorder as a failure of biomechanical organisation or motor control. However, Brandt's conceptualisation is supported by evidence from studies in humans without pathology. These demonstrate functional interplay between sensory systems and the potential, following manipulation of sensory information, for individuals to experience illusory sensations, make erroneous judgements or be caused to exhibit changes in motor behaviour.

For example, Lackner described perception of illusory movements and distortion of the orientation and shape of body parts induced by tonic muscle vibration (Lackner, 1988).

He also highlighted how starting postures and additional sensory information could influence the final interpretation of physical size, shape or alignment. Tonic vibration of neck muscles has also been shown to change the position of the eyes in the head, to influence dynamic vergence movements of the eyes (Han & Lennerstrand, 1998) and induce the perception of head rotation (Ivanenko, Viaus-Delmon, Semont et al., 1999). Experimentally sustained head rotations have been shown to affect visual function in terms of inducing asymmetrical optokinetic responses (Kalberg & Magnusson, 1996).

The complexity of sensory interrelationships and their potential to impact on motor function has been demonstrated in other studies. Kasai (2002), described a variety of changes in anticipatory postural behaviours induced by the stimulation of different muscle groups. Ivanenko (2000a; 2000b) demonstrated the range of muscles (extending from neck to lower limbs muscle groups) with the potential to generate proprioceptive feedback and influence on-line regulation of the speed and direction of walking.

The acceptance of a functional interactive relationship between vestibular, visual and somatosensory systems is implicit to the concepts of recalibration, substitution and compensation, which form the basis of vestibular rehabilitation programmes (Zee, 2000). Increased sensitivity to vestibular stimulation has been reported in participants with diabetic neuropathy involving somatosensory loss (Horak & Hlavacka, 2001). Cumulative negative effects on postural control have been reported with multiple system involvement in the elderly (Anand, Buckley, Scally et al., 2003). It has also been demonstrated, in the absence of pathology, that additional information from one system can substitute for absence in another, such as light touch in the dark (Lackner, Di Zio, Jeka et al., 1999).

There is clearly a functional interrelationship between sensory systems. There is also the potential to induce illusory perceptual experience and modify motor actions via manipulation of sensory information in participants without pathology. The decoding or interpretation (consciously or otherwise) of human sensory information is, therefore, open to misperception in the presence of ambiguous sensory information or under conditions of unusual or imbalanced sensory stimulation. Motor behaviour can be directly influenced by manipulation of, or imbalances in or between, sensory systems.

The experience of dizziness or other forms of perceived sensory disorientation is an accepted consequence of sensory imbalance. It is possible that aspects of postural instability, such as those seen in the study participants, have their basis in the perception of illusory movement consequent to sensory impairment. It is also possible that motor or biomechanical abnormalities observed in association with sensory dysfunction have a similar basis.

The development of appropriate management strategies or intervention programmes is dependent on the generation of accurate causal hypotheses. Where participants are observed to have multiple impairments in sensory and physical systems, consideration must be given to how they may interrelate and to the fact that observations may be a mixture of primary and secondary factors. In this respect it is useful also to consider the potential contribution that any process of adjustment or adaptation may have contributed to the reported symptoms or observed findings.

For example, Bove and colleagues (Bove, Brichetto, Abbruzzese et al., 2004) suggest that such a process of adaptation (away from an increasingly unreliable head-centred frame of reference) forms part of the longitudinal response to the development of cervical dystonia and that this explains differential assessment findings across study participants relative to the length of the disease process. A similar hypothesis, citing the use of a midsaggital trunk (rather than head) reference point in the estimation of straight in participants with torticollis, has been previously advanced (Anastasopoulos, Nasios, Psilas et al., 1998).

12.1.4 Muscular co-contraction

Muscular co-contraction was frequently observed across the studied group, occurring spontaneously within functional movement and in conjunction with reflex muscular responses during the assessment process. Co-contraction is a tool used by the nervous system to modify the mechanical properties of body parts appropriate to changing tasks and is not in itself a sign of abnormality. Co-contraction is also commonly seen as a protective mechanism to immobilise any area of injury immediately after trauma and in response to continuing pain, for example in the case of chronic headache (Pozniak-Patewicz, 1976).

Cervical range of motion

Many of the studied participants (24) had reduced neck mobility. In only one third of these cases were there any reports of pain or discomfort. More commonly, there was movement limiting reactive co-contraction congruent with reports of dizziness or attempted head motion. In many cases there appeared to be a strong relationship with demands to increase speed of movement, frequently during VOR testing. There were also cases when the reflex contraction appeared to be related to movement in a specific plane or in a specific direction. Some issues relating to the latter have already been explored with respect to spatial neglect. In a few cases, there was a similar muscular response during body on head rotation.

There are a number of vestibular, cervical and visual reflexes that are associated with the control of the eyes, head and neck. Some reflexes such as the vestibulo-ocular reflex (VOR) have been the subject of extensive research and are relatively well understood. Others have received only limited attention, particularly in relation to human function and the cervical reflexes fall into this category. However, it is known that the vestibulocollic reflex (VCR) actively stabilises the head relative to space, is dependent on stimulation of cervical afferents, rather than information from trunk or limbs, and results in reflex muscular contractions opposite to the perturbation (Allum, Gresty, Keshner et al., 1997). The cervicocollic reflex (CCR) modifies head and neck posture in response to disturbed trunk posture and may have a primary role in stabilising the head in the vertical plane (Hain, Ramaswamy, & Hillman, 2000). The CCR has a significantly weaker effect than the VCR in the horizontal plane (Peng, Hain, & Peterson, 1999) and may be facilitated after vestibular loss (Hain et al., 2000). The cervico-ocular reflex (COR) appears to have a limited role in augmenting VOR function in healthy humans but, as with the CCR, becomes more dominant in the presence of vestibular dysfunction (Hain et al., 2000).

All but one of the studied participants were either symptomatic (became dizzy or had a significant deterioration in visual acuity) on VOR testing or were unable (or unwilling) to achieve or sustain rhythmic head rotations sufficient to fulfil the testing criteria. The reactive neck muscular co-contraction seen during VOR testing, postural adjustment or other challenging functional movements may therefore result from compensatory reflex responses to stabilise the object of gaze or achieve a perception of postural stability. Those who anticipated difficulty and were either cautious or unwilling to proceed also demonstrated a volitional dimension that must be taken into account. They appeared to be acting on prior experience although not all could articulate the reason for avoidance. This type of avoidance behaviour was observed across a range of assessment activities during the study and although not formally collated, cumulatively left a strong impression. An important aspect for future investigation, and a potentially effective target for therapeutic intervention, is the dissociation in some cases between established, apparently learned behaviours, and current levels of symptoms.

12.1.5 Dizziness and disorientation

The majority of the study participants (24) reported some form of sensory disorientation or awareness of aberrant sensations. Reports included classic spinning sensations, rocking, bobbing and swaying, being pushed or pulled and feelings of weightlessness or incongruent awareness of supporting surfaces. We have already touched on aspects of the experience of aberrant sensations in the form of illusory movement and how this might relate to postural instability. Most of the descriptions of dizziness and sensory disorientation reported by the study participants refer to some degree to the subjective perception of motion that does not conform to what is objectively observed and might reasonably be classified as illusory movement. Exceptions would be the reports of incongruent perception of objects within the environment, such as the misperception of the interface between self and supporting surfaces, and the abnormal perception of the nature of body parts in terms of their relationship with the environment, such as the feelings of weightlessness. However, these exceptions taken together with the sensations of illusory movement could be classed as perceptual manifestations within the conceptualisation of vertigo proposed by Brandt (Brandt, 1999e).

Rotational dizziness is regarded as the most commonly described symptom of vestibular system malfunction (Honrubia, 2000). Pulling, pushing and rocking are also recognised symptoms and are said to be suggestive of otolith dysfunction (Honrubia, 2000). Other descriptions of disorientation, such as light-headedness or floating, are recognised as recurring reports but are also known to be less specific to vestibular system disorders (Honrubia, 2000). Interestingly, sensations of light-headedness and floating unsteadiness have been recently highlighted as the mostly likely descriptions of dizziness of cervical origin (Brandt & Bronstein, 2001).

Classic dizziness, as experienced in acute onset peripheral vestibular dysfunction, has been explained in terms of sensory conflict between the two balance organs. That is, the dizziness is the result of the perception of a mismatch between two sources of sensory information. It is now accepted that the experience of dizziness or other forms of sensory disorientation under normal conditions is an indicator of imbalance somewhere in the wider balance system, though not necessarily an indicator of where the imbalance is (Honrubia, 2000).

Dizziness or sensory disorientation can result from a range of sources linked to the vestibular system, as well as from peripheral vestibular dysfunction. 'Visual vertigo' can result from oculomotor dysfunction (Brandt, 1999i), diplopia or refraction errors (Anand et al., 2003; Brandt, 1999i) or when a visually dependent person is forced to deal with stimulating or moving visual environments (Bronstein, 1995, 2004; Page & Gresty, 1985). 'Cervical vertigo' remains a controversial entity, in part because there is no specific diagnostic test and accurate diagnosis is therefore dependent on careful exclusion of a whole range of other possibilities (Brandt & Bronstein, 2001). There has also been a series of theoretical mechanisms proposed that have not been proven. A recent subject review concluded that the most convincing mechanism was based around altered upper cervical somatosensory input leading to sensory mismatch between cervical and vestibular inputs, particularly during active head movements (Brandt & Bronstein, 2001).

Dizziness of central (CNS) origin is often described as being more moderate in intensity but more persistent than when from peripheral dysfunction (Honrubia, 2000). It is important to consider the context of this statement and in particular that it is generated from a base of experience in dealing with mainly peripheral disorders where dizziness often takes a clear rotatory form and can be dramatically severe. Study of the wider field of central vestibular disorders clearly identifies a more complex situation of varying types, patterns and descriptions of sensory disorientation (Brandt & Dieterich, 2000). This includes recognition of central vestibular system disorders without complaints of dizziness (Brandt & Dieterich, 2000).

Dizziness can occur in the absence of vestibular system dysfunction. It has been associated with a broad range of so-called psychiatric disorders. There has been much debate over diagnoses such as Psychiatric Dizziness (Brandt, 1999d; Furman & Jacob, 1997) and Phobic Postural Vertigo (Brandt, 1996, 1999c; Bronstein, Gresty, Luxon et al., 1997), with an increasing awareness of the links between current or past organic vestibular system dysfunction and some psychiatric diagnoses such as panic disorder or agoraphobia (Furman & Jacob, 1997; Yardley, 1994).

There has also been acknowledgement of past over-inclusion in diagnoses of psychiatric dizziness and the need to narrow the definition to include only dizziness that occurs exclusively in combination with other symptoms as part of a recognised psychiatric symptom cluster (Furman & Jacob, 1997). Phobic postural vertigo (not being a recognised psychiatric diagnosis) would fall outside this tight definition but according to Brandt and colleagues is often found in persons with personality disorders, particularly obsessive-compulsive disorder (Brandt, Huppert, & Dieterich, 1994). Brandt considers phobic postural vertigo to be psychogenic in origin (Brandt, 1999c). There is evidence in people with this diagnosis of over reliance on proprioceptive information and difficulty in using visual information (Holmberg, Karlberg, Fransson et al., 2003). Links between inadequate coping strategies and progressive disability have also been postulated (Holmberg, Karlberg, Harlacher et al., 2005). Whatever the genesis, Brandt and colleagues report a greater than 70% improvement rate with short term behavioural therapy, including repeated exposure to vertigo inducing situations (Brandt et al., 1994).

Dizziness is also a symptom of a range of cardiovascular pathologies. This is most commonly described as feeling faint. Problems of autonomic regulation influencing both respiratory and cardiovascular control can occur as a direct result of vestibular system lesions, but these effects are usually short-lived (Yates & Bronstein, 2005). Finally, dizziness can be experienced as part of an epileptic aura, secondary to medication or in association with some familial or hereditary neurological disorders (Brandt, 1999e).

The dizziness and sensory disorientation reported by participants within the studied group is not attributable to a single causation. Symptoms described across the group are consistent with peripheral vestibular organ damage affecting canals and otolith organs, visual dependency and dizziness of cervical origin. The additional perceptual anomalies may relate to abnormalities in the perception of tactile and proprioceptive information and in the perception of gravitational force. In one case dizziness was at least exacerbated by hyperventilation.

12.1.6 Central and ill-defined balance system disorders

The relationship between the experience of sensory disorientation described by study participants and what may be classed as 'central vestibular disorders' remains unclear. This is in part a function of a lack of clarity in what constitutes a diagnosis of central vestibular disorder. It also relates to wider limitations of classification and the nomenclature available to describe less commonly recognised peripheral system dysfunction and other dysfunction associated with disorders of the balance system. This applies to a whole range of disorders that do not fit currently recognised medical diagnoses. This lack of nosological clarity has been a significant limitation in effectively describing and analysing some of the findings in this study. Several elements of current diagnostic practice contribute to this lack of clarity and limit its effective application to the studied group.

Conventional diagnostic methodology

The diagnostic methodology in use is strongly reliant on understanding the history of onset and symptom progression (Honrubia, 2000; Shepard & Telian, 1996b). For example, sudden onset continuous dizziness preceded by a recent history of viral illness and in the absence of auditory symptoms would lead to a working diagnosis of vestibular neuritis, unless the patient did not recover in the short term or had subsequent repeated events (Shepard & Telian, 1996b).

The content of the clinical examination and the choice of diagnostic tests are also guided by what the history suggests (Honrubia, 2000; Shepard & Telian, 1996b). For example, intermittent and short lived movement provoked dizziness without hearing loss would suggest BPPV and such a diagnosis would be confirmed by a positive Dix-Hallpike test (Shepard & Telian, 1996b).

Reported histories of onset and progression that do not fit with the patterns assigned to specific diagnoses may lead to a diagnosis by exclusion, to onward referral or to no diagnosis at all. The outcome in such cases will be influenced by the experience and opinion of the consulted clinician. Thus diagnoses are conventionally developed from a cluster of evidential factors, based on onset, symptom progression and clinical findings.

Some clinical diagnoses can be confirmed by laboratory tests or suspicions explored via additional diagnostic evaluation. Some diagnoses are derived from excluding other possibilities, the outcome being dependent in part on the breadth of exploration undertaken. Some individuals with symptoms that do not conform to recognised presentations may not receive a diagnosis or their symptoms may be (rightly or wrongly) attributed to non organic factors.

Applying conventional diagnostic methodology to TBI

'Onset' versus 'outcome'

People with TBI have a common history of trauma and if this is regarded as resulting in a homogenous group it offers little help in differential diagnosis. General vestibular rehabilitation texts often regard TBI as a single diagnostic category and unless presenting symptoms fit a circumscribed diagnosis accepted as being associated with trauma, such as BPPV or perilymph fistula, authors can regard treatment, and so diagnosis, as outwith their (otolaryngological) area of expertise (Shepard & Telian, 1996g). This offers little assistance to the quest for more specific diagnoses.

Authors with a special interest in balance disorders from outside otolaryngology focus less on TBI as a homogenous group and more on potential 'outcomes' of the trauma. For example Shumway-Cook (a physiotherapist) reports the risk of central and peripheral dysfunction and details the need to consider both (and wider issues) in the assessment process. She gives examples of possible traumatic damage to the end organ including BPPV, perilymph fistula and skull fracture resulting in peripheral organ concussion (Shumway-Cook, 2000). Treatment options focus on the functional effects of disorder: vertigo (dizziness), eye-head co-ordination, and postural control. This approach describes broad options for rehabilitation without specifically addressing the issue of diagnosis.

Brandt (a neurologist) focuses more on questions of diagnosis and, within his overall construct of vertigo as previously described, links the potential outcome of head and neck injuries together under the heading of traumatic vertigo. He adds detail to the sub categories described by Shumway-Cook, including clear recognition of the potential for significant damage to the otolith organs, the possibility of cervical vertigo and, in addition, the potential development of phobic postural vertigo (Brandt, 1999b). He also describes in more detail specific cerebral areas likely to be associated with traumatic vertigo such as the brainstem, central vestibular pathways or the vestibulocerebellum and other secondary cerebral damage, such as Wallenberg's Syndrome as a result of vertebral artery dissection (Brandt, 1999b). This diagnostic taxonomy, primarily developed around anatomically specific lesions (occurring directly as an outcome of the trauma) offers a more comprehensive structure around which to develop understanding of the presenting symptoms of those study participants whose presentation does not conform to classic vestibular system diagnoses.

Symptom history and progression

After TBI, because of the traumatic nature of the injury and the likelihood of co-existing deficits, there is often a confused symptom history. For example, the visual system may be directly damaged complicating the appreciation or description of visual signs associated with vestibular dysfunction, there may be memory deficits affecting the ability to recall or there may be restrictions of language or in social communication affecting the reliability of self report (Campbell, 2000b). Co-existing deficits that are present at the point of clinical evaluation can limit the examination or confound its findings. Management of these additional challenges requires the development of enhanced assessment procedures that better ensure an accurate and complete symptom history and that, at a minimum, acknowledge the potential impact of co-exisiting deficits within the clinical examination (Campbell, 2000b).

Classic symptom histories such as those linked with BPPV or with clear cases of vestibular hypofunction cover only a proportion of presentations after TBI. It is therefore necessary to be alert to softer indicators as reported in the literature, for example, a history of popping sensations in the ear and fluctuating levels of dizziness being suggestive of perilymphatic fistula (Fetter, 2000) or linear sensations, perceptions of tilt or feelings of walking on pillows being suggestive of otolith damage (Gresty, Bronstein, Brandt et al., 1992; Honrubia, 2000). At the same time it must be recognised that these types of signs are open to interpretation and not sufficiently robust to be regarded as diagnostic in themselves. With regard to indicators of central disorders, the primary body of work available for consultation is that of Brandt and Dietrich as previously discussed (Brandt, 1999a, 1999f, 1999g, 1999h; Brandt & Dieterich, 1994, 1995, 2000).

Diagnostic tests

The diagnostic tests in routine use have been developed to aid the diagnosis of the currently recognised disorders and are mainly focused on peripheral, primarily horizontal semicircular canal, function. While sampling function in one area of the labyrinth is a satisfactory approach in suspected disorders of the global labyrinth or the vestibular nerve, there are obvious limitations in this approach when isolated dysfunction elsewhere in the end organ is suspected or when both a peripheral and a central disorder is regarded as a possibility, as is the case after TBI.

There is no routine laboratory test of otolith dysfunction and no clinical test that is able to differentiate between end organ and brainstem/midbrain lesions (Halmagyi & Curthoys, 2000) although progress is being made in this area (Clarke, 2001) and a wider range of tests may be used in specialist centres or in association with research studies. Posturography can identify functional limitations and sensory preferences in maintaining upright stance but does not provide lesion specific information (Shepard & Telian, 1996d). Similarly, full field optokinetic testing may reproduce visually mediated disorientation (Bronstein, 2004).

Imaging may be used to confirm suspected cerebral lesions or other diagnostic investigations undertaken to explore wider questions, for example, when vascular insufficiency is queried. However, exploration of possible cerebral involvement is generally the province of a different medical speciality from that which deals with peripheral disorders and therefore suspicion of cerebral involvement (in the absence of a known diagnosis) usually marks the point of onward referral from vestibular services. From experience, however, this does not seem to apply to those with a diagnosis of TBI, who tend not to be referred on for further exploration or rehabilitation following inconclusive assessment within balance clinics but are more often told that there is nothing further on offer. Diagnosis of dizziness of cervical origin remains one of exclusion, with no specific test (Brandt & Bronstein, 2001), and is dependent on the interpretation of the assessor that the symptoms are not cerebral or psychogenic in origin.

Diagnostic labels and conventions for classifications

The diagnostic labels that are currently in use are not set within a standard system of classification but are variously derived from pathogens, lesion locations and presenting symptoms. There is no clear convention to follow in describing clusters of symptoms that do not currently have a label.

The question of how disorders that are not already clearly described in the literature should be classified or labelled, in the absence of an agreed systematic approach, is further complicated by anomalies in the delineation between peripheral and central classifications in relation to recognised diagnoses since the cranial nerve and nucleus, housed in the brainstem, are often included as part of the peripheral system.

Limitations and challenges

The convention of regarding the TBI event as an indicator of symptom onset or as representing a single diagnostic category is unhelpful beyond flagging a set of risks for balance disorder. The risks associated with TBI are not universally agreed but are currently most comprehensively described by Brandt (Brandt, 1999b), using a largely anatomical lesion-based taxonomy. Careful documentation of injury mechanisms and access to detailed imaging, particularly with respect to differential diagnosis, would further assist in the development of this taxonomy.

Symptom history and progression can assist in diagnosis but the collection of this history requires enhanced information gathering beyond direct self-report to ensure accuracy and completeness. It cannot be assumed that a symptom history that is not immediately recognisable to those in standard vestibular rehabilitation practice is synonymous with a non-organic disorder since well described diagnostic indicators cover only a percentage of the potential organic disorders in this group. Neither can it be assumed that the unusual symptoms are cerebral in origin. The potential for co-existing deficits to limit or confound examination findings needs to be acknowledged and factored into developing diagnostic methodologies.

Diagnostic tests in routine use have limited value for specific diagnosis and 'normal' results do not necessarily indicate the absence of an organically based disorder. This applies in particular to otolith dysfunction, central lesions and dizziness of cervical origin. In the absence of a clear convention for categorising disorders, symptom sets currently require a lengthy narrative description linking signs and symptoms with possible lesions.

Evidence of central and ill-defined balance system disorders in the studied group

The full narrative relating to each study participant can be found in appendix 2. It is important, however, to highlight examples of presenting symptoms observed across the group that are suggestive of disorders affecting the balance system but that do not currently attract a clear diagnosis.

Otolith or vertical canal dysfunction

Fifteen of the 27 studied participants were assessed as symptomatic on the Dix-Hallpike test, where a classic response of transient dizziness and rotatory nystagmus is regarded as an indicator of BPPV. However, beyond those cases that were clearly suggestive of BPPV, there were cases were no nystagmus was seen and some, in addition, where classic dizziness was not reported. However, because of visible or reported distress they were classified as symptomatic.

There was a variety of descriptions of unpleasant sensations and observed distressed behaviours, for example, a feeling of oddness accompanied by very frequent blinking or a head filling sensation accompanied by visible pallor. Some of the participants reporting non-standard dizziness were more aware of the unpleasant sensations on return to the starting position than when in the extreme position of the test. There were a few who denied dizziness who experience transient loss of postural stability on return to the upright sitting position. These non-standard, but symptomatic, responses suggest that the movement associated with Dix-Hallpike manoeuvre provoked an abnormal sensory experience. Such an experience must be associated with changes in normal levels of sensitivity of peripheral sensory receptors or abnormal changes in the flow of information as recognised by central receptors.

In a few cases there were also reports during functional movement of feeling that the head was left behind or that a sensation of head movement continued after real movement had stopped. These reports always related to the direction of the movement in question, rather than a rotational or unrelated movement. They would seem to be consistent with perception of abnormal function of the otolith organs, either during movement against gravity or during (or after) linear acceleration. Otolith dysfunction may explain the experience of those participants that were more symptomatic on return to the upright position in the Dix-Hallpike manoeuvre or who experienced after motion on rising from sitting to standing. Otolith dysfunction would also be consistent with abnormal perception of linear acceleration as in the lagging or continuing head motion associated with sudden starting and stopping of walking.

Of the 26 participants who had limitations of VOR, 24 included problems with vertical VOR. It is of note that although in each case with symptomatic vertical VOR there were also limitations of horizontal VOR, these were rarely of a similar magnitude. In six cases there was a probable interaction with co-existing deficits, such as ocular motility. In about half of the remaining 18 uncomplicated cases the vertical VOR was the most problematic. This suggests differential damage within the labyrinth or in central connections specific to the various planes of action of the VOR rather than generalised vestibular hypofunction as a result of vestibular nerve damage. In the case of vertical VOR this means either local damage to the vertical canals or the otolith organs, the structures mediating the vertical VOR, or in the associated central connections.

Graviceptive pathway dysfunction

There has already been a full discussion of abnormalities in postural orientation and associated difficulties in the identification of gravitational vertical that may indicate disruption of the graviceptive pathways. Limitations in this data collection with reference to the direct assessment of estimation of visual vertical have been acknowledged. It is important, however, not to lose the key message that there is a strong indication of this category of central vestibular disorder as described by Brandt and Deitrich (Brandt & Dieterich, 2000) being part of the picture of balance disorder after TBI. Further work is clearly required to explore this and the relationship with otolith dysfunction, which is also emerging as a key factor.

Vestibulocerebellar dysfunction

Evidence of vestibulocerebellar dysfunction was frequently, although sometimes subtly, apparent in the studied group. Eighteen participants demonstrated limb ataxia but two thirds of these were categorised as minor. There were mixed patterns of occurrence, sometimes involving both limbs on one side, contralateral upper and lower limbs, some bilateral upper limbs and some single upper limbs only.

Limb ataxia can result from damage to the cerebellar hemispheres (Nolte, 1999a). However, cerebellar function is also dependent on the integrity of its connections and the quality of information available. Thus cerebellar-like symptoms may emanate from dysfunction in the brainstem vestibular nuclei or via their connecting fibres which travel to the cerebellum via the inferior peduncle (Nolte, 1999a).

Proprioceptive information travelling via the spinocerebellar and cuneocerebellar tracts to the cerebellum is crucial in the regulation of movement. The anterior spinocerebellar tract carries proprioceptive and cutaneous information from the lower trunk and lower limbs and travels to the cerebellum via the superior peduncle crossing the midline twice on the way.

The posterior spinocerebellar tract carries proprioceptive information from the trunk and proximal lower limbs, and together with the cuneocerebellar tract which carries proprioceptive information from the upper trunk and upper limbs, travels via the inferior peduncle, remaining consistently on the ipsilateral side. The cuneocerebellar tract originates in the medulla as a continuation of fibres from the posterior columns (Nolte, 1999f).

The distinct pathways conducting proprioceptive information from diverse body parts, including the different final routes to reach the cerebellum (superior versus inferior cerebellar peduncles) and the complexities added by the double decussation of the anterior spinocerebellar tract may explain the variance in the scope and severity of presentations of ataxia seen in the studied group.

Several participants demonstrated eye movement disorders consistent with cerebellar/cerebellar connection damage. These included dysmetric saccades, associated with damage to the vermis near the horizontal fissure (Nolte, 1999b), poor initiation of smooth pursuit associated with hemispheric lesions, reduced velocity associated with damage to the flocculus and problems of sustaining smooth pursuit (Moschner, Crawford, Heide et al., 1999; Nolte, 1999b; Straube, Scheurer, & Eggert, 1997). There was also fine nystagmus with adaptive holding of off-centre gaze to achieve steady vision as is often seen in congenital nystagmus.

12.1.7 Functional signs of balance system dysfunction

The primary functional movement observed within the assessment protocol was gait and a number of parameters of gait were frequently observed to be at variance with normal values.

Loss of movement fluidity and excursion

None of the studied participants walked freely with a standard gait. Two were unable to fully weight bear and were dependent on walking aids, one due to healing lower limb fractures and the other due to pain associated with a poor outcome from an ankle/foot fracture. However, in the absence of similar significant musculoskeletal causes in the other twenty five participants, there was a high level of loss of fluidity of movement and limitations of movement excursion.

Assessment notes frequently used descriptors such as no rotation, stiff, moved en bloc, stilted, two dimensional, rigid, fixed or with co-contraction. There was commonly a reduction in, and often an almost complete absence of, the rotational or spiral components of movement as observed in normal gait. This may, in part, have related to the general slowness of walking pace adopted by the majority of participants but there was also an impression of active fixation, sufficient to limit excess movement but not to the extent that movement had to become jerky to overcome the fixation. Furthermore, the quality of movement rarely improved with requests to increase the walking pace.

Head and visual fixation

There was often a fixed head position, sometimes with visual reference to the floor and sometimes rigidly looking forward. Commonly there was difficulty when asked to change the preferred position. There was a greater difficulty when those who were able to achieve a position with regard to the normal visual horizon where asked to try and scan the environment or generally look around while walking. Participants were unable to co-ordinate this or experienced dizziness or nausea or loss of postural stability. There were several participants who described a preference for walking towards a plain wall in the assessment space and an active dislike of walking toward the wall with wall bars. One participant expressed a similar dislike of walking through a brightly lit anteroom with a low reflective (painted) ceiling.

Other fixation behaviours

Participants also demonstrated a variety of fixation/co-contraction behaviours beyond eye and head postures during gait. This included facial clenching, breath holding, gripping hand postures, braced knees, and adducted lower limbs so that stepping took place primarily from the knee down.

Loss of variability in walking pace

As well as having a preferred walking pace that was clearly slower than standard, most of the participants were unable to increase their walking pace or to sustain any increase for more than a few steps. Some had almost as much difficulty when asked to walk at less than their preferred speed. There were three participants who either reported feeling more stable when asked to walk at increased speed or whose gait pattern moved closer to normal. However, none of these were able to sustain this over any length of time and they described dizziness or fatigue as the reason. The majority of participants slowed significantly before changing direction and this was more apparent when being requested to walk faster than their preferred pace. Eight participants effectively stopped to accommodate 180° turns.

Postural control

Abnormal postural alignment

Many of the abnormalities of postural alignment previously described in standing continued to be observable during gait. Backward inclinations (significant in eleven participants) limited effective forward weight transference and contributed to the inability to increase walking pace. Lateral inclinations (significant in nine participants) often resulted in deviations away from a straight forward progression, either in the direction of the deviation or to the opposite side in what appeared to be an overcompensated corrective strategy.

Base of support and foot placement

Only two participants walked with a classically wide-based 'ataxic' gait. One other participant described being aware of actively controlling a tendency to go to a wide base. Five participants adopted a narrow base and demonstrated foot placements that crossed the midline with associated lateral deviation on attempted forward progression.

Saving reactions

A few participants demonstrated upper limb saving reactions, in two cases clearly related to hip instability during weight-bearing. Other participants reacted during changes of pace and several on changing direction and when coming to a halt, especially when having walked at increased speed.

Common manifestations of balance disorder with reference to gait

Participants presented with individualised gait patterns that varied in detail but which also comprised common functional features:

- Participants were resistant to changes in their established movement habits in terms of postural alignment, visual reference and speed of movement.
- A core characteristic across the group was the adoption of strategies to maximise visual and postural stability and to avoid movement provoked or visually induced dizziness or disorientation.
- The chosen strategies were broadly successful in that in the majority of cases they resulted in safe and comfortable ambulation within the context of the assessment environment. However, the lack of flexibility of response and the high incidence of failure to visually attend to the environment has very significant implications for safety and functional ability in more challenging real life tasks and busier environments.

12.2 Symptomatic Minor Injury

The original observations reported in this thesis with regard to the outcome of apparently minor injuries raise questions with respect to our current understanding of immediate and longer term sequelae of minor traumatic brain injury (MTBI). The findings in terms of physical and sensory symptoms are an important addition to a sparsely studied area. The nature of some of the findings, and their association with established diagnostic criteria for post concussion syndrome, is of particular import for the wider health community.

12.2.1 Natural history of mild/minor TBI

It is acknowledged that there are still significant limitations of understanding concerning the effects of MTBI and the natural course of recovery remains an area of controversy (Bohnen, Jolles, & Twijnstra, 1992; Gasquoine, 1997). Most studies indicate that in the majority of cases symptoms have largely resolved within three months of injury but that there is a small subgroup of patients who continue to report persistent symptoms (Kashluba, Paniak, Blake et al., 2004).

Alongside the reporting of problematic outcomes following MTBI there is recognition of some potential risk factors in terms of prior injury, neurological illness or substance abuse (Corrigan, 1995; Ponsford, Willmott, Rothwell et al., 2000). Some work has been undertaken to try and predict who will have persistent symptoms but this has so far not yielded answers for the period beyond three to six months (King, Crawford, Wenden et al., 1999).

Although allowances have to be made for the impact of methodological differences, studies have documented a consistent core of postconcussion symptoms including problems of concentration, memory, anxiety, depression, irritability, headache, dizziness, visual disturbance and fatigue (Gasquoine, 1997) . However, the nature of some of these symptoms and their association with a range of non brain injury factors have added to the controversy as to their genesis (Gasquoine, 1997). Studies have been undertaken that identify objective correlates of some of the subjective symptoms, most notably in the area of neuropsychological assessment (see 9.2.2), and so there is a developing body of evidence of organic damage.

Clinical experience is, however, skewed towards those individuals who have developed significant difficulties and in this context much is attributed to maladaption rather than organic injury (Mittenberg & Strauman, 2000). These people may be given a diagnosis of post concussion syndrome (see 9.2.3). Further confusion and barriers to the development of understanding of the effects of MTBI relate to imprecision in the assessment of severity and in the application of diagnostic labels.

12.2.2 Limitations in determining and describing severity

Standard measures of severity (coma depth and duration, length of posttraumatic amnesia (PTA) and head imaging) have been previously described (see 5.1). The general nature of their limitations as independent measures and the need to triangulate findings to compensate for those limitations has also been described. The source and impact of these limitations as they apply to less severe injuries is worthy of further consideration so as to set the study findings in context.

Imprecise use of terminology

The immediate and early effects of minor injury are labelled generically as *concussion* (essentially a disruption of consciousness). However, the term concussion is used both casually to refer to transient symptoms of disorientation and more formally, notably in contact sports, when concussion symptoms are graded and include a category for witnessed loss of consciousness.

There is overlap between the use of the term concussion, other labels such as *comotio cerebri,* and the diagnosis of MTBI, as derived from Glasgow Coma Scale (GCS) scores (13-15/15) or length of PTA (< 1hour) (von Wild & Terwey, 2001). There is further confusion between the diagnosis of MTBI and the use of the term *post concussion syndrome* which, although a formal psychiatric diagnosis relating to a set of continuing symptoms, is sometimes imprecisely used to describe symptomatic minor injury in more general terms. Moreover, with reference to post concussion syndrome, there are two sets of criteria for diagnosis (DSM-4 (American Psychiatric Association, 1994) and ICD-10 (World Health Organisation, 1992)) which although largely overlapping, differ in detail (Mittenberg & Strauman, 2000)

Content and conventions in assessment

Not all of the confusion results from imprecision in the application of terminology in the immediate post injury period. Part of the problem relates to the limitations of standard measures of severity to identify those minor injuries that are likely to be symptomatic and the imprecise practice of revising estimations of 'severity' in the light of developing symptoms or when deficits become apparent as the injured person tries to return to normal activities and fulfil routine life roles. There is an associated lack of differentiation between initial injury severity and severity of effect or functional impact.

Beyond the clear parameters measured by the GCS and the conventions used in relation to this to assign a severity label within the first 24 hours, much of the determination of 'severity' in clinical practice depends on longitudinal evaluation of presenting symptoms and patterns of recovery, essentially severity of effect rather than initial injury severity.

There is no agreed convention to delineate between initial severity as measured by Glasgow Coma Score and sometimes quantified in structural terms by imaging (usually CT scanning) and subsequent evidence of deficits or functional limitations derived from assessment of PTA or from other methods of assessment and analysis.

Nature and derivation of acute severity measures

Glasgow Coma Scale

The Glasgow Coma Scale (GCS) is used throughout the world to describe diminished levels of consciousness and in particular to define coma. Prior to the development of the GCS there was not a common vocabulary to define coma or to allow comparison of the outcome of new interventions being developed to manage acute TBI.

It is important to note that the subscales and detailed content of the GCS were derived from observational studies of those primarily with *severe* injuries and relate strongly to indicators of diminished levels of consciousness associated with increasing levels of cerebral oedema or other mass effect (such as large haematomas). The use of the GCS as an alerting mechanism to deteriorating consciousness levels that may be amenable to surgical or other intervention has been, and continues to be, a pillar of good acute TBI management. However, it is *only* in the severely injured TBI group who develop cerebral oedema or other mass effects that there is a proven relationship between GCS scores and actual severity of brain injury.

It is only valid to drawn conclusions from GCS scores that relate to injuries with a mass effect. It is not valid to assume that a high GCS score is indicative of no injury to the brain, only no injury producing a significant mass effect. Indeed, a study that specifically examined the usefulness of the GCS scores in predicting outcome following MTBI found no that it had no predictive ability (McCullagh, Ouchterlony, Protzner et al., 2001).

There remains, however, a presumption in significant areas of clinic practice that organically based sequelae cannot follow a mild injury as assessed by the GCS. In this context, the symptomatic findings in many of the study participants with MTBI as defined by GCS scores would be unexpected.

Imaging

Imaging was developed to inform acute management plans and in particular to guide surgical intervention. However, while there are now guidelines in the UK advising use of CT scanning in the majority of cases seeking medical evaluation (National Institute for Clinical Excellence, 2003; Scottish Intercollegiate Guidleine Network, 2000), these have yet to be fully implemented so that early imaging is not always available for reference. In any case, there are limitations of CT scanning in the detection of lesser structural damage in the acute phase (Cihangiroglu, Ramsey, & Dohrmann, 2002). MRI better detects a range of brain injury characteristics including diffuse axonal injuries and injuries affecting the brainstem (Cihangiroglu et al., 2002). MRI is used rarely in the clinical management of TBI in the UK. Brain perfusion imaging is reported to be 50%

more sensitive than CT, to detect changes earlier and to identify changes in areas that appear normal on both CT and MRI scanning (Cihangiroglu et al., 2002). To date perfusion imaging has only been used with reference to TBI in the research field.

Longitudinal assessment

The continued reliance on first day GCS scores to grade injury severity, and so guide expectations of long term outcome, is acknowledged within TBI rehabilitation as being less than ideal. Individuals who are clearly symptomatic following an apparently minor injury would not be excluded from services. This convention to respond to symptom presentation is consistent with medical practice in general but is clearly dependent on the presenting symptoms being recognised and accepted as likely to be secondary to the injury. Conversely, if the presenting symptoms are not immediately recognised as a known effect of TBI they might not be validated or they may be attributed to non organic factors. In this context, misdiagnosis for study participants with MTBI and complaints of dizziness and disorientation is a real risk given the link with post concussion syndrome (see 9.2.3)

Where there is uncertainty of attribution, objective evidence of organic injury may be sought. This is more likely to occur when there is a medicolegal interest rather than in cases simply requiring a clinical response. Currently this would be via consideration of length of PTA and wider neuropsychological assessment and sometimes via imaging.

Post traumatic amnesia

The importance of establishing the length of PTA and of focusing on this measure rather than GCS score in symptomatic MTBI has been stressed by practitioners who have taken particular interest in this spectrum of injury (Gronwall & Wrightson, 1980). Gronwall and Wrightson also highlighted the methodological difficulties in doing so since one quarter of their study sample revised their early post injury report of when continuity of recall returned when re-interviewed three months later. There have been attempts to standardise prospective assessment of PTA (Levin, O'Donnell et al., 1979; Shores, Marosszeky, Sandanam et al., 1986) but this still remains problematic (Tate et al., 2000).

PTA is essentially a disorder of function. PTA is regarded as a marker of general brain dysfunction in that the appreciation, storage and retrieval of new knowledge requires functioning senses, cortical processing, limbic and cortical storage and cortical retrieval. Absence or short duration of PTA may, therefore, be regarded as indicative of limited diffuse brain injury but cannot be seen as excluding isolated brain injury or diffuse injury insufficient to cause complete loss of function.

Neuropsychological assessment

A wide range of deficits have been identified on neuropsychological assessment in various studies of symptomatic MTBI. Deficits are consistently reported in relation to attention, information processing, reaction times and memory, for example, (Gronwall, 1997; Leininger, Gramling, Farrell et al., 1990; Mathias, Beall, & Bigler, 2004; Voller, Benke, Benedetto et al., 2001). The strength of evidence for the validity of neuropsychological measures being indicative of brain injury or dysfunction is further supported by studies that also identify lesions (Hofman, Verhey, Wilmink et al., 2002; Voller et al., 2001), identify differences in functional brain activity (Chen, Johnston, Frey et al., 2004), have pre-injury comparative data (Macciocchi, Barth, Alves et al., 1996) or report links with serum protein levels associated with damage to neural cells (Waterloo, Ingerbrigsten, & Romner, 1997).

There are only a few studies referring to sensory or physical sequelae as well as cognitive limitations after apparently minor injuries (Cicerone, 1996; Freed & Hellerstein, 1997; Geurts et al., 1999; Haaland, Temkin, Randdahl et al., 1994).

Imaging

MRI imaging is more sensitive than CT scanning for posttraumatic lesions except for skull fractures and subarachnoid haemorrhage and is recommended in the literature as the best modality of use for follow up or subacute analysis (Besenski, 2002; Cihangiroglu et al., 2002). However, MRI scanning time is longer than CT and in the UK MRI is rarely ordered outside the medico-legal process. Research evidence also indicates SPECT perfusion imaging as a potentially useful modality in detecting abnormalities in mild and moderate injuries (Abdel-Dayem, Abu-Judeh, Parker et al., 2000). Imaging studies with regard to sensory or physical sequelae following apparently minor injuries are limited to single cases as previously discussed (Beck & Meckler, 1981; Bonilha et al., 2002; Catalano et al., 1986; J. R. Howe & Miller, 1975; Jani et al., 1991; Saeki et al., 2000)(see 9.1).

Summary of limitations in the assessment of severity

There are a number of interweaving factors contributing to a lack of consistency in the determination of what type and how much brain injury has occurred in any single case and therefore what conclusions that may be drawn in terms of expected short and longer term outcome. Problems in the use of terminology, compounded by a reliance on insensitive acute measures and a failure to differentiate between early signs and developing symptoms, prevent the identification of recognisable subgroups.

Absence of direct evidence from the potentially rich source of MRI and SPECT imaging further frustrates the development of greater clarity, although it is known that isolated lesions of brainstem and midbrain do occur following minor and moderate injuries (Sganzerla et al., 1992; Wong, 1993). Although research has confirmed the presence of cognitive limitations in studied participants, predictive factors to enable extrapolation to the wider population have yet to be identified.

Studies examining the presence of sensory or physical limitations after MTBI are extremely limited. Some of the regularly reported post concussive symptoms are not adequately explained by the cognitive limitations reported in neuropsychological studies and are most likely to be regarded as having a non-organic basis.

12.2.3 Post concussion syndrome and other presumptions of non organic symptoms

Individuals who continue to report a range of symptoms that they attribute to MTBI in the absence of evidence of cognitive impairment, or after any cognitive impairment is expected to have resolved, may be given a diagnosis of post concussion syndrome (Mittenberg & Strauman, 2000). Alternatively, particularly in the context of medicolegal proceedings, they may be suspected of malingering (Mittenberg & Strauman, 2000). Objective evidence of malingering is currently based on patterns of performance on neuropsychological testing (Larrabee, 1997; Mittenberg, Rotholic, Russell et al., 1996), although there is also concern within the neuropsychology profession that reliance on test results without adequate consideration of alternative explanations may lead to misdiagnosis (Miller, 2001).

Post concussion syndrome

Post concussion syndrome (PCS) has been generally regarded as a psychological disorder, an emotional response to the trauma. However, diagnosis of PCS has been inconsistent even when practitioners adhere to 'agreed' diagnostic criteria. This is consequent to the subtle but important differences in the two prominent published sets of criteria (DSM-4 and ICD-10). For example, ICD-10 requires 'a loss of consciousness' whereas DSM-4 requires 'significant cerebral concussion (e.g. loss of consciousness, PTA or seizure)'. ICD-10 includes 'subjective concentration, memory, or intellectual difficulties without neuropsychological evidence of marked impairment' whereas DSM-4 includes 'neuropsychological evidence of difficulty in attention or memory'. Both formal sets of diagnostic criteria for PCS include subjective complaints of dizziness, headache, anxiety and fatigue.

Clearly the development of these diagnostic criteria is incomplete and open to challenge. Indeed, more recent subject reviews of post concussion symptoms describe a wider range of commonly reported symptoms including a range of visual disturbances, problems with hearing and tinnitus and nausea (Gasquoine, 1997; King, 2003). There is also a developing theme that suggests we should be open to the possibility that at least some of the outcomes result from a combination of both organic injury and psychological predeterminants and processes (King, 2003). This approach is supported by the evidence that managing predictable psychological processes by the proactive provision of explanatory and advisory information leads to a reduction in the levels of anxiety and of reported symptoms at three to six months post injury (Ponsford, Willmott, Rothwell et al., 2002; Wade, King, Wenden et al., 1998).

However, developments in this area have been based almost entirely on signs and symptoms relating to cognition and emotion and largely without reference to symptoms that may be associated with physical or sensory dysfunction.

In considering factors contributing to a formal diagnosis of PCS, and with reference to the observations reported in this study, the inclusion of dizziness (undefined) as an indicator of non-organic symptomology is of concern. Of 27 participants in this study 24 reported dizziness or disorientation. The analysis of group data revealed a trend towards increasing numbers of objective vestibular system signs (not inclusive of subjective reports of dizziness) associated with MTBI. What may be of key importance here is the predominance of clear signs of peripheral vestibular dysfunction as measured by positive Dix-Hallpike manoeuvres or suspected otolith involvement in the MTBI participants. Signs of vestibular organ concussion were observed in 15 of the 27 participants, whether or not they also had signs suggestive of brain dysfunction.

This taken together with evidence of high levels of postural instability in a symptomatic minor/moderate population found by Guerts and co-workers (Geurts et al., 1996) and the high level of peripheral dysfunction in minor injuries identified on caloric testing by Basford and colleagues (Basford et al., 2003) suggests that organic causes of reported dizziness should first be excluded before this symptom is factored into a diagnosis of post concussion syndrome.

12.2.4 Brain Injury

In the absence of systematic targeted imaging no definite conclusions concerning structural brain injury can be drawn with reference to the MTBI participants included in this study. However, several participants defined as MTBI in terms of GCS score demonstrated deficits consistent with damage to brainstem/midbrain/cerebellar connections, base of skull and the tentorium, territory implicated as being at risk by the research published to date. These deficits included abnormal postural orientation (6), eye movement disorders (6), diminished sensory awareness and speed of response (10) and limb ataxia (9).

12.3 Assessment structure and interpretation of findings

A number of learning points emerge from the assessment process undertaken to gather the data and in subsequent attempts to understand the importance and functional impact of some of the findings.

12.3.1 Assessment structure and content

The broad structure of the assessment schedule proved to be valid and not over inclusive, given the spread of deficits observed across the chosen domains. The discipline of the predetermined structure was valuable in facilitating broadly comprehensive and concise data collection in the face of complex presentations. The question of whether and how to include estimation of visual horizontal and vertical as part of the baseline clinical assessment needs further consideration.

Where the need for additional assessment or onward referral was highlighted, the content and/or potential source was clearly identified by the process. Importantly, the assessment structure also offered an appropriate context within which to consider the results of this additional information gathering.

The anticipation of problems of reliability of self report within the studied population was validated by the discrepancies noted between reported (or, more correctly, unreported) problems and behavioural observations. These discrepancies were clearly identified and could be challenged within the process of the assessment, and by extending information gathering to multiple informants.

Key issues

Key issues emerging or reinforced with regards to assessment and information gathering are:

- The importance of knowing the clinical history, including injury mechanism, early signs and symptoms, progress and management
- The importance of knowing prior clinical history and pre-injury skills and habits

- The importance of knowing the participant's cognitive profile, any issues affecting memory or self-report or awareness of current self in terms of strengths and limitations
- The need to triangulate reports and observations and to test any apparent discrepancies

Augmenting the assessment process

While the structure of the assessment schedule provided discipline and ensured consistent data collection, there were also indications of the need to sometimes augment the core data set. Flexibility to test apparent discrepancies within the first contact assessment has already been identified as one course of action. Similarly, the importance of identifying additional informants or professional consults has been discussed.

There were also some cases where additional clarity could have been achieved via behavioural observations or recording of activities over a more extended period or when subjective symptoms may have been better described following proactive recording of frequency, nature and intensity of symptoms and associated provoking factors.

12.3.2 Interpretation of findings

As has been identified repeatedly throughout this thesis, this is an area in which distinct limitations of knowledge and understanding apply, both in terms of knowledge of factors that may underlie balance disorder after TBI and in the sharing of knowledge across disciplines to advance understanding of TBI balance disorder and other TBI sequelae. In this context assessment findings need to be interpreted with caution but equally it is important to highlight emerging themes.

Cautions

The need for caution in simply accepting the self-report of individuals recovering from TBI has already been stressed. A second issue relates to causal attribution and the need to consider a range of factors that, in addition to the documented injury, may have contributed to the presenting state. This is important to prevent misattribution and to identify potential barriers to recovery and assist in the development of management plans. Finally, given the emerging multifactorial nature of TBI balance disorder it seems important to consider a guiding principle for the interpretation of assessment findings that considers the findings as a whole, their interrelationship and potential for functional impact.

Cumulative impact of multiple impairments

The cumulative effect of multiple physical impairments appears largely self-explanatory in that it is easily recognised that with each additional limitation of flexibility, power or control there would be an increased challenge to achieving a range of functional tasks requiring motor skills. This type of challenge was clearly seen in the small number of participants with significant motor dyscontrol, soft tissue adaptation and altered biomechanics.

In addition, however, there were several participants who presented with relatively minor dysfunctions within individual assessment domains but across several domains. Importantly, deficits commonly (but not exclusively) affected the sensory systems, limiting the capacity for compensation and in some cases adding to inaccurate or inefficient monitoring of the environment or of the body within that environment. Taken on their own, individual symptoms were sometimes at the level that their functional effect may be almost disregarded and in some cases may have been considered as borderline normal. However, when considered together with other subtle signs a cohesive picture of interrelating signs and symptoms could be seen.

The cumulative effect on functional ability was significant and observable in all cases even within the relatively controlled and predictable assessment environment. As previously described, strategies to achieve visual and postural stability and to avoid experiencing sensory disorientation resulted in habitual gait patterns that were limited in, or completely without, flexibilty of repertoire.

In many cases there was strong resistance to, and sometimes complete absence of, an environmental scanning dimension. This lack of attention to the (potentially changing) environment often seemed to extend to a lack of awareness of visual information in the wider visual field so that participants would be suddenly 'surprised' by environmental changes at the last minute rather than anticipating the need to negotiate them in advance. This has significant implications for function in the wider environment in terms of safety and in terms of cognitive and emotional demands in situations when individuals are forced to move or interact within a busy or unpredictable environment.

Even in the presence of relatively minor individual deficits across domains it would seem appropriate to fully examine the ability of an individual to respond flexibly while moving within a controlled environment before assuming little functional impact. It is also reasonable to assume that those individuals who manage to successfully negotiate busy environments, despite deficits within the sensory systems upon which monitoring the environment depends, will experience these activities as demanding.

Functional impact of poor performance on sensory testing with a cognitive load

Although there were only a few participants with tactile deficits on single stimuli (3), there were larger numbers who had difficulty discriminating between different stimuli (20) and whose response to stimuli was significantly slowed (17). There were also some participants who appeared to take time to 'tune in' to the task, to identify the novel stimuli, before going on to perform relatively well.

The functional impact of difficulties identified in the controlled test situation in attending to, making sense of, and responding to stimuli needs to be fully considered. This applies in particular to anticipating performance in situations that require immediate registration or a speedy response. When these difficulties occur together with limitations of vigilance and lack of anticipation as seen consistently in functional gait the effects could be significant.

The potential impact on functional ability of poor performance on sensory testing with a cognitive load should be actively considered in association with other limitations. Individualised testing to challenge abilities in demanding situations should be considered, particularly if the individual intends to undertake demanding activities such as working at heights or carrying children while negotiating stairs.

Early high-tonal states and subsequent movement patterns

Only a few of the participants (3) were known to have experienced the type of high tonal states associated with initial severe injury. In each of these cases there was residual soft tissue adaptation consistent with a period of overactivity in the upper trunk and neck extensors and in the posterior tibials. This was even the case in the participant who had had surgical intervention to lengthen both achilles tendons. In all cases there was a degree of muscular co-contraction, even at rest, in contrast to the fixation response to movement seen in those participants who were experiencing significant sensory disorientation or frank dizziness.

It is of note that even though there were residual restrictions of range in the neck, around the feet and ankles and to a lesser extent, distally in the upper limbs, there was in some cases contrasting limitations of proximal control, particularly around the hip and pelvis.

Lack of fractionation

Much of the functional movement observed in participants across the studied group was characterised by limitations in movement fractionation. However, there were subtle differences in how this presented. For example, in the small subgroup just described who demonstrated motor dyscontrol associated with neuromusculoskeletal factors, there was widespread lack of fractionation affecting skilled movement throughout the limbs and in relation to intersegmental movement. In participants with less obvious neuromusculoskeletal deficits, whose abnormal movement was influenced more by sensory dysfunction, the lack of fractionation was primarily limited to intersegmental movement, more associated with eye and head movements and less apparent in isolated limbs.

It is important to consider biomechanical, neuromuscular and sensory contributions in developing an understanding of the factors contributing to lack of fractionation within functional movement in individual cases and in particular to distinguish between primary limitations of motor control, protective strategies to gain visual stability or a sense of postural control and limitations of soft tissue extensibility, secondary to established movement habits.

Interrelated signs and symptoms

In a number of cases it was not possible to definitively assert which of the observed signs were the primary deficits and which the secondary effects. One factor contributing to this difficulty is the potential reciprocal relationships between signs. For example, limitations in eye movement excursion resulting from restriction in cervical motion contrasted with restrictions in cervical range being secondary to neglect and associated limitations of excursion of eye movement.

A second contributory factor concerns the impact of the period of time elapsed since injury, especially when there is a lack of a clear early history or documentation of subsequent progress. An assessment conducted at some distance from the time of injury and with limited reliable history may result in the generation of alternative hypotheses concerning causal factors and secondary effects.

When the assessment process results in the generation of alternative hypotheses it is necessary to adopt a pragmatic approach guided by management needs and the constraints introduced by dominant symptoms, and to focus on stepwise remediation and management of the disabling symptoms.

Speed and capacity of information processing

Difficulties in discriminating sensory stimuli, reduced speed of response and reduced speed of movement have already been noted as affecting many of the study participants. The first assumption is that these deficits result from organic brain damage or from the debilitating effects of vestibular system dysfunction. However, in a minority of cases other factors may have contributed to capacity and speed of response.

Chronic pain and low mood associated with high levels of pain have been shown to affect cognitive performance (Brown, Glass, & Park, 2002; Grigsby, Rosenberg, &

Busenbark, 1995) and these may have been significant factors in three participants. In two of these three participants there was also the potential effect of pain relieving and anti-emetic medication, both of which can have central nervous system sedating effects.

The potential impact of pain, mood and medication on assessment performance and symptomatic findings must be fully considered in the overall formulation of assessment findings to avoid misattribution of causal factors and the development of inappropriate management plans. However, the presence of these potential confounding factors cannot be assumed to preclude organic brain or peripheral vestibular system damage and the same pragmatic approach to definitive assessment and treatment as outlined above is likely to be appropriate.

Pain or low mood can result in diminished activity levels. Medication can suppress the error signals required to drive normal compensatory processes following vestibular system damage. All of these factors must also be considered when anticipating the potential to gain from active intervention programmes.

12.4 Summary

12.4.1 Newly identified factors underlying TBI Balance Disorder

- Postural malorientation of the head and trunk secondary to disruption of normal perceptions of verticality with respect to gravity, probably resultant from dysfunction of the graviceptive pathways (brainstem and midbrain nuclei and connections with otolith organs).
- Postural malorientation of the head associated with loss of oculomotor range, visual field or acuity, achieving single vision in the presence of diplopia or achieving stable vision in the presence or nystagmus or impaired VOR.
- Restricted exploratory motor behaviours of the eyes and head similar to more generalised neglect/inattention behaviours associated with the neglect syndrome.
- Difficulties in judging orientation within the environment affecting the midline and the horizontal.
- Difficulties in negotiating obstacles while in motion or in dealing with a (physically or visually) moving environment.
- Postural instability associated with predominant vestibular or cervical dysfunction, and minor/moderate TBI as well as after severe TBI.
- Postural instability secondary to illusory sensations of movement.
- Muscular fixation behaviours associated with attempts to achieve visual stabilisation or a perception of postural stability.
- Habitual fixation or avoidance behaviours based on prior experience of disorientation or loss of postural stability, sometimes despite resolution of, or reduction in, the provoking noxious experience.
- Dizziness and other forms of sensory disorientation (beyond that consistent with BPPV) associated with canal and otolith dysfunction, visual dependency and dizziness of cervical origin. Dizziness exacerbated by hyperventilation.
- Perceptual anomalies reflecting disordered appreciation of tactile and proprioceptive information and of gravitational force.

- Gait patterns characterised by restricted movement repertoire and strategies to maximise visual or postural stability and minimise movement provoked or visually induced disorientation or loss of balance.

12.4.2 Key issues for the assessment of TBI Balance Disorder.

- Current clinical concepts of balance or postural control and taxonomies of balance disorder need further development and refinement to form a suitably comprehensive assessment base and promote the development of appropriate diagnostic methodologies.
- Clinical history, including prior medical history, pre-injury skills and habits, forms a key component of the assessment process but this requires an enhanced information gathering process to ensure accuracy and completeness. Enhanced information gathering should be structured with due regard to the individual's cognitive profile and with particular consideration of any issues affecting memory, self-report or awareness of current strengths and limitations.
- The interpretation of assessment findings, especially in relation to the presumption of a non-organic basis of symptoms, should be set in the context of the developing knowledge base rather than restricted to established diagnostic categories. The impact of confounding factors such as the presence of pain, low mood or the use of medication must also be considered.
- The interpretation of assessment findings requires careful consideration of potentially interrelated factors. For example, physical presentations, including motor behaviours, may be secondary to other primary motor dysfunction or sensory dysfunction, including the experience of illusory movement, as well as potentially reflecting a primary deficit of motor control or biomechanical organisation.
- Additional longitudinal assessment may be required in the form of extended behavioural observation or via pragmatic progressive intervention strategies, to test hypotheses derived from the initial assessment or disentangle interrelating factors.
- Full consideration must be given to the potential functional impact of multiple 'minor' deficits or evidence of diminished speed or accuracy on increasingly complex tasks both in terms of risk and in predicting levels of fatigue. Additional

personalised assessment may be applicable to test perceived risks or maintenance of ability over a period of demanding activity.

12.4.3 Key issues with implications for the understanding of TBI

- Localised brainstem and midbrain lesions, including cerebellar connections, may occur in minor and moderate TBI. Likely mechanisms include base of skull fractures, tentorial edge impacts, hyperextension and side-flexion injuries.
- Some of the debilitating symptoms experienced by those with minor/moderate TBI who remain symptomatic may be associated with vestibular system damage. These include significant postural instability (which does not have a direct relationship to the severity of the TBI) as well as dizziness and other disorientating sensations. Organic causes of reported dizziness, therefore, should first be excluded before this symptom is factored into a diagnosis of post concussion syndrome.
- Greater care in the documentation of injury mechanisms and formal studies including detailed imaging are required to develop a more detailed understanding of both central and peripheral lesions, associated symptoms and functional impact.

13 CONCEPTUAL LIMITATIONS AND LESSONS FROM POSTURAL CONTROL THEORY

13.1 Conceptual basis of data collection

The data collected in this study was structured around a low-tech clinical assessment protocol derived from a systems analysis approach to postural control as applied to TBI. The protocol included enhancements to control for anticipated challenges to accuracy and completeness in information gathering and to determine pre-injury influencing factors so as to avoid misattribution. Thus the various components contributing to postural control described from an experimental base by Nashner (1982) and translated into a systems analysis approach by Shumway-Cook and Olmscheid (1990) formed the conceptual base of the assessment protocol. This conceptual base was then examined and interpreted to reflect the potential sequelae of TBI.

There was not an existing assessment package sufficient to cover the full range of domains and target behaviours. Mechanisms of assessment to observe the target behaviours were therefore chosen from a range of sources. As has already been fully explored, the sources from which they were drawn did not share a single conceptualisation of balance or postural control (see chapter 3). Sources often had a limited focus and so offered a specialised contribution to the composite package. There was always a risk that assessment findings derived from a composite of assessment methods would raise conflicts in interpretation.

13.1.1 Conceptual approach and group observations

The process of primary analysis collated pathological findings across the group as a whole. Prior to collation the defining criteria used related to each individual assessment item consistent with the published literature or clinical practice in the source area. The use of assessment items derived from this diverse sampling approach did not present any specific challenges to the collation and presentation of the frequency and spread of pathological findings across the group as a whole.

13.1.2 Conceptual approach and single case analysis

The process of secondary analysis reviewed assessment findings at single case level and so involved comparative analysis across the full range of findings for that individual. At this level of analysis the composite conceptualisation, realised via a collection of independent assessment items, did not provide a sufficiently cohesive basis for the interpretation of the sometimes complex findings. This was particularly apparent for observed elements that were unexpected or novel, when observations had the potential to be interlinked or when observations had the potential to confound other assessment items.

While the systems analysis approach provided a logical structure around which to build a fairly comprehensive assessment process, an explicit underpinning theory for this conceptualisation was found lacking when it came to the interpretation of a range of assessment observations. In this context, interpretations were developed by a process of critical analysis and via reference to a wide literature (see chapter 9) rather than with reference to an established theory.

13.2 Postural control theory

Research activity and theory development in relation to postural control and balance function is consistently set in the context of a wider field of study, for example, biomechanics, or perception and action. At the same time researchers who work within these wider fields or have a particular interest in a balance subsystem may explore only a single element in depth or via a range of experimental approaches. The scope of exploration and the focus on detail in research activity both acknowledge the complexity of the subject.

There has been progressive development of knowledge within subfields and cross-fertilisation of ideas and findings. For example, biomechanical modelling has developed beyond the limitations of aiming for static equilibrium to acknowledge and address the complexity of the human postural control system and the importance of environmental context. This is exemplified by methods of analysis moving from simple linear approaches to the application of more complex mathematical methodologies, such as stabilogram-diffusion analysis (Collins & de Luca, 1993) and recurrence quantification analysis (Riley, Balasubramaniam, & Turvey, 1999). Both of these approaches attempt to predict behaviour equivalent to that observed in the human, during quiet stance and in the presence of a changing environment. Similarly, two seemingly isolated motor strategies identified in early EMG studies as 'predictable' responses to contrived perturbations are now seen as only part of a flexible continuum of potential motor actions, dependent on behavioural goals and environmental context (Horak, Henry, & Shumway-Cook, 1997).

However, exploration is incomplete and the nature of the discovery process means that at any one time a range of possibilities are under consideration and uncertainty remains. This presents a significant challenge to describing a clear and comprehensive model which both summarises current understanding and reflects areas of debate. Never-the-less, theoretical models are essential to provide a frame of reference against which to consider emergent findings and develop further hypotheses for subsequent testing.

13.2.1 Essential characteristics of a theoretical model

Congruent with motor control theory

Human balance or postural control has a symbiotic relationship with motor control, the study of the nature and control of movement. Chapter 2 reviewed a range of perspectives on motor control and distilled a core consensus. An acceptable theoretical model of postural control would need to be consistent with this consensus (see 2.1.1).

Specifically, it would need to:

- reflect an intelligent self-regulating system
- define component parts and their characteristics
- postulate relationships between components parts and with the environment
- characterise function.

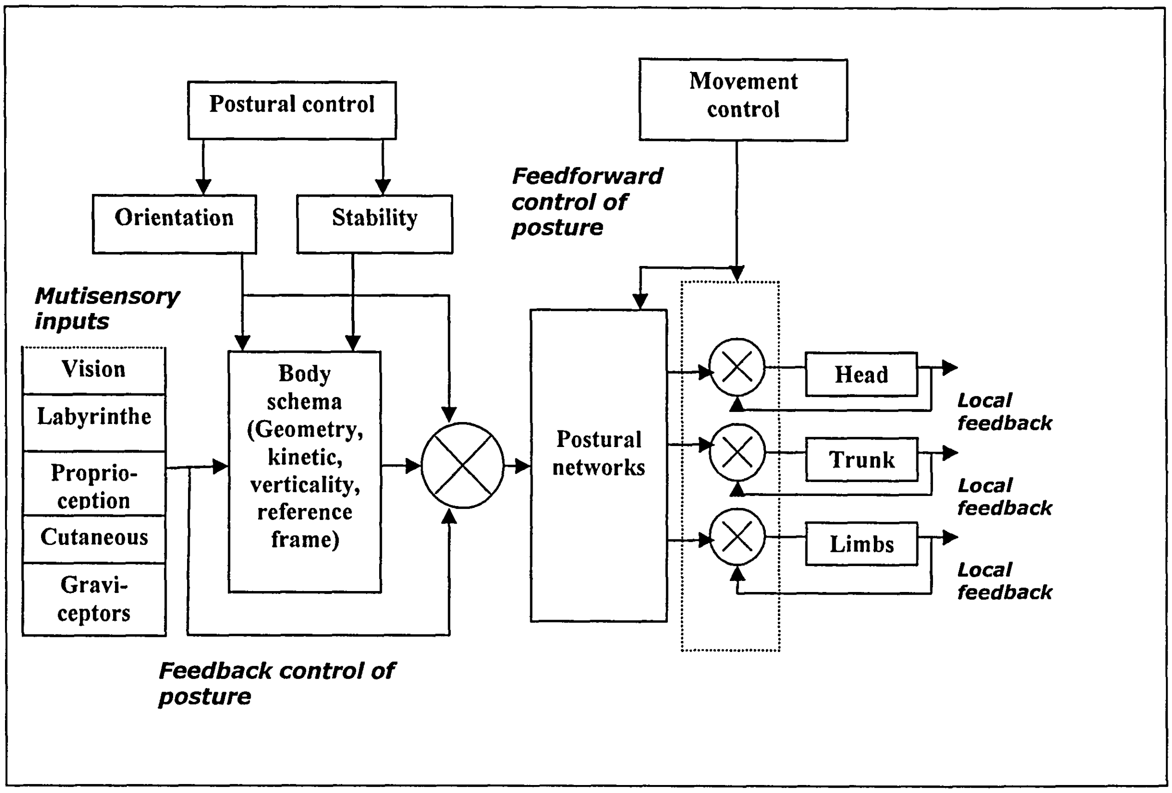
13.2.2 Schematic overview of postural control

Massion (1994) presents a theoretical model that meets the essential criteria of being congruent with motor control theory. The model is presented as a schematic overview (see figure 13.1) of the central organisation of postural control.

This model attributes two primary functions to the postural control system:

1. Stability: a whole body antigravity function that ensures equilibrium is maintained.
2. Orientation: a segmental orientation and positional function that forms the basis of a reference frame for perception and action with respect to the external world.

Figure 13.1



Massion's model of postural control (1994)
(reproduced with permission from Elsevier)

Stability and orientation are in turn dependent on an internal representation of the body, Body Schema, with subcomponents of body geometry, body kinetics, representation of verticality and reference frame. Body Schema is said to be developed via multisensory inputs, which also provide an online mechanism for error detection.

The postural task is enacted via Postural Networks which integrate feedforward movement control with the baseline reference values of achieving the two primary functions (stability and orientation), the internal reference of the Body Schema and the error information provided by the multisensory inputs.

The delineation of two primary functions of postural control in this model is underpinned by evidence of the existence of two control systems: one which fixes the orientation of body segments with respect to the external world and the second which ensures stability, including the stabilisation of the centre of gravity. There is a suggestion that in humans body geometry changes in order to regulate the position of the centre of gravity but the true relationship between the two systems is not yet clear (Massion, 1994).

Massion discusses research that demonstrates the relative stability of the internal representation (Body Schema) in changing environmental conditions but also the impact of context on perception of orientation and movement in space. Context is inclusive of variations in the sensory information available for use.

Evidence is presented to demonstrate that postural responses are also influenced by context, being dependent on initial body geometry, on support conditions and on available afferent information. The choice and execution of postural reactions is flexible and adaptable to task demands, within biomechanical constraints.

More specifically in terms of sensory roles, both central and peripheral vision are seen to be involved in the regulation of postural stability. There is a dynamic relationship between vision and somatosensory input in their contribution to stability, dependent on the size of the base of support.

Evidence is also presented demonstrating that anticipatory postural responses, while part of the feedforward system, are amenable to change based on new experience. This is not, however, clearly seen in the schematic representation.
Many aspects of the postural control system are, therefore, flexible and adaptable and the sensory systems in particular are inherently open to a wide range of compensatory possibilities. The internal representation of the body (Body Schema) appears to be a

stable core upon which execution of these compensatory processes is dependent. Choice of postural reactions is constrained by the environmental context and the biomechanical properties of body segments.

13.2.3 Postural control theory and the key findings of this study

The postural control theory summarised above refers to function and underpinning components in the absence of pathology. Further consideration will now be given to how it relates to function and underlying deficits as reported for the participants in this study.

Functional dimensions

All of the functional limitations of postural control seen in the study participants could essentially be categorised as either problems of stability or orientation or both. It is interesting to observe that while all participants reported feelings of instability and were found to have limitations of function related to instability, none of the 17 found to have postural malalignment reported awareness of disordered orientation.

In considering the fit of two main functional categories, those participants with fixation behaviours are regarded as having problems of stability. This is both in terms of being abnormally fixed during many functional activities and in having underlying instability of posture and gaze requiring a compensatory postural response: that of fixation.

Multisensory inputs

Massion lists five sensory inputs, with graviceptors included as a separate input unit alongside the more standard visual, labyrinthine, proprioceptive and cutaneous. While the otolith organs (part of the labyrinth) are generally considered to be the primary graviceptors in the human, Massion is including here additional graviceptors that are thought to be distributed among the body segments but have yet to be clearly defined.

Many of the study participants had deficits across all five of these senses, although more widely distributed graviceptive sensors or questions designed to identify their dysfunction were not explicitly included in the data collection process. It could be that perceptual anomalies experienced by a few participants in relation to limb weight and weight bearing are given meaning by considering the presence of distributed graviceptors.

Body Schema

Body Schema is thought initially to develop via multisensory inputs but, when established, it is by contrast said not to be malleable and so to provide a stable and reliable reference frame. It may be assumed, then, that changes in sensory information flow resulting from deficits in any of the multisensory inputs would not be directly responsible for any apparent variance from normal values in any of the components of Body Schema. If this is so then the problems of body geometry and deviations from the vertical observed in the study participants might be seen as either problems of motor execution or as indicating damage to structures involved in the immediate generation of the entity referred to as Body Schema.

Body Schema may be relatively stable and a reliable reference in the face of a changing external environment but it cannot be immune to change in the face of internal malfunction.

When such an internal malfunction occurs and results in the development of an abnormal reference frame, its dominance within normal postural control could then translate into an equally dominant factor which by nature of its stability in the face of fluctuations in sensory information flow is likely to override potentially 'corrective' sensory information.

Not only would functional movement be developed around an abnormal internal reference frame for orientation and/or stability, but sensory input would also be interpreted in the context of the faulty internal reference frame with all attendant possibilities of distortion. This would certainly seem to fit the behavioural presentation of a large number of the study participants who consistently adopted the same malaligned orientation of body segments away from the vertical. It may also offer an explanation for the experience of some participants who had an internal perception of themselves as oscillating while apparently still to the external observer.

However, although Body Schema is constant in normal circumstances, the conscious perception of postural stability and alignment is influenced by sensory inputs and external environmental context. That is, although there is a constant internal reference frame, the interpretation of how stable and aligned the body is with reference to that internal reference frame is open to the influence of sensory information.

There were many examples in the studied group of the influence of absence or addition of sensory information on stability and alignment. This was seen to be both positive, when reliable sensory information was added, for example, a cutaneous reference in the form of fingertip contact, and negative, in the presence of unreliable information, for example, unstable or inaccurate vision. Participants were always aware of the impact on stability but not always on changes in alignment and, in terms of the latter, usually only at the point it impacted on their perception of stability.

The continuous comparative process that is central to Massion's postural control model is highly dependent on streams of reliable and cross validating sensory information. It requires a level of vigilance and accuracy that would clearly be compromised in participants with multiple, even minor, deficits. If any or all of the systems involved in the error reporting role (comparing the actual posture with the internal reference frame) are limited or malfunctioning it would not be without effect.

Discrepancies between two or more sensory message systems are recognised in terms of sensory conflict, sometimes manifest in the experience of dizziness. It is not clear if there is a perceptual experience or an increased cognitive load associated with a continued inability to fully resolve missing data or sensory input that consistently but inaccurately identifies an error between intended and actual posture. Neither is it clear if there is a mechanism to adapt to altered sensory systems in the same way that repeated sensory conflict is resolved in terms of dizziness reduction. Finally, it is not clear whether or not a faulty internal reference frame may be rebuilt via multisensory inputs.

Movement control and postural networks

In the model, anticipatory and reactive postural adjustments are mediated via Postural Networks in parallel with segmentally specific action and sensory monitoring loops. The Postural Networks are informed by all aspects of the system already described: the reference values of orientation and stability, the internal reference frame of the Body Schema and the error detecting system dependent on the multisensory inputs.

In normal circumstances, choice of muscle synergies is influenced by body geometry and current activity, that is, choice is influenced by what is known about how the body is at variance with the core internal reference frame and what is required to achieve the task. A failure to identify abnormal geometry or alignment, as would be the case when the internal reference frame is inaccurate, may be expected to compromise strategy choice and/or timing. An example of this would be failure to anticipate an approach to the limits of stability leading to delay in enacting saving reactions.

This type of behaviour was observed in a few participants but more commonly there was evidence of adapted behaviour that significantly reduced degrees of freedom and the opportunities for such errors to occur. In terms of critical thinking this fixation behaviour was explained by the need to achieve either gaze or postural stability. The model offers the possible interpretation that these fixation behaviours are adapted feedforward behaviours, that is, changes that have occurred in anticipatory behaviours borne out of the experience of repeated failure of pre-existing 'normal' anticipatory behaviours.

There were three participants who produced upper limb saving reactions subjectively well in excess of the externally assessed threat to loss of postural stability. All of these participants had had neck trauma and were habitually very fixed in terms of gaze and head position. All reacted with sudden large amplitude upper limb saving reactions during some head on neck movement, one so large that he induced a backward fall.

If Body Schema is accepted as being a stable internal reference point, such an apparently enhanced postural reaction must be generated via a significant cross-sensory error message or enacted via a sensitised postural synergy or a postural synergy chosen in the presence of high levels of biomechanical constraint. Ankle or hip strategies or stepping were not used. It could be postulated that the high levels of co-contraction seen in these participants acted as a significant biomechanical constraint. The genesis of this level of co-contraction is open to debate. All three participants experienced disorientating sensations (other than frank dizziness) on head movement and all had had significant levels of pain on head movement that may well have contributed to habitual avoidance of movement in the first instance.

Another issue worthy of consideration was the magnitude of the response and whether this was simply a factor of lack of expression of the postural response elsewhere. An alternative consideration is that the movements were hypermetric as a result of involvement of cerebellar connections.

13.2.4 Value and limitations of the model

The theory and schematic presentation of a postural control system model as described by Massion (1994) is derived from research findings and evidence-based predictions. It is developed primarily from experimentation involving normal humans. The model offers the basis for a level of interpretation of assessment findings beyond the systems analysis approach as described by Shumway-Cook and Olmschied (1990). This additional level comprises two dimensions: the inclusion of the concept of an internal reference frame and some detailed description of how all of the model components are believed to interrelate and interact.

It is interesting to note that in a development of the systems analysis concept Shumway-Cook and Woollacott (Shumway-Cook & Woollacott, 2001e) also include a dimension called Internal Representations. They also discuss separately, but do not include in their conceptual model, what they term higher level neural processes or cognitive influences on postural control. Within this they include control of the adaptive and anticipatory aspects of postural control and attention, motivation and intent. The extended systems analysis approach widens and develops the component-based concept of a multifactorial postural control system. However, without a theoretical model of how these components interrelate, the same limitations for interpretation of potentially interacting symptoms remain.

While both the theoretical and conceptual models presented by Massion and Shumway-Cook and Woollacott include the perception of sensory information, this is in the context of normal postural control. What is not addressed, even though it does occur in normal humans under abnormal demands, is any overt reference to processes dealing with the perception of noxious sensations, such as dizziness. More importantly in terms of sustained difficulty the model does not consider the impact of associated emotional response.

In the application of Massion's model to those with pathological disruption of the postural control system the lack of consideration of emotional response and associated cognitive processes is a key omission. The potential impact of reactive cognitive responses, consciously perceived or otherwise, that form part of the process by which experience of failure, awareness of risk and the drive for self-preservation may be translated into changes in feedforward motor behaviour needs to be recognised. In the studied group these changes affected both the quality and flexibility of available behaviours and in many cases this resulted in a 'choice' of one dominant antigravity postural set with very limited ability to respond to environmental change.

Massion's postural control model is developed from a research base focused on normal postural control. It offers a sound theoretical framework as a basis for explanation and analysis of complex assessment findings associated with balance disorder. However, the model is limited in terms of those aspects related to response and adjustment to pathological experiences, particularly with regard to sensory-perceptual disorientation and adaptation over time.

13.3 Sensory based conceptualisation of balance disorder

In direct contrast, Brandt has developed a conceptualisation of balance function from a base in clinical practice which has sensory dysfunction at its core. As previously reviewed (see 9.1.4) Brandt uses the umbrella term Vertigo to describe a multisensory, sensorimotor syndrome which can result in perceptual, postural, ocular motor and autonomic manifestations (Brandt, 1999e). While this conceptualisation has its base in pathological disorders it is also applied to the experience of sensory disorientation in those with normal balance systems when they experience abnormal sensory stimulation.

In this analysis, subjective reports of disorientation or perceptual disturbance, any autonomic response and any observed motor behaviours are regarded as expressions or effects of the experience of Vertigo. Vertigo is a singular term indicating a disturbance or dysfunction in sensory systems including those aspects of the central nervous system upon which they depend. This would be inclusive, therefore, of what Massion would term Body Schema and its constituent parts.

Within this broad conceptualisation, Brandt describes a series of syndromes relating to specific pathologies (including psychiatric diagnoses) and/or anatomical locations of lesions. In addition he recognises a syndrome which he terms Phobic Postural Vertigo that is predominantly anxiety based but often has its routes in prior organic pathology (Brandt, 1996).

Brandt's conceptualisation sees all observed or reported behaviours as secondary to Vertigo. The concept is well supported by known neuropathophysiological processes and a continually developing evidence base. Brandt and colleagues' work has generated a framework for understanding many oculomotor and postural behaviours associated with a range of lesions within the wider balance system. However, it deals with balance disorders in isolation and essentially in a context that presumes no co-existing pathology. Furthermore, without an explicit associated theoretical model or schematic representation of interrelating factors, non standard findings are difficult to explain.

13.4 Balance mechanism and balance sense

Balance function has been viewed from a locus of postural control and from a locus of sensory disorientation. There is value in the insights derived from both of these approaches but independently they are inadequate as a complete framework within which to fully understand balance disorder after TBI. De Weerdt and Spaepen (1999), as previously discussed in 3.2.2, acknowledge two aspects of balance requiring attention in clinical practice: the sense and the mechanism. It is essential that both of these aspects are given equal weighting if a comprehensive understanding of balance function is to be developed.

Massion's postural control model requires further development to more clearly indicate the potential for adaptive change in the feedforward system in the absence of pathology. A further action dimension from postural networks reflecting Eyes would be appropriate to acknowledge this aspect of the balance and postural control system. Both of these additions apply to modelling of normal postural control.

Modelling of postural control in relation to abnormal experience or in the presence of impairment probably requires a range of schematic representations. It would be wholly appropriate to have an augmented version of Massion's model as a basis for each of these representations. In this way each could be amended and progressed in line with knowledge development and at the same time form a reference frame for the interpretation of assessment findings.

13.5 Summary

- The conceptual framework provided by the systems analysis approach provided a good basis for the development of a fairly comprehensive assessment protocol.
- The assessment protocol development process did not give sufficient emphasis to the perception or estimation of verticality, although the value of information generated via current methods of clinical assessment in this area is equivocal.
- The assessment protocol generated information sufficient to identify the range and frequency of deficits within and across domains and to exclude some potential causal factors. For some participants there was a clear causal hypothesis but in others there was more than one hypothesis or a single hypothesis contrary to accepted knowledge.
- Where there was insufficient clarity, the conceptual approach lacked a process and theoretical framework against which to compare findings and generate new hypotheses.

- Massion's postural control model provides a good theoretical framework for advanced analysis of single cases and the generation of new hypotheses.
- Massion's postural control model would be enhanced by the development of a further dimension reflecting the process by which feedforward movement control is adjusted by experience. This should include conscious and unconscious cognitive processes, including emotional responses that impact on changes in motor behaviour.
- Further development of this postural control model to reflect processes in the presence of impairment would benefit from consideration of balance from the locus of sensory disorientation, as described by Brandt.
- Balance disorder can only be fully understood when consideration is given to both the sense and the mechanism of balance.

14 IMPLICATIONS FOR HEALTHCARE AND NEUROPHYSIOTHERAPEUTIC PRACTICE

14.1 Advances in the understanding of TBI balance disorder

Balance disorder after TBI is a multifactorial entity potentially involving a range of systems and each of those systems to a varying degree. Balance disorder after TBI may result from damage to brain tissue or cranial nerves, from traumatic damage to the balance organ, from associated cervical trauma or from a combination of these injuries. Balance disorder after relatively minor TBI is likely to emanate primarily from balance organ or cervical trauma but there are also indications that focal brainstem or midbrain lesions can occur during minor injury and may contribute to the overall picture. Balance organ dysfunction is not restricted to cranial nerve damage and BPPV but can also involve the otolith organs and damage to individual semicircular canals.

Signs and symptoms of TBI balance disorder include:

- the experience of noxious sensations of dizziness and other forms of disorientation within the environment
- a range of ocular and visual manifestations
- postural malalignment
- postural instability
- perceptual anomalies including illusory self and environmental motion and disordered appreciation of body segments
- primary and reactive limitations of motor behaviour, and
- significant restrictions in the available range and flexibility of functional movement leading to risk, failure or avoidance of task.

Presentation in any one individual may be complex and is likely to include primary deficits, secondary effects and compensatory behaviours. Assessment processes need to take into account additional potential sequelae of TBI including limitations of cognition and expression. Assessment findings may be challenging to interpret because of their range and nature and also because of limitations of knowledge with respect to the mechanisms underlying postural control and the nature of TBI balance disorder. A systems analysis approach to structured assessment, based on a broad conceptualisation of human balance and postural control and knowledge of TBI and associated injuries, can provide a comprehensive data set and allow basic analysis of the nature of balance disorder. A fuller analysis of novel or potentially interrelating findings requires reference to a wide literature and is facilitated by comparison to an evidenced-based theoretical model of postural control.

14.2 Challenges for current service provision in the UK

The range and complexity of elements identified as impacting on balance function in the studied group confirms the need for analysis of balance problems following TBI to be set in a broad conceptual base. The impact on observed behaviours of changes in environmental or task demands gives emphasis to the fact that provision needs to reflect the dynamic relationship between the individual and the environment. This includes assessment of the individual's ability to adapt to environmental or task demands.

The disparate roots and limited and diverse development of concepts of balance within clinical practice have been previously reviewed (see chapter 3). Singular or exclusive concepts of balance which have formed the traditional basis of health care practice, whether science, pathology or discipline based, are clearly inadequate to provide sufficient context for the analysis of balance disorder after TBI.

14.2.1 Service developments

There have been practice developments in the UK, particularly in the development of Balance Clinics from within established audiological service bases. There is a developing role of Audiological Physician with an associated supporting team including audiological scientists and balance therapists and sometimes including psychologists and physiotherapists. However, while this model might reflect a form of holistic management developed from an acknowledgement of the need to see balance disorder in a wider context, it still has its base (and core competencies) in dealing with pathologies of the peripheral vestibular system.

The composition of the team is also to some extent influenced by parallel developments in services designed for the management of tinnitus which have grown from a common base. Physiotherapists, when included, are often peripheral team members and will usually have been added to the team to provide skills in the assessment and management of neck and other upper trunk soft tissue disorders. While these therapists will have core skills in postural and movement analysis, they will less commonly have experience in dealing with the cognitive and other significant sequelae of TBI.

14.2.2 Specific needs of TBI survivors

The potential for a person who has sustained a TBI to have multiple co-existing deficits is an important dimension when considering what appropriate service provision might comprise. It is important in terms of that person being likely to require assistance to overcome or adapt to a range of other significant changes. The nature of the challenges commonly experienced after TBI is that they can strongly impact on a person's ability to interact and engage with healthcare services and this often requires management in the form of specially designed service provision. It makes most sense, therefore, for service provision for TBI balance disorder to be set within the context of specialist TBI rehabilitation, support and adjustment services.

14.2.3 Neurophysiotherapeutic developments

Neurophysiotherapeutic practice has begun to respond to a growing awareness of the need to widen the conceptual base in relation to a range of motor performance issues including disorders of balance or postural control. This process of practice development is underway within TBI rehabilitation provision and specifically in relation to balance disorder. Progress has been slow due to the paucity of pathology-specific research, lack of clear delineation of discipline-specific responsibilities and difficulty in influencing parallel complementary developments in associated areas of clinical practice such as rehabilitation medicine, vestibular science and ophthalmology.

14.3 Key components of a meaningful service response

Much of this thesis has been concerned with complexity, with confusions of language use, imprecise definitions, limitations of understanding and inappropriately compartmentalised service provision.

TBI balance disorder has been described as a multifactorial entity, potentially involving many systems as a result of various types and severities of injury. Service provision has been identified as requiring both structure, to ensure comprehensive coverage, and flexibility, to permit focused analysis of individual assessment findings. Both of these factors are important to allow a reasoned analysis of core underlying deficits and other contributory factors.

The service demands to address this context of wide scope and personalised depth may be regarded as daunting and potentially costly, in terms of finance and in investment of time. Service provision needs, therefore, to include an effective filter mechanism to deliver assessment and intervention appropriate to individual needs. This filter needs to be set within a service context that recognises the larger potential picture.

Considering appropriate provision from the viewpoint of the service user provides an apposite perspective and emergent clear service focus. The factor that is common to all cases of balance disorder likely to benefit from service support is that there is a degree of functional limitation.

Balance disorder for the individual is not a diagnostic conundrum but the current experience or ever-present anticipation of sensory disorientation or ineffective control of their body such that they fear, avoid or fail to achieve everyday physical tasks. What a person with TBI balance disorder seeks from service provision is validation that the problem exists, understanding of why it is so and advice as to how the situation and its impact on everyday life might be improved or managed. What they also require is support and guidance to effectively action any improvement or management plan.

Service provision needs, therefore, to comprise comprehensive and skilled assessment, to communicate its findings well and to set those findings and any proposed actions in the individual's real-life context and in the context of co-existing needs. It needs to be accessible, understandable and meaningful to the service user.

14.3.1 The neurophysiotherapist as a service orchestrator

The professional within the rehabilitation team concerned with disorders of physical function and their impact on an individual's ability to fulfil life roles is the physiotherapist. Within TBI service provision it will be a specialist neurophysiotherapist.

This study has demonstrated that a neurophysiotherapist already has or can easily develop the appropriate observational and assessment skills to apply a systems analysis-based screening assessment to identify subjective complaints, functional limitations and underlying deficits. It has also demonstrated that this process is sufficient to exclude some causal factors and to identify, when appropriate, the need for additional specialist assessment. By referring to an enhanced knowledge base and the assessment findings of specialist colleagues when required, the neurophysiotherapist can develop sound working hypotheses to guide feedback to the individual and the development of intervention or other management plans.

In endorsing this enhanced role of the specialist neurophysiotherapist the health community would gain an effective filter into specialist assessment clinics appropriate to the particular needs of each individual. It would assign the locus of control appropriately within service provision already invested with the task of assessing and addressing multiple potentially competing or interacting issues and needs.

The person with balance disorder would have an accessible interpreter of findings able to negotiate with them appropriate and timely intervention. This would allow the development of a person-centred, goal appropriate service and proper resource use.

14.4 Service provision model for TBI balance disorder

The findings of this study suggest that the primary referral point for individuals with suspected balance disorder after TBI should be a specialist neurophysiotherapist with an interest in balance disorder, either working within or in close collaboration with a TBI rehabilitation team. This practitioner should undertake an initial screening assessment to establish if a disorder of balance is present and if so to identify a working hypothesis concerning the underlying primary deficits, secondary effects and compensatory mechanisms.

In some cases additional specialist assessment may be required to develop or confirm the working hypotheses. Disciplines or services most likely to contribute to advanced assessments are audiology and vestibular science, neuro-otology, neuro-ophthalmology and orthoptics, psychology, occupational therapy and neurorehabilitation medicine. All of the disciplines involved need to acknowledge and accept the required wide conceptual base and the need for the service locus of control to sit with the neurophysiotherapist advanced practitioner.

Balance disorder should be seen as a factor limiting physical function and so a person's ability to achieve tasks and fulfil life roles, as a limitation of dynamic function. The assessment process and negotiation of intervention or other management plans should recognise individual needs and personal goals, taking full account of co-existing rehabilitation, adjustment and support targets.

14.4.1 Neurophysiotherapeutic competencies

In order to understand and complete the assessment screening process a neurophysiotherapist is likely to have to undertake personal development in terms of widening their knowledge base and extending assessment skills. However, as outlined earlier in this thesis (see 7.4.2), the required development would be easily achieved by an experienced neurophysiotherapist. To ensure appropriate analysis and interpretation of assessment findings, including correct onward referral and formulation of working hypotheses, there would be further knowledge development needs.

Key knowledge requirements are as follows:

- TBI balance disorder is likely to be a result of multisystem dysfunction and different systems can be involved to varying degrees
- TBI balance disorder may result from brain and cranial nerve injury, from injury to the balance organ, from injury to the cervical spine or from any combination of these injuries.
- TBI balance disorder may be seen across the whole spectrum of injury severities as graded by GCS.
- Balance disorder following minor TBI is more likely to be associated with balance organ injury or neck injury but focal injury to the brainstem or midbrain can occur in minor TBI and may involve key centres for balance or postural control.
- Balance disorder following severe TBI is more likely to be associated with brain and cranial nerve injury but can also include elements of balance organ dysfunction or neck trauma.
- Signs and symptoms of TBI balance disorder include:
  - dizziness and other forms of sensory disorientation
  - ocular/visual abnormalities
  - postural malalignment
  - postural instability
  - perceptual anomalies (personal & environmental)
  - primary and secondary limitations of motor behaviour
  - decreased range and flexibility or functional movement
  - risk, failure or avoidance of task
- Individuals with TBI balance disorder may present with a mixture of primary deficits, secondary effects and compensatory behaviours
- Individuals with TBI balance disorder are likely to have additional deficits and challenges as a result of their injuries that need to be fully taken into account during assessment and management
- Limitations of knowledge with respect to TBI outcomes and the factors and mechanisms underlying postural control add to the challenge of constructing an appropriate assessment process and interpreting assessment findings. Assessment is usefully structured around the systems analysis approach as developed via this study. Interpretation of assessment findings is assisted by considering presentation

in the light of Massion's model of postural control (enhanced) and with reference to wider and developing literature, including the developing taxonomy of key TBI balance disorder causal factors, based on the work of Brandt and others (see appendix 3).

- It is essential in developing a personal conceptualisation of balance disorder to consider both the sense and the mechanism of balance in equal measure.

14.5 Developing clinical practice

The data collected and analysed in this study and the subsequent discussion and development of ideas has focused on identifying the nature of TBI balance disorder and on effective mechanisms of clinical assessment. There is much work to be done from this base in relation to the design and evaluation of a range of management processes and programmes. There will be opportunities to borrow from existing programmes but there is also a clear need to develop TBI specific solutions.

14.5.1 Supporting research programmes

The large number of existing fields of enquiry with the potential to provide findings of ongoing interest to the field of TBI balance disorder has been clearly described throughout this thesis. Of particular value would be work in developing understanding of the senses and mechanisms of computing verticality and the relationship or otherwise with gravitational force. Similarly, investigations relating to possibilities for remodelling internal reference frames to rebuild accurate body schema would inform programmes of remediation.

All of the progressive work moving towards research paradigms which replicate dynamic postural control within increasingly complex or variable environments may also prove informative. However, at a basic level what is first required is a prospective TBI study, involving subjects with a range of injury mechanisms and severities, documented with reference to the full range of existing measures of injury and symptom severity and including appropriately detailed and focused imaging. The objective of such a study would be to detect any relationships between severity, mechanism, lesions, symptoms and outcomes and to establish if the hypothesised link between postural malalignment and focal brainstem or midbrain lesions can be objectively supported.

15 EVALUATION OF THE RESEARCH PROGRAMME

15.1 Research focus and programme design

This research was undertaken with the broad objective of improving clinical practice with regard to suspected balance disorder after TBI by developing the knowledge base that underpins it. A mixed methods approach was chosen to provide a flexible framework within which to explore the different dimensions of the research programme while ensuring the outcomes of each constituent part could be brought together for full consideration and applied to clinical practice.

15.1.1 Initial concept and design

The research programme had three aims:

- to identify and describe factors that have shaped and influenced healthcare practice concerning balance and balance disorder and so understand barriers to improved practice
- to develop a better understanding of the nature of TBI balance disorder,
- to establish proposals for an improved healthcare response for those with suspected balance disorder following TBI.

As the aims are inter-related and interdependent but each aim is qualitatively different, each arm of the research programme required a different approach to collection, exploration and synthesis of data within a single framework. The individual aims needed to be progressed in set chronology and the research design needed to allow for the potential impact of emerging knowledge. The programme was; therefore, conceptualised within a single flexible framework with the methods to achieve each aim varying and being defined by research questions associated with each aim. The overall conceptual framework at this time conformed with a standard experimental design that followed the pattern, literature review, experiment, results, discussion and conclusions.

Assumptions and amendments

One of the primary assumptions at the beginning of the project was that the outcome of the focus on the first aim (to understand and describe current practice) would include a clear description of a consensus view on balance and balance disorder and that this would be sufficient to allow the consensus view to be tested and developed with reference to TBI. However, one of the key outcomes from this initial review of influencing factors and current knowledge and practice was that there was no clear consensus across healthcare practice and a very limited understanding of TBI balance disorder. Understanding was so limited that the anticipated approach required to address the second aim (to develop a better understanding of TBI balance disorder) had to be reviewed and amended to take account of the need to freshly explore the subject rather than be in a position to test a current hypothesis.

15.1.2 Emergent concept and design

The change of focus of the data collection phase from experimental to observational, changed significantly the balance of the conceptual framework. The programme as a whole now had a pre-experimental focus approximating to that of Grounded Theory. The programme components now comprised, definition of context, observational study, descriptive and thematic data analysis, discussion of emergent issues with reference to the literature, application of new learning and development of theory.

The flexibility offered by the mixed methods design and so the ability to amend the internal components of the research programme in response to emerging knowledge validated the adoption of this approach from the outset. Similarly, the chosen chronology, developed from the identification of the inter-relationships between the programme aims, proved to be accurate as evidenced by the need to review the data collection phase to address appropriately the development of understanding of TBI balance disorder in light of the findings of the knowledge review.

15.2 Reflections on the research programme

15.2.1 Challenges

The key challenge in pursuing this research programme was the limited availability of knowledge specific to the core research objective combined with the significant width and depth of knowledge with the potential to offer insight into such a minimally researched area. In addition, the wider literature and practice review revealed limited consensus and a range of unresolved questions, some under active enquiry within individual specialist areas. It proved impossible in this context to reduce all of this into definitive truths and in some instances even to distil key or competing hypotheses.

15.2.2 Appropriateness of the approach

The mixed methods approach, set within a flexible framework, proved to be appropriate in that it allowed internal redesign appropriate to emerging knowledge and with limited redundancy of the initial literature reviewed. While not all of literature was presented within the thesis, the contextual understanding derived was invaluable in the development of the research programme and in identifying potential areas of focus for the secondary literature review presented within the discussion.

15.2.3 Strengths

The key strength of the programme design was its flexibility and in particular its responsiveness to emerging knowledge. This allowed research methods to be always appropriate to the research questions. The final design with its primary focus on deriving new knowledge via description of context, observation and thematic analysis was exactly right for the level of current knowledge in this research area. This type of examination allowed acknowledgment of the existing (limited, conflicting and confusing) context and a fresh observation of the subject and its manifestations with free exploration of potential and underlying causal factors. From this there has emerged new knowledge, new ideas and new theory. Adherence to a more rigid quasi-experimental design would have reduced the focus of the enquiry and would not have provided the opportunity for the same exploration of potential causal factors. Given the range of the discussion that emerged from the chosen approach, including the range of new questions to be explored, it would seem likely that the outcome of an experimental approach would have been unsatisfactory in terms of immediate content and in the development of rationale for new lines of enquiry.

15.2.4 Limitations

The primary limitation of the programme design is its focus on only two small sections of the population sustaining and surviving TBI and the caution that therefore has to be applied to the generalisation of the findings. It could also be argued that there is further bias in the sample in that all of these individuals had been referred for rehabilitation. In balancing these two issues, it is probably important to reflect on the relevance of a symptomatic sub-population for this research in that the applications relate to clinical practice and developing a response for such a symptomatic group. The findings are, therefore, more applicable to those post TBI who seek rehabilitation. It will be necessary to repeat these observations in similar populations and compare findings.

A second limitation is the speculative nature of some of the findings. While these are grounded in objective observations and given clarity and meaning with respect to the knowledge base, they remain to be formally tested.

15.2.5 Conclusions

The research design chosen for this programme of enquiry facilitated its progression and was appropriate to each of the research questions. The enquiry began with a perception of need to develop knowledge underpinning clinical practice for suspected balance disorder following TBI. The process identified major flaws in the knowledge base and allowed the description of some key foundations for practice development and the identification of areas for further study. The design of the research programme was effective in both identifying the bases of barriers to progress and in developing the of understanding for TBI balance disorder through systematic observation and discussion.

At the end of this process of enquiry, a clear direction of travel has been defined that will facilitate ongoing development.

16 CONCLUSIONS

16.1 Fulfilling the objectives of the enquiry

At the outset of this enquiry there were three primary objectives. The first was to understand the confusion around the concept or definition of balance within healthcare practice. The second was to examine the nature of balance disorder after TBI. Finally, the third objective was to bring forward suggestions to improve patient care for those with suspected balance disorder after TBI.

16.1.1 Concepts of balance within healthcare

Differential approaches to concepts and definitions of balance within healthcare were explained by understanding the evolution of ideas in each discipline area. Historical factors, purpose and associated areas of practice were all influential features and potential elements of confusion. A key issue of relevance to all healthcare areas was a lack of appreciation of the full context affecting human balance and an adherence to an established focus without successful regard to a holistic context.

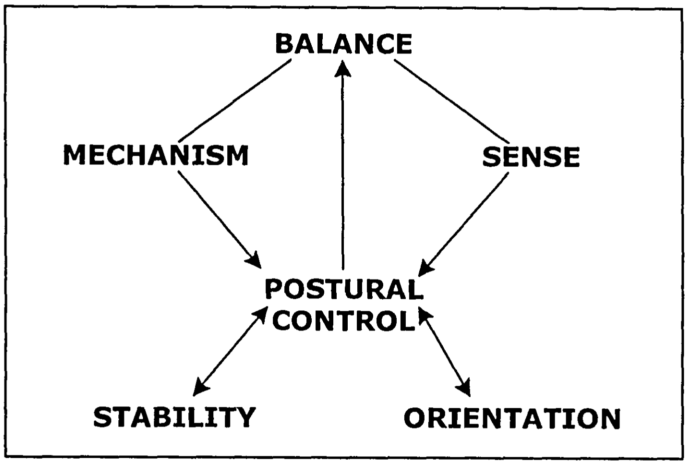
There are many possible ways to conceptualise balance function, influenced by perspective. Common foci relate to performance in the absence of pathology or concentration of interest in one or more dysfunctional subsystems. Limited conceptualisations are not necessarily detrimental when dealing with isolated dysfunction in an otherwise normal system or when pursuing specific lines of enquiry in research. Multisystem dysfunction, however, demands a comprehensive framework of understanding. Such a framework is presented in figure 12.1.

Within this framework balance is:

- *defined* as the optimal state of perceived and actual postural control
- *conceptualised* as comprising two components: a sense and a mechanism, and
- *achieved* via the process of postural control
- postural control has two dimensions: stability and orientation

- postural control is actively influenced by the both the sense and the mechanism of balance

Figure 16.1



Balance: framework of understanding

This definition of balance reflects the functional interdependence of perception and action in effecting, or attempting to effect, a state of balance appropriate to the current motor goal. It also allows for the dynamic 'on-line' nature of the balance task during the execution of the motor act, including the potential for performance to be influenced by a range of sensory, cognitive and emotional factors that sub-serve perceived (balance) status at the level of the individual. Finally, it acts as an alert to the professional to consider both sensory and physical dimensions of the online process, establishing both dimensions clearly as being of equal importance in the overall conceptualisation.

The diagrammatic framework of understanding maps a reciprocal relationship between the postural control system and the concept of balance. This allows full consideration of how theoretical models, individual systems or deficits and personal perceptions or adaptations might interact. It is essential for the progression of understanding of balance and balance disorder that clinical observations, study findings and study designs are set in this wider context.

16.1.2 Understanding the nature of TBI balance disorder

This enquiry has significantly progressed understanding of the nature of TBI balance disorder. It is clearly established as multifactorial both in terms of causal factors and deficit profiles.

Signs and symptoms can emanate from brain damage, balance organ damage, neck damage or damage to the visual system and may present in a complex mix. The brainstem, the midbrain and their cerebellar connections emerge as key cerebral areas. Balance organ damage frequently involves the otolith organs and vertical canals in addition to peripheral nerve damage and BPPV.

Severity of TBI is not in itself a clear predictor of postural dyscontrol, indeed significant postural instability as a result of balance organ damage is more likely to affect those with minor TBI. However, postural malalignment, which would appear to reflect lesions of the brainstem or midbrain, may also affect those with mild/moderate TBI's. Sensory disorientation and misperception is a significant dimension affecting perception of safety, motor behaviour and levels of activity.

Further work is now indicated to explore the many issues of interest identified in the process of this study. The development and testing of management strategies can now be progressed.

16.1.3 Improvements for patient care

Assessment and management of TBI balance disorder must be recognised as an area of specialist healthcare provision. It is recommended that services are redesigned on a person-centred basis with the objective of responding to individually reported or observed functional limitations. The initial point of service contact for those with suspected balance disorder following TBI should be a specialist neurophysiotherapist working within, or collaborating with, a specialist TBI rehabilitation, support and adjustment service.

The wider health community needs to acknowledge the full context and functional impact of balance disorder, in line with the framework of understanding presented in figure 12.1. It must recognise the pivotal role of the neurophysiotherapist as screen and filter and as primary interpreter of comprehensively gathered assessment findings. In order for the role to be effective and efficiently delivered, the neurophysiotherapist will need full direct referral rights to colleagues able to provide additional specialised assessment and consultancy. The role will also need to be recognised within commissioning arrangements.

Neurophysiotherapists operating in this role must demonstrate enhanced knowledge and advanced assessment skills, including the formulation of working hypotheses. Assessment and management of TBI balance disorder, including both the mechanism and sense of balance, must be established as an appropriate focus of neurophysiotherapy practice. Further standardisation and validation of the assessment protocol developed for this study will be required to support this process.

Rehabilitation teams working with individuals following TBI need to understand in full the scope of functional impact of TBI balance disorder and make appropriate adjustments to established service provision to take account of new learning.

Service evaluation and formal research programmes should support stepwise implementation and development of the newly designed service.

16.1.4 Summary

Each of the three objectives of this enquiry has been fulfilled.

A suggested common framework of understanding for balance has been presented. A suitable working model of postural control has been developed from an existing evidence-based model and recommendations for the development of pathology specific models have also been made.

The scope and variance of TBI balance disorder has been described. Developments in the understanding of detail have been progressed in a number of areas. Some hypotheses have been developed and can now be tested.

Recommendations for the structure and content of appropriately redesigned service provision have been made to improve patient care. Primary areas of knowledge and skill development for neurophysiotherapists undertaking the key assessment role in the new service have been described. Further work to standardise and validate the assessment process will be required to support full implementation.

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List of Appendices

Appendix 1:

Assessment schedule proforma

CLIENT CODE:

D.O.B.:

D.O.I.:

Lowest GCS: Surgical Intervention: YES / NO

Other medical/process info:

Hypertension/diabetes/heart disease/endocrine dysfunction

D.O.E.:

TIME SINCE INJURY:

ADDITIONAL INFO FROM: CARER STAFF
Detail and initial (C or S)

CLIENT CODE:

Thinking about before your injury

Q1 DID YOU WEAR GLASSES? YES / NO
Detail:

Q2 HAVE YOU EVER HAD ANY OTHER PROBLEMS WITH YOUR EYES? YES / NO
Detail:

Q3 DID YOU HAVE ANY PROBLEMS WITH YOUR BALANCE? YES / NO
Detail:

Q4 DID YOU HAVE NECK PROBLEMS OR INJURIES? YES / NO
Detail:

Thinking about since your injury

Q5 HAVE YOU NOTICED ANY PROBLEMS WITH YOUR EYE SIGHT YES / NO
Detail:

?Diplopia:
constant/intermittent
near/distant/off-centre

Q6 HAVE YOU NOTICED ANY PROBLEMS WITH YOUR BALANCE YES / NO
Detail:

- stumbling?
- feeling unsteady?
- any other odd sensation? e.g. dizziness, nausea
  - sensation of motion, tilting, pulling?

when? where? what? how would you describe it?

Q7 HAVE YOU HAD PROBLEMS WITH YOUR NECK? YES / NO
Detail:

Q8 IS THERE ANY OTHER PHYSICAL DIFFERENCE OR PROBLEM THAT YOU HAVE NOTICED SINCE YOUR INJURY? YES / NO
Detail:

Q9 WHAT ABOUT YOUR SENSE OF SMELL & TASTE?

Q10 HOW IS YOUR HEARING (tinnitus) ?

CLIENT CODE:

MOTOR PERFORMANCE / PHYSICAL STATUS

M1 Known post injury motor dysfunction (notes and physical exam):

Describe symmetry, alignment, functional level and characteristics of movement

Baseline safety / risk assessment

M2 SITTING
(static→dynamic)

3D alignment: achieved/maintained if placed/eyes open/eyes closed
Base of support/trunk on base/head on trunk/eyes in head
[p]Pain-free ROM head in neck+/- over-pressure

rot⇨R
rot⇨L
ext
flex
sflex R
sflex L

M3 Preparation for standing:

M4 Success? Achieved by?:

1 of 3 trials

M5 STANDING
(static→dynamic)

3D alignment: achieved/maintained if placed/eyes open/eyes closed/foam
Base of support/pelvis over feet/trunk over pelvis/head on trunk/eyes in head

Antigravity muscles

[p] record pain or other self-reported sensory dysfunction on diagram A, page 6

M6 **GAIT:** quality / variability

CLIENT CODE:

?with/without collar if ataxia present

M7 OTHER MOTOR PERFORMANCE ISSUES

Finger/nose R active

Finger/nose L active

M3&4 trial 2

Movement induced

Past pointing

Additional injuries/soft tissue adaptation/immobilised parts (record pain on sensory chart page6)

CLIENT CODE:

SENSORY SCREEN

S1 **In supine:** comfort / alignment (record alternative exam position if necessary)

S2 **ASK ABOUT SELF-REPORT OF PAIN, DISCOMFORT OR SENSORY CHANGES and** ***record on diagram A***

S3 **TEST** **tactile (light touch)**
single stimuli
double stimuli (T,V,A)
tactile (sharp touch)

compare subjective sensation between limbs of opposite sides and between upper and lower limbs
record accuracy on diagram B, note speed of response:

- **prompt** ☐
- **hesitant** ☐
- **slow** ☐

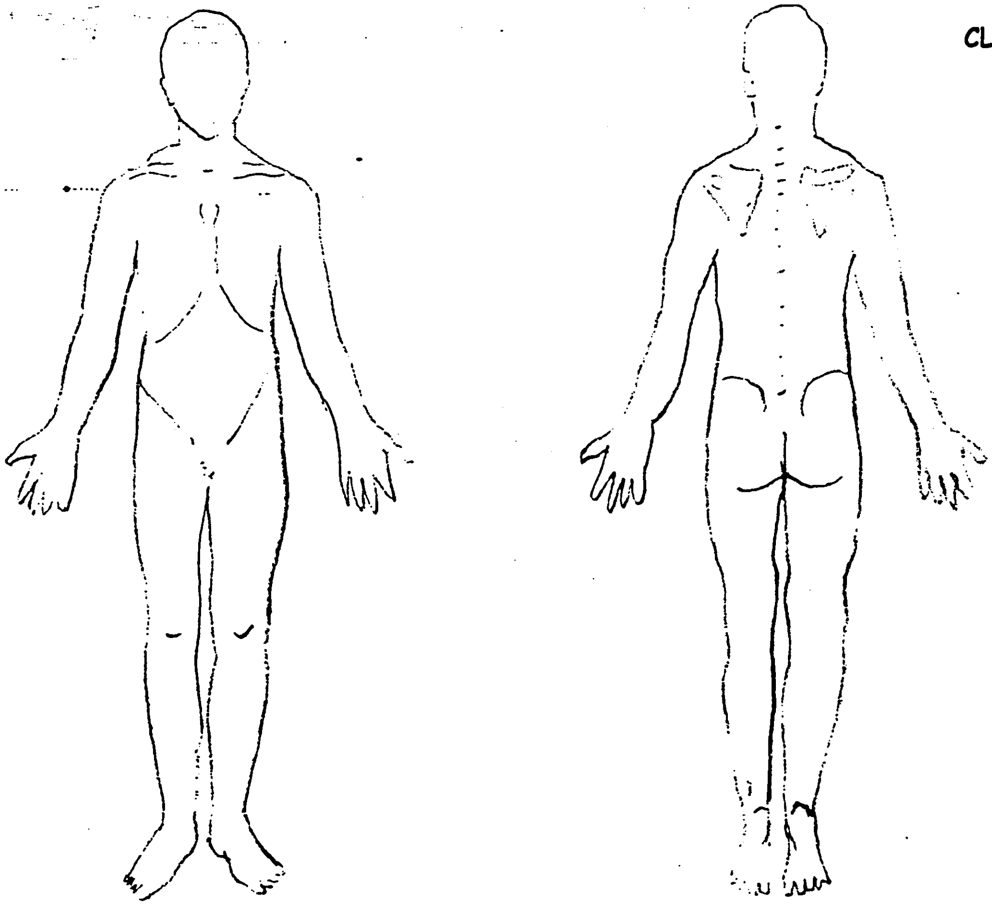
joint movement/position
single joints (shoulder/knee, finger/toe +/-)
multi-joints (mirroring)
temperature appreciation if appropriate

S4 **CHECK RESPONSE TO RIGHT AND LEFT SIDE LYING**

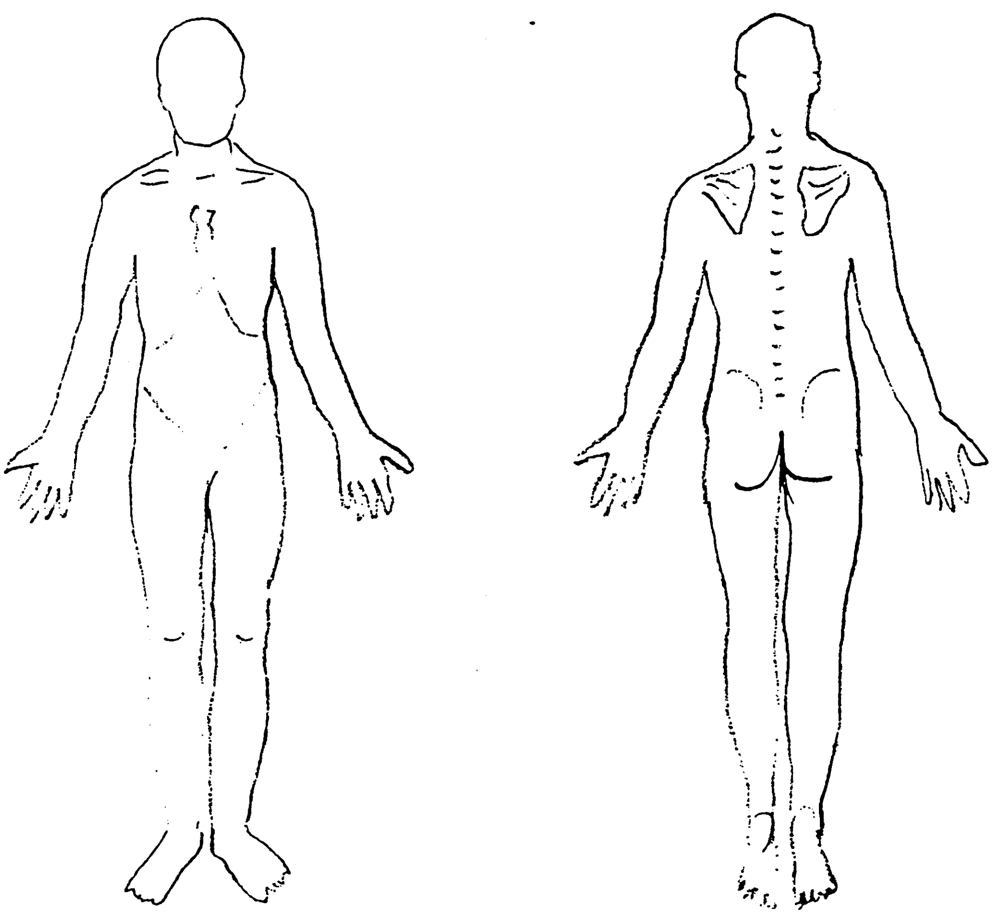
S5 **THERAPIST'S COMMENTS / IMPRESSION:**

fatigue/headache/other

CLIENT CODE:



(S6) Diagram A



(S7) Diagram B

CLIENT CODE:

In sitting

S8 **eye resting position**

(include spontaneous nystagmus in light & observation/subjective report of simple central fixation)

S9 **visual acuity** (snellen @ 20feet)

S10 **field confrontation**

(include double confrontation)

S11 **occlusion R**

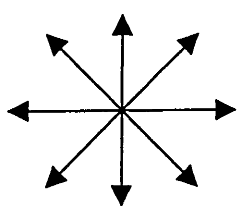
S12 **occlusion L**

position under closed lids

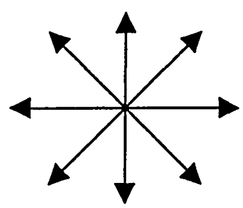
S13 **near point of convergence**

(n=3-4"; start at 18" or 2ft if a problem)

S14 **pursuit**



right



left

performance/subjective report

S15 **saccades**

visual/;H/V; near/far; record number

S16 **observe blink rate / peripheral awareness**

M3&4 trial 3

S17 Fukuda

S17 Dix-Hallpike

(latency/direction/fatiguability)

S18 VOR

H V

(H&V; passive (cancellation) "go with the movement", then "watch my nose" / hamalgyi / active for up to 60 seconds using snellen after; subjective report)

S19 COR

S20 optokinetic

subjective feeling / postural response(degrees from the upright)

S21 observe eye movements in response to head movements during normal activity

S22 observe habitual strategies

(S23 copy writing)

(S24 response to visual stimulus [holding central gaze])

(S25 follow moving target against optokinetic background)

(S26 circular walking test)

(neck exam)

Appendix 2:

Clinical summaries & secondary review narratives

Subject 1:

20 year old female, 11 weeks post injury, GCS 14, side impact RTA

CLINICAL SUMMARY

Pre-injury influencing factors

None identified*

Notable findings

- Visual acuity of the right eye significantly less than the left. *F says her right eye has always had poor vision but there is no evidence of pre injury eye tests or glasses (and she was working in a laboratory doing visually demanding work). The right pupil was noted to be sluggish on A&E examination.
- Left divergent squint on convergence testing.
- Subjective difficulty (experience of dizziness) and some observed loss of conjugate eye movements on smooth pursuit, especially at speed. Jerky quality of movement.
- No observed difficulties on saccadic movement but transient dizziness reported.
- Good accuracy and speed of response on tactile/proprioceptive and auditory testing.
- Greatly diminished VOR gain and difficulty with VOR cancellation on the left. Active attempts at fixed focus with head movement, even at moderate speed, produced rapid increase in neck muscle tone and associated noxious sensation.
- Postural drift, back ward and to the left evident in sitting and standing and increased with eye closure and sometimes associated with rotational feeling of dizziness. F is slow to perceive the positional drift at a conscious level but adopts fixation strategies using the limbs and neck muscles, which suggests that she is automatically generating an adaptive response. F reports that her 'eyes go funny' if she has to sustain a difficult position (e.g. standing) over a period of time and this will quickly be followed by headache.
- F does not always produce anticipatory postural adjustments before changing position, with resultant transitory loss of equilibrium and feeling of 'light' dizziness.
- Hand eye co-ordination is diminished.
- Gait is clearly abnormal, and moreso than would be anticipated from limb deficits alone.
- F reports distress with sudden/loud noise and residual fatigue.

Opinion

- On one level F appears to be working at a fairly high level, demonstrating accuracy and speed of response to sensory testing, including speedy discrimination abilities. However, this is not the case in terms of awareness of drift and speed of correction in the trunk. This combined with the jerky eye movements and poor performance on the finger-nose test is suggestive of local or connection problems involving the cerebellum.
- F's visual difficulties are of particular concern given her student status and a specialist assessment would be of value in establishing a proactive management plan. Exercises to improve VOR gain may be hindered by her focusing and accommodative problems and a collaborative programme involving physiotherapy and orthoptics may be indicated.
- It will certainly be necessary to ensure that she is capable of extended periods of visual attention before contemplating return to study.

Recommendations

- An ophthalmic/orthoptic opinion (Mr John Burke, RHH) and discussion of collaborative management plan.
- Work in physiotherapy to include balance re-training with eyes closed.
- Work in physiotherapy to stress increased speed of movement and forward weight transference.
- Progression to active hand/eye and eye/head co-ordination in open 3D space and involving pen and paper tasks and specific VOR training regime (after visual assessment).
- If cerebellum/cerebellar connections are involved, this may slow the process of VOR re-education and therefore future plans should be tailored accordingly

SECONDARY REVIEW

Injury history

Initially assessed as a minor injury and only admitted for observation because of a sluggish right pupillary response and the history of high energy injury. Complained only of neck pain in A&E, loss of memory for events for several months pre-injury identified after admission to rehabilitation unit.

Synthesis of presenting problems

Minor left upper-limb ataxia. Postural asymmetry and postural drift (back, left greater than right), even with eyes open. Slow recognition of this drift, corrective actions only at the very edges of limits of stability. Odd walking pattern with posterior postural inclination and high stepping/creeping gait. Describes walking as stressful and exhausting. Visual problems affecting acuity (R only), eye movements (jerky) and vergence. Light dizziness reported on visual testing. Poor VOR and VORc (left eye wandering) with immediate increase in neck muscle tone (co-contraction) and reports of light dizziness (distressed, increased blink rate on observation). Sudden/loud noise reported as distressing and producing immediate feeling of fatigue; pallor/increase tone reaction confirmed by health staff. Good accuracy and speed, peripheral sensation.

Issues raised by presenting problems

The range of impairments and the functional impact following apparently minor injury - possible influence of side rather than head on impact. Postural orientation within the environment and the nature of postural drift – orientation with respect to gravity, possible influence of vision. 'Reflex' increase in neck muscle tone associated with reports of noxious sensation. The need for corroboration of reported pre injury status, especially in light of retrograde amnesia. Visually provoked dizziness.

Subject 2:

29 year old female, 32 weeks post injury, GCS 3, fall at home

Clinical summary

Pre-injury influencing factors

Glasses for reading/watching TV as adult. Skin tightness around shoulders from previous burns. Reported to have previously misused drugs. Epilepsy.

Notable findings

- Expressed fear of falling – while walking and with eyes closed or occluded vision.
- Anticlockwise spinning – with eyes closed and associated with headache.
- Self-perception of A-P and S/S sway – often not visible to the observer, seen to build during testing.
- Pulling sensation left cervico/thoracic area.
- Daily a.m. headache from which dizziness can follow
- Decreased visual acuity for letters with current glasses on, left worse than right
- Consistent right rotated head position and consistent left deviation of resting eye position (to achieve visual straight ahead)
- Diminished VOR gain
- Nystagmus on right Dix-Hallpike manoeuvre, with fatigability.
- Suspected visual peripheral awareness deficit
- Subtle visual pursuit/gaze deficits to the right and in elevation

Opinion

- T certainly has a significant balance deficit at the level of integration
- The subtle pursuit deficits could simply be secondary to the habitual rotated head position.
- The head position may be dictated by visual acuity problems, especially since left vision appear less than right.
- Headache is consistent with referral from upper cervical spine
- There is a suggestion of peripheral vestibular pathology – rotational dizziness is more commonly reported with vestibular system problems rather than neck related dizziness and there was one episode of latent nystagmus on right Dix-Hallpike

Recommended action

- Have prescription for current glasses checked out and corrected if applicable/possible.
- Physiotherapy treatment to mobilise cervico-thoracic spine, incorporating active exercise, especially retraction rotation
- Subsequent work on increasing VOR gain
- In the interim work on desensitizing the response to movements with increasing velocity (other than head on body movements until increased pain-free range is achieved).
- If rotational dizziness is still a problem ask for a further opinion / investigation from Dr Tungland, Audiological Physician (RHH).

SECONDARY REVIEW

Injury history

Fractured occiput, right hemispheric contusions and small extra-dural haematoma. Full mechanism of fall not known.

Synthesis of presenting problems

Obvious functional balance deficit, fearful when walking with associated avoidance behaviours. Perception of self motion at rest with eyes closed in sitting (A-P sway) when not visible to assessor. Build up of A-P sway seen in standing and unable to maintain eye closure. Possibly still in PTA at time of assessment (certainly having problems with memory for recent events), so recall and description of symptoms need cautious interpretation. However, there was observable visual/attention impairments and signs of vestibular dysfunction, complicated by abnormal neck posture and movement (reinforced by soft tissue limitations as a result of childhood burns). Peripheral sensory impairments, including multi-joint proprioception and speed of response to stimuli.

Issues raised by presenting problems

Weighting self-report and behavioural observations in the presence of cognitive dysfunction, exploration of avoidance behaviours during assessment. Inter-related signs and symptoms and pragmatic prioritisation in planning interventions. Predicting the functional impact of poor performance on sensory testing with a cognitive load. Illusory movement and 'corrective' behaviours.

Subject 3:

23 year old male, 14 weeks post injury, GCS 3, RTA

CLINICAL SUMMARY

Pre-injury influencing factors

G reported a left eye injury at age 4. No further details were available. G had a pre-injury history of drug misuse and a prior associated left radial nerve palsy. G has epilepsy.

Notable findings

- Visual signs & symptoms
  - Fluctuating levels of double vision
  - Occasional left gaze nystagmus
  - Gaze instability in the primary position with a subjective feeling of the eyes pulling together when forced to hold central gaze
  - Convergence difficulties
  - Saccadic movement stopping short of full on left, slight left ptosis, evidence of diminished peripheral awareness on the left
  - Difficulty with VOR cancellation to the left
  - Brief nystagmus on left Dix-Hallpike manoeuvre (but no report of dizziness)
  - ? acuity problems – tested twice and eyes varied - ? a recording error /related to visual degradation
- Integrative deficits
  - Loss of postural stability, increasing with eye closure and greater in standing
  - Slight rotational dizziness on eye closure
  - Diminished VOR gain and tonal neck muscle response + report of visual degradation
  - Some reports of nausea associated with a tight feeling in the throat (G observed to repeatedly swallow during/after eye movement testing, when he reported brief dizziness).
- Minor inaccuracies on tactile and proprioceptive testing on the left side
- Residual ROM limitations and excessive upper cervical spine extension. Apparent difficulty reorienting head to the midline

Opinion

Although G's left-side symptoms in themselves are all relatively minor, together they would seem to tie together and provide a rationale for his functional difficulty of negotiating obstacles in the left visual space. It would be useful to look again at his visual acuity to clarity the situation. I think it would be reasonable to attempt to 'train-up' individual components in an effort to improve the speed at which he can deal with the visual information and by freeing up his neck movements improve the proprioceptive feedback.

Suggested Action

- Exercise to improve upper cervical spine alignment/movement +/_ other intervention as appropriate
- Eye convergence exercises, eye movements, eye/head and head/body combinations, including VOR training
- Re-test visual acuity
- Overt, whole body schema awareness, obstacle negotiation, and at speed.

SECONDARY REVIEW

Injury history

Fractured occiput, bilateral frontal contusions. Tracheostomy after 6 days.

Synthesis of presenting problems

Primary visual signs (associated with CNS dysfunction) and visual degradation associated with vestibular dysfunction. Provoked sensory disorientation (with increased neck tone) and some autonomic response (reported nausea, observed increased swallowing rate when dizziness reported). Subtle left-sided sensory/attention issues, some loss of postural tone in left leg on sustained stance. Problems with midline judgement. Minor upper-limb ataxia (bilateral).

Issues raised by presenting problems

Functional impact of cumulative 'minor' impairments. 'Reflex' increase in neck muscle tone associated with reports of noxious sensation. Influence of vision on neck posture. Autonomic symptoms.

Subject 4:

28 year old male, 7 weeks post injury, GCS 5, motorcycle RTA

Clinical Summary

Pre-injury influencing factors

None identified

Cautions in the interpretation of findings

There were several inconsistencies between reported symptoms and objective findings/observed behaviours

- Visual difficulties reported as intermittent with double vision being denied at the same time and closing one eye to achieve functional tasks requiring hand/eye co-ordination
- Functional impact of double vision denied while still reporting only able to read with one eye at a time
- Failure to report falls
- Dizziness reported as debilitating – but not provoked/acknowledged during assessment (W did 'pale' at the same time as a few beats of nystagmus were observed during Dix-Hallpike test– he was keen to return to the upright position but at the same time denied any discomfort.

Notable findings

Reported problems

- Intermittent visual difficulties
- Episodes of rotational dizziness (possibly associated with headaches)
- Neck stiffness

Observations

- Abnormal resting position of left eye, left partial ptosis, obvious positional adjustments in both eyes on occlusion testing, right eye divergence on convergence testing.
- Few beats nystagmus on left Dix-Hallpike manoeuvre, observable 'wobble' in left eye on VOR testing
- Suggestion of right auditory extinction
- Postural sway in standing increased with eye closure – W denied dizziness but could not maintain the eyes closed condition for more than 30 seconds.

- Inability to sustain head movement to complete VOR testing
- Abnormal response to optokinetic testing

Opinion

- W clearly has residual primary visual difficulties affecting his oculomotor system. I understand that a referral for full ophthamological/orthoptic assessment has already been made. While rotational-type dizziness is thought to reflect vestibular system dysfunction there is no hard evidence of peripheral dysfunction on my limited assessment. This may be because compensation has already taken place, the assessment was not vigorous enough (somewhat limited by W's bony injuries) or it may be an indication of central vestibular dysfunction. It could also be that the suggestion that rotational dizziness is linked (only) to vestibular dysfunction is a flawed assertion and that his experiences of spinning sensations emanate from other sources such as his dysfunctional vision, the factors that produce his headache or epileptiform activity. The fact that W's self-report may be misleading also needs to be taken into account.

Suggested Action

- Specific intervention will be dependent on the results of further systematic enquiry. This may not be possible in full until there is some resolution in W's apparent cognitive clouding.

SECONDARY REVIEW

Injury history

Fractured base of skull with CSF rhinorrhea. Fractured left maxilla, left femur, right clavicle and right second rib. Ventilated for 10 days. Femur surgically repaired and full weight-bearing allowed.

Synthesis of presenting problems

Significant cognitive clouding leading to incongruous self-report of symptoms being experienced. Clear visual problems affecting the occulomotor system. Possible peripheral vestibular involvement. Certainly, postural instability, worse on eye closure and apparently distressing, although actively denied. Unable to complete VOR testing, apparently experiencing noxious sensation but denying same. Known history of falls denied during assessment.

Issues raised by presenting problems

Weighting self-report and behavioural observations in the presence of cognitive dysfunction, exploring avoidance behaviours during assessment. Impact of co-existing impairments, including predictable recovery patterns, on the assessment process – considerations for definitive assessment timings.

Subject 5:

29 year old male, 39 weeks post injury, GCS 11, pedestrian RTA

CLINICAL SUMMARY

Pre-injury influencing factors

None identified

Important injury factors

Possible direct trauma to the right ear, ?perforation – history of hyperacusis and rotational dizziness – both now reported as resolved.

Notable findings

- Abnormal head on body alignment, apparent in various conditions including supine, i.e. when the position is not necessarily dictated by the need to achieve single vision.
- Difficulty orientating to the midline and a tendency to deviate to the right during ambulation
- Skewed resting eye position, double vision in the primary position, single vision achieve by tilting and rotating the head.
- Double vision in primary position reported as temporarily resolved during assessment, following convergence testing.
- Requires prescription glasses for reading (nil pre-injury).
- <u>No</u> significant postural drift in unsupported sitting and standing but uses upper limb to support when possible and adopts inappropriately narrow base for walking.
- Minor tactile discriminatory deficit/multi-joint proprioception in left leg consistent with local damage associated with tib/fib fracture.
- Suggestion of right inattention – maybe influenced by eye resting position but always names/acknowledges left side stimulus first in response to bilateral presentations
- Neck movement abnormal in quality and limited in range – complains of resting stiffness and pain on movement (head on body). However, body on head movements (i.e. when head held stable and body rotated by moving the chair seat) revealed relatively free and painless range of movement suggesting that neck stiffness may be secondary to maintaining acceptable vision

Opinion

- The primary dizziness associated with the ear trauma appears to have resolved, but functional imbalance is still apparent and this appears to have two ?inter-related components. The most obvious is that of vision, which dictates the head position during function – and may or may not influence the second issue of poor midline orientation and positional deviation during movement. I understand that T did have a visual assessment early on and had prism glasses for a period. Further opinion should be sought to ascertain whether prescription and/or exercise may assist the resolution of double vision without recourse to head tilt.

Suggested Action

- Future intervention will be dependent upon whether it is functionally appropriate to correct the habitual head position or whether, if the position is required for T's visual safety, a regime would then need to be designed to limit the secondary musculo-skeletal effects of the abnormal posture. Depending on the visual opinion, further assessment of T's body/ environment relationship may be indicated.

SECONDARY REVIEW

Injury history

Fractured frontal bone, decreased density bilateral frontal lobes, swelling both temporal bones. Fractured left ribs 2-9 with haemopneumothorax. Compound fracture left tibia and fibula, conservatively treated. Complicated recovery including readmission to ITU. Possible direct trauma to right ear, ?perforated drum – history of hyperacusis and rotational dizziness.

Synthesis of presenting problems

Functional imbalance, narrow base with centralised left leg and veers to the right when walking. Abnormal head on body alignment in upright and supine and difficulty orienting to the midline (rotates to left, right sided/forward tilt and right shoulder elevation). Further accentuation of this posture in standing with eyes closed, right shoulder drifts back. Double vision, resolved by head tilting and rotating, also for a time after convergence testing. Range and quality of cervical movement poor, movement freer when body moved on head (in office chair) but also associated with loss of single vision. Significant right upper limb ataxia.

Issues raised by presenting problems

Genesis of head position – only related to achieving single vision? Clear history of ear/ bilateral temporal bone trauma and a period of rotational dizziness - sensory symptoms resolved but functional imbalance continuing. Limb ataxia.

Subject 6:

41 year old female, 14 weeks post injury, GCS 3, passenger RTA

CLINICAL SUMMARY

Pre-injury influencing factors

E has worn glasses since the age of 12 or 13. There is some suggestion that she may have had 'a lazy eye' and that the vision in her left eye may have been poor for sometime before she obtained her glasses. This may have an impact on the ways she uses her eyes now.

Notable findings

- Eyes and vision
  - Partial ptosis and abnormal resting position of the right eye
  - Double vision, probably present constantly but only recognised during particular functional tasks
  - Minimal excursion of smooth pursuit to the left in both eyes and limited vertically in the right eye, especially downward gaze – no evidence of the eyes working together, no convergence
  - Saccadic movements performed only within the range available on smooth pursuit, i.e. not past the midline towards the left or below the horizontal in the right eye
  - Same problem evident on VOR testing, e.g. apparently unable to cancel the VOR on head rotation to the left, unable to use the VOR on right head rotation, i.e. the eyes don't make it to the left of midline at all
  - Visual acuity:
    - *with glasses* left 6/6 with one error - ?acuity, ?scanning
right 9/6
    - *without* left 24/6
right 12/6
    - frequent scanning errors in the left hemi-field but no obvious field deficit on confrontation testing and no extinction.
- Tactile & proprioception
  - Good speed of response to single stimuli

- Poor discrimination between single and double stimuli applied to same limb or between stimuli of different natures. Apparently more difficulty on the left, no extinction
- Greatly diminished speed of response when trying to mirror multi-joint movements, i.e. when interpretation and/or application of sensory information is required, rather than a simple response
- Resistance to the maintenance of static head position when body rotated to the left (in office chair), i.e. evidence of soft tissue adaptation restricting free rotation between head and body and indicating the dominance of the left rotation of head on body as an established compensation for lack of eye movement (or in response to an abnormal perception of midline)

- Vestibular & integrative function
  - No complaints of dizziness and none provoked during the assessment, no clear evidence of peripheral vestibular dysfunction (negative Dix-Hallpike), abnormal response to Halmagyi head thrust but without corrective saccades (my interpretation is that this probably reflects the primary visual/attention problem rather than a unilateral vestibular deficit)
  - However, also rotation to the left and major forward drift on Fukuda Stepping Test
  - Leftward drift on walking with eyes closed
  - Rightward drift on walking with eyes opened
  - Maintenance of straight line when given specific straight-ahead target.

Opinion

The visual deficits are the current dominant factor in E's balance disorder. There are several components to these deficits:

- Cranial nerve induced weakness
- Primary eye movement generation deficit
- Poor acuity with possible pre-injury convergence problems.

Functionally with vision removed E's orientation within the environment is biased to the left. However she appears to be using vision to compensate <u>but</u> her estimation of straight ahead is inaccurate leading to a bias to the right. She can walk in a straight line with eyes open if given an appropriate target.

Suggested Action

- Check glasses prescription to optimise drive to use both eyes together.
- Investigate with other team members the factors around attention to the left visual hemi-space and the ability to improve tracking throughout that space.
- Advise re management strategies for safety in mobility at night/when vision is compromised

SECONDARY REVIEW

Injury history

Right temporal subarachnoid bleed with intraventricular blood and cerebral oedema. Fracture right proximal ulna, left hamate, trapezium and ring finger. Childhood history of 'lazy eye' with late prescription of glasses (age 12).

Synthesis of presenting problems

No complaints or history of dizziness. Limited visual excursion to the left with both eyes and downward with the right eye (smooth pursuit, saccades, on VOR and VORc). Habitual head position rotated to the left, able to rotate to right on request but strong resistance to maintenance of static head position while body rotated to the left in office chair. Lack of conjugate vision (probable pre-injury artefact). Estimation of midline strongly to the right of straight ahead with eyes opened and strongly to the left with eyes closed. Able to proceed in a straight line if given accurate target to aim for. Significantly abnormal gait; stiff body, head and limbs except right arm swing, little forward weight transference. Minor upper limb ataxia, testing possibly influenced by limitations of vision. Much reduced speed of response on sensory testing requiring discrimination/ co-ordination, moreso on the left.

Issues raised by presenting problems

Estimation of straight ahead, co-existing preponderance to the right with eyes open and left with eyes closed. Cumulative functional effects of multiple impairments, influence of speed of processing on functional balance. Absence of anticipatory postural adjustments.

Subject 7:

48 year old male, 22 weeks post injury, GCS 4, probable fall/possible assault

CLINICAL SUMMARY

Pre-injury influencing factors

- John is reported to have had periods of high alcohol intake prior to this injury. While this has not been objectively quantified and no previous sensory or physical effects have been documented, the potential for excess alcohol intake to influence balance performance remains a possibility.
- There is transient reference in the medical notes to a previous Parietal fracture but I have not been able to either substantiate or refute this report. John, himself, did acknowledge previous fall(s) after having one too many but it is not at all clear to me if his reports of past events are always consistent with reality (as a result of residual cognitive dysfunction and particularly in view of his difficulty maintaining topic during conversation).

Notable findings

Vision

- John has recently obtained reading glasses for the first time in his life. I understand he is also to have Varifocals. It may be that he had a need for glasses prior to this injury as he does recall having difficulty seeing the dartboard (and reports this as being unrelated to his alcohol intake).
- On the day of examination John <u>denied</u> having any double vision. Resting eye position was unremarkable. However, observation revealed a number of oculomotor abnormalities that would be associated with the perception of two images in the presence of binocular vision. As he does not report double vision it may be that there is some form of suppression of one of the images.
- On field confrontation John was initially slow to recognise stimuli from the *left* - on tests of smooth pursuit, however, the *right* eye did not initially follow and there was limitation of horizontal excursion to *right and left*. Nystagmus was noted on upward and outward gaze in the *left* eye. Excursion of saccadic movements was also reduced towards the *left* field and John had some difficulty not using compensatory head rotation. Vertical saccades were produced with the left eye deviated toward the nose. On testing visual acuity using a Snellen chart John consistently failed to read the top

line raising the question of an altitudinal neglect. Left eye occlusion produced small positional adjustments in both eyes, right occlusion a small adjustment in the left eye only.

Posture and stability

- In contrast to John's limited awareness of his visual deficits, he reported feeling at risk of falling during basic, routine physical activities such as rising to standing and climbing and descending stairs. This level of awareness has obviously been learned over time as he had previously tried to negotiate stairs in his wheelchair earlier in the recovery process.
- In sitting, basic alignment was displaced behind and to the left of normal with further drift during attempts to maintain the sitting position. Although a steady drift was observable it was not associated with observable sway, even in the eyes closed condition. Some stability was achieved by tucking the feet back and gripping the seat between thighs and calves. Neck range of movement was slightly reduced to the *left* but with no complaints of pain or dizziness.
- John actively prepared for standing on each observed occasion by widening his based and using upper limb propulsion. He was able to reduce the base when in standing on request, and maintain. Initially with the wide base there was an observable antero-posterior sway. In the eyes closed condition the sway was more apparent and perceived by John. Although he tried on a number of occasions, he could not sustain eye closure. In all standing conditions there was a drift into lower limb joint flexion, i.e. he had difficulty maintaining adequate activity in his antigravity muscles.

Other findings

- John was unable to perform the Fukuda stepping test, immediately falling backwards. Dix-Hallpike manoeuvre was negative to both sides. There was immediate reactive/protective increase in neck muscle tone on passive VOR testing to an extent that the Halmagyi head thrust was not attempted. Right eye movement was very limited and left eye nystagmus was induced in the horizontal plane while there was drift of the right eye towards the nose in the vertical. Movement of body on head to the right (requiring the allowance of head movement to the left) was strongly resisted by increase muscle tone in the neck. Optokinetic response was absent in the right eye to the right and in the vertical plane.

- John's initial performance on tests of tactile and proprioceptive sensation was poor but improved each time he "tuned in". His responses remained slow, however and he had great difficulty discerning two stimuli applied to any single limb. He was not fully accurate when mirroring of limb positions that required multijoint adjustments.

Opinion

- John's current cognitive-communicative difficulties add confusion to the immediate assessment process and so our ability to estimate the impact of aspects of his pre-injury lifestyle on his current physical presentation. However, there does appear to be three or four sensorimotor issues contributing to his physical safety at present, namely:
  - oculomotor deficits
  - additional left-sided and ?altitudinal attention deficits
  - problems recruiting/maintaining adequate antigravity muscular activity
  - diminished speed of response, difficulties of interpretation and diminished speed and grading of action
- It seems feasible that his visual/attentional limitations contribute to/reinforce his habitual left/backward drift and that this is also a function of his difficulty in sustaining extensor activity. Changes in weight-bearing abilities in standing as a result of the right fractured tibia and fibula may also contribute to the pattern of weight distribution in standing (see hypothesis below).

Recommended action

- I do not think that John is a good candidate for Varifocals in terms of his safe mobility. Concerning the oculomotor problems it would be useful to gain the combined advice of an ophthalmologist and an orthoptist with experience of TBI patients regarding the potential to help John via exercise or compensatory means.
- Concerning the inattention issues I believe it would be worthwhile exploring John's ability overcome the detrimental physical behaviours using strategies known to reduce neglect and practice of segmental rotational movements.
- Other compensatory behaviours (e.g. use of arms as weight-bearing structures and as a primary balance strategy) can then be tackled via substitution and practice of lower limb and trunk strategies.

John Kerrigan: Hypothesis

1. left inattention, diminished saccadic eye movement towards left
2. increased use of head orientation to the left to compensate for (1)
3. resistance to head on body movement to the left → en bloc head/trunk rotation to the left
4. limited extensor activity allowing uncontrolled backward drift (predominately on the left side because of (2) & (3)
5. decreased weight-bearing on right in standing / increased weight-bearing left in standing due to right lower limb fracture, reinforcing the pattern developed by (1) to (4)

- John is aware of 'falling 'backwards
- The difference in the behavioural impact between the limited right eye movement and the problems on the left side seem to be that compensatory right head rotation on the body is freely available to overcome what is a *purely motor action* problem whereas the problem on the left is more complex in terms of attention/eye movement generation.

SECONDARY REVIEW

Injury history

Right temporal fracture, possible right parietal fracture. Bilateral tempero-frontal contusions. Fractured right humerus and tibia (nailed).

Synthesis of presenting problems

Possible influence of probable pre-injury excess alcohol intake. Significant cognitive-communicative dysfunction at time of assessment. No complaints or history of dizziness. Possible left sided and altitudinal visual inattention/neglect and a range of occulomotor impairments affecting both eyes, however, no complaints of visual difficulties. Strong feeling of postural instability during routine physical tasks. Postero-lateral trunk inclination (left) at rest in sitting, increasing drift with eye closure, but with no oscillation. Feeling of stability improved by fixing/gripping with lower limbs. Preferred wide base in standing. A-P sway observable, increased on eye closure and perceived (by subject) as too risky to maintain. Loss of extensor activity in the lower limbs whether eyes open or closed, apparently not perceived and not corrected. Fell backwards on single attempt to try the Fukuda stepping test. Negative Dix-Hallpike but reactive tonal increase in neck muscles and left eye nystagmus immediately on passive VOR testing. Resistance to right body rotation (left head rotation) in office chair. Improving performance over time on peripheral sensory testing but slow on discriminatory/co-ordinating tasks. Significant upper limb ataxia.

Issues raised by presenting problems

Postural orientation away from the line of gravity. Monitoring of postural drift in trunk and limbs, maintenance of extensor postural tone. Central vestibular signs without reports of dizziness.

Subject 8:

16 year old male, 58 weeks post injury, GCS 8, assault.

CLINICAL SUMMARY

Pre-injury influencing factors

M reports that he has had only partial sight (light/dark at distance, partial shapes close-up) in his right eye from birth. He also suggests that he has had regular reviews at the eye clinic and that surgery for strabismus was under consideration before this injury. Without access to records of his pre-injury status it is difficult to be sure about the additional impact of his TBI on his oculomotor system.

Notable findings

- It is important to record that M reports that several of his symptoms have decreased in frequency and intensity following recent PT intervention. This applies in particular to his experience of dizziness and the frequency of his headaches. This should be balanced with the knowledge that M has a history of under-reporting his difficulties when compared, for example, to the reports of his parents.

Resting head position and oculomotor signs

- Habitually adopts an abnormal tipped-back and slightly right side-flexed head position during all static and dynamic postures and had difficulty maintaining visual fixation straight ahead when asked to adopted a normal primary position. Central eye position on the right was only momentarily achieved and could not be sustained (resultant convergent drift). Reported discomfort while maintaining the left eye looking straight ahead. Had difficulty in reversing the associated over extension of the upper cervical spine during forward flexion and side flexion of the neck suggesting that this is a well-established habit which may pre-date the TBI. The head position also appeared to impact on M's ability to increase walking speed having, along with some backward inclination of the upper trunk, an observable braking effect even when stepping action became more rapid.
- A number of pathological signs were observed relating to right eye movement and absent binocular activity which are presumed to predate the TBI. However, it was also noted that two saccades were repeatedly required to locate a pen held to left of central gaze and that there was also an infrequent optokinetic response to the left and

upward in the vertical plane. Vertical VOR was also problematic, especially with head flexion.

Dizziness and headache

- Experiences headaches, felt at the back of the eyes, at times of concentration and when tired. Reports frequently feeling tired and knows that he is perceived by family members and his ex-employers as lazy and lacking in motivation. Headaches are reported as less of a problem since starting work on increasing (horizontal) VOR gain. Dizziness is reported to occur when looking down from heights and on returning to the upright after forward flexion. Also said to be less of a problem since recent intervention. "Dizziness" is described as: everything going darker, feeling wobbly in the head and then perceiving the environment as spinning in an anticlockwise direction. Recovery is reported as starting within seconds and being complete within one minute (though ongoing fatigue is often a consequence). Loss of balance may also occur and when it does is always associated with falling to the left.

Signs of vestibular imbalance

- There were both subtle and significant preponderances to the left observed during the assessment. There was an initial large deviation of weight to the left during standing from sitting with immediate correction and no suggestion of impending loss of balance. Left-sided drift was just perceivable to the experienced eye during gait, again with evidence of immediate and ongoing correction. The Fukuda stepping test was positive with significant forward drift and 90°rotation to the left. No nystagmus was observed during the Dix-hallpike to the left but subjective feeling of "oddness" was reported on return to the upright and increased frequency of blinking was also noted. Similarly, although reporting no problems, M maintained left side lying in a stiff and awkward fashion, appearing altogether more relaxed on the right..

Other findings

- Except for a small area distal to the right knee, appreciation of tactile and proprioceptive stimuli was both accurate and prompt. No discernible sway in sitting even with eyes closed. Small antero-posterior sway in standing with eyes closed. M was aware, in control and able to accurately describe the muscles active in maintaining his balance.

Opinion

- The assessment findings suggest left vestibular hypofunction. Recent changes in symptoms consistent with intervention driving central decompensation, reducing the provocation of dizziness. Given M's positive response to intervention targeting the horizontal plane it would be reasonable to attempt a similar process with the vertical. However, even if episodes of dizziness are minimised the assumed underlying vestibular hypo function remains. M should therefore be fully informed of the risks associated with his faulty balance and advised to take appropriate precautions. He has an accurate and speedy peripheral sensory system which helps compensate for the vestibular imbalance.
- The question of M's pre-injury visual status and any additional problems associated with this injury should be clarified. The impact on his vestibular compensation of any surgery should be actively considered, including the possibility that a change in visual status may result in a recurrence of dizziness requiring further intervention to recalibrate the system.

SECONDARY REVIEW

Injury history

Traumatic subarachnoid haemorrhage, left parietal contusions. On ICU for 24 hours.

Synthesis of presenting problems

Low vision in right eye since birth with probable impact on current assessment findings. However, pathological signs also observed relating to left eye, maintaining static gaze, extra saccades, intermittent absence of normal optokinetic response. Head held in over extension and some right side flexion, possibly influenced from pre-injury eyesight *but* significant back and slightly to the right inclination of trunk during gait, even when trying to increase speed. Reports falling to the left and could be observed actively correcting a tendency to deviate to the left during several parts of the assessment. Clinical testing suggested left vestibular hypofunction. Episodes of dizziness and frequency of headaches reported as reducing since recently instigated physiotherapy programme looking at provoking behaviours and horizontal VOR. Good peripheral sensation, including speedy response.

Issues raised by presenting problems

Postural orientation away from the line of gravity. Differentiating between primary and secondary causes of pathological observations. The value of intact sensory systems in achieving successful compensations.

Subject 9:

34 year old male, 105 weeks post injury, GCS 14, motorcycle RTA

CLINICAL SUMMARY

Pre-injury influencing factors

T has two previous documented TBI's in 1986 and 1995 which may have potentiated the negative effects of this current injury. The 1995 injury was associated with a symptomatic whiplash injury producing neck pain, stiffness and recurrent headaches. T reports that while he still had neck stiffness from time to time prior to this injury, the headaches had settled after about one year post injury. He has a congenital fusion of two cervical vertebrae.

Notable findings

- A dominant feature in T's daily life is the pain and functional limitations resultant from a troublesome left ankle fracture. At present T bears weight on the outer border of his foot and uses a TENS machine to help control pain. Secondary effects of his awkward gait and the heavy use of walking aids have also induced neck and back pain.

Vision

- Reported sensitivity to light, more so when tired and which can culminate in headache. Initial difficulty focusing now much reduced but present when tired. Helped by rest and sleep. Several 'soft' signs involving the right eye observed: slight slowness to acknowledge stimuli approaching the right visual field, some minor adjustments of eye position on right occlusion, suggestion of a slight divergence on convergence testing. Difficulty following a moving target (pen) at moderate speed with resultant visual blurring and transient loss of focus. Ability to read an additional line on the Snellen chart (9/6) with both eyes than could with either eye on its own. No problems observed with saccadic movements. Difficulty with optokinetic testing, with inability to focus/follow in either horizontal or vertical planes.

Dizziness and loss of balance

- Frequent episodes of stumbling and loss of balance described. Most recent fall reported as within the last two months. Unable to identify any particular activity involved but associates increased loss of balance with fatigue. Described a direct relationship between fatigue and dizziness. Dizziness described as similar to being drunk with internal feelings of motion and external perception of a spinning room. These episodes are managed by taking Buccastem (a buccal preparation of and antiemetic).

- Difficulty in maintaining static sitting position observed with tendency to drift back and slightly to the left – but corrected without external prompting. Easily observed antero-posterior sway standing with eyes closed, again self-corrected. Uses stick in left hand producing lots of co-contraction throughout. Unable to perform Fukuda stepping test. Dix-Hallpike, feeling of head filling sensation on right side with observable change in pallor (not on left).

Other findings/issues

- Slowness of response to tactile stimuli, poor discrimination of dual stimuli to same limb.
- Generalised reduction in speed of action and easily fatigued (required rest during assessment – enforced by assessor).
- Dominance of foot posture / pain – impacting on all activities.
- Medication used to treat symptoms of dizziness and nausea prevents re-calibration and while it offers immediate relief from symptoms it may also prolong the experience of dizziness.
- Established coping mechanisms may now be limiting progress (foot and medication)

Opinion

- There is an overall issue of speed and capacity of sensory information processing with T and this is exacerbated by subtle oculomotor difficulties and vestibular dysfunction. It is not possible to say from this clinical assessment whether there is a peripheral vestibular component or if T's symptoms result solely from central processing deficits. Either way a graded programme of desensitisation and intervention to drive the recalibration process would be worthwhile – but this cannot be attempted while he is taking Buccastem.
- T would benefit from a full oculomotor review by a specialist orthoptist, including advice on potentially suitable specialised glasses prescription. Any eye exercises could be incorporated into the vestibular programme.

- Before any of this is undertaken there are two key sensitive issues that need to be discussed with T at a suitable time. Firstly, there is a need to explore, with orthopaedic and other colleagues, all the possibilities of achieving a biomechanically improved gait (and therefore to diminish the number of negative secondary effects). Secondly, the negative issues surrounding his medication should be discussed with him and the appropriate medical practitioners so that T may make an informed decision about how he wishes to proceed.

SECONDARY REVIEW

Injury history

Possibly unconscious at the site of the accident. PTA estimated at between 3 to 7 days. Fractured left talus, surgically repaired but continuing to cause debilitating pain and the use of walking aids. Two previous minor TBI's, two and eleven years prior. The most recent of these two injuries was also associated with a significant whiplash injury and a period of headaches which was reported as being settled for a year before the third injury.

Synthesis of presenting problems

Presentation dominated by reports and consequences of ankle pain. Pain, dizziness and fatigue appear to be dominating the subject's life, with associated low mood. Right visual/vestibular signs and symptoms. Some limitation of cervical range and generalised right-side pain. Reports frequent episodes of dizziness and is dependent on anti-emetic medication. Postural instability (A-P sway), with drift on eye closure predominantly back and to the left, intermittently corrected. Unable to assess free gait as using stick and weight bearing only on the outer border of the left foot. Hesitant, and has difficulty with discrimination on sensory testing, especially on the right.

Issues raised by presenting problems

Speed and capacity of information processing, the impact of pain, medication and low mood. Cumulative effects of repeated minor injuries. Medication and inhibition of compensatory processes.

Subject 10:

27 year old female, 224 weeks post injury, GCS 15, RTA

CLINICAL SUMMARY

Pre-injury influencing factors

L has a history of infrequent migraine.

Notable findings

- L has two prescribed medicines to inhibit nausea. She had not taken them in the days previous to this assessment.

Vision

- L complained of light sensitivity, some perceptual disturbance (pictures tilted on walls, depth perception), episodes of blurred vision and difficulty dealing with escalators. She also described double vision, which only occurs at the time of a migraine. She has recently sought the help of a friend who is an optometrist and anticipates that he may prescribe some sort of tinted lenses, ?for the light sensitivity.
- On examination, visual acuity, fields and occlusion testing revealed no abnormality. She was unable to sustain convergence, with both eyes diverging. L had a good range of smooth pursuit and saccadic movements. However, she reported feeling nauseous when trying to follow a brisk moving target. VOR gain was reduced, vertical motion perceived as more difficult. There was a suggestion that the excursion of the right eye was less on vertical testing. Optokinetic response was reduced in the right eye with right moving, upward and downward stimuli.

Neck and peripheral sensation

- L reported frequent neck ache since the time of her injury and felt that this often progressed to headache. She had not made any links with this and her increased frequency of migraine attacks. The neck ache and associated headaches had been helped by "manipulation". L still sees a musculoskeletal physiotherapist once per month.
- Resting head position was slightly rotated to the left and with a degree of upper cervical extension. Head movements were generally protective in quality and more so to the right. There was some right-sided pain on extension and the chin-up position noted at rest was increased following this movement.

- Speed of response and accuracy on simple tactile stimulation was unremarkable but L slowed down and was inaccurate on two-point discrimination. She was equally slow on tests of joint position and movement. There was a suggestion that the lower limbs and the left leg in particular were more affected.

Balance and movement

- L described frequent stumbling and some falls. She fell as recent as the week prior to the assessment. She reported often feeling unsteady, having a sensation of the environment rocking around her and experiencing associated nausea. She also suffers from periods (days) of illusory motion after sea crossings.
- Sitting position was unremarkable except for a slightly wide base. However, L was anxious in the eye-closed condition and was not able to sustain beyond 10-15 secs. An antero-posterior sway was observable in quiet standing and the period of sustainable eye closure was less even than sitting. The Fukuda Stepping test was therefore not possible with L describing a fear of falling backward and to the right. Dix-Hallpike was clear to the left and although no nystagmus was seen or actual dizziness described, L found the right test position noxious and nausea inducing. She experienced right side lying in a similar way.
- Finger/nose tests were performed slowly, especially on the right and there was widening of arm position and some right drift on past pointing. L's gait was narrow-based and stiff in quality. She did not look ahead. At speeds below her choice she described physical and concentrational difficulties. Faster speeds were perceived as easier but she deviated to the left of midline.

Other observations

- L also reports back and right knee pain, diminished sense of smell and taste and some difficulties with hearing; less acute but sometimes hyperacusis. There was occasional extinction of left clicks on simultaneous presentation.

Opinion

- L's subjective report and the objective assessment reveal a number of subtle right-sided symptoms. There also appears to be reduced speed of processing and the overall characteristics of movement are suggestive of adaptation to diminished co-ordination/control. Although the vestibular-visual link system is obviously affected her symptoms are not classically 'vestibular'. In my opinion the combined picture is suggestive of either otolith or combined otolith/cervical dysfunction. Functionally there is evidence of dysfunction in the spino-cerebellar system.

- L is, by her own report, easily made nauseous. This would appear to be a well-established autonomic response, potentiated by the repetitive experience. She has had to use medication to quell sickness and although this has allowed her to manage symptoms the central sedative effect will have inhibited recalibration.
- I would recommend a graded programme of visual/vestibular work combined with continued spinal mobilisation and increasing demands on speed of response and action. Such an active programme would need to take place *after* withdrawal from inhibitory medication. L would need to be given management advice to achieve successful withdrawal from medication.

SECONDARY REVIEW

Injury history

RTA in Ireland. Not admitted to hospital at the time. PTA estimated at one week. Involved in second RTA around 12 months post initial injury, side impact, no LOC. Is normally dependent on anti-emetics (has two on prescription) and also regular use of pain relief for neck, knee and headaches. Did not take the anti-emetics for one week prior to assessment. Has had physiotherapy treatment (manipulation) for neck and still has a monthly review.

Synthesis of presenting problems

Primary reported problems in summary relate to negative responses to dealing with a visually moving and/or physically unpredictable environment (dizziness/nausea/illusory after movement). Also neck pain progressing to headache, left knee pain. Head resting position into left rotation and upper cervical extension. Discomfort reported on active extension, right rotation is limited. Subtle limitations of right eye movement, particularly related to the vertical and on optokinetic testing. Postural instability (A-P sway) observed in standing with eyes closed, but assessment limited by subject's inability to maintain the eyes closed condition, due to fear of falling. Subtle signs of vestibular imbalance/sensitivity affecting postures leaning to the right / with predominant weight bearing to the right. Reactive increase in right cervical muscle tone on attempts to rotate body to the left in the office chair. Reduced speed of response on interpretive/multi-joint sensory testing, especially in lower limbs. Some specific difficulty on proprioceptive testing around the left knee.

Issues raised by presenting problems

Impairments patterns and minor injuries (as measured by GCS). Symptoms suggesting vestibular involvement that are not obviously attributable to (horizontal) semi-circular canal dysfunction. Medication and inhibition of compensatory processes. Potentiation of autonomic responses. Possible links between altered proprioception, the development of abnormal biomechanics and the development of pain.

Subject 11:

27 year old male, 36 weeks post injury, GCS 14, motorcycle RTA

CLINICAL SUMMARY

Pre-injury influencing factors

No negative influencing factors were identified. Prior to this injury M was a keen participant in martial arts. This suggests that his postural control may have been more highly tuned than average.

Notable findings

- M sustained major facial injuries at the time of his TBI which resulted in the surgical removal of his right eye five days after the injury.

Dizziness / postural control

- M reports that he has repeatedly bumped into objects on his right and he attributes this to his loss of vision. He reports that the frequency of these events is diminishing. M also describes episodes of dizziness, associated with head extension, on occasions when dancing and following other quick movements. He reports that the dizziness lasts less than 10 seconds and mainly consists of feeling that his head has been momentarily left behind. He admits to falling off his bicycle once and says that this was because he was not paying adequate attention.
- In quiet sitting, M held his head rotated slightly to the right and there was a slight elevation of the left shoulder. The upright sitting position was maintained with ease, with eyes open and when closed. Head/neck movements were all performed with the right rotational bias maintained. There were no reports of pain but a brief sensation of dizziness was reported on head extension (which was carried out in slight right rotation). In quiet standing there was no perception of unsteadiness and no observable sway, even with eyes closed. There was a suggestion of over-control, of a lack of normal postural sway: this may reflect his previous martial arts training.
- The Fukuda stepping test was abandoned after 40 seconds since M had moved so far forward that he was in danger of injuring himself on surrounding furniture. He had also rotated 45° to the left. Dix-hallpike was unremarkable to the right and M denied any problem to the left but his physical appearance and behavioural reaction suggested some level of discomfort. Six trials of sit/stand rotate resulted in corrective stepping to regain balance and ultimately to a wide-based stance, although

M did not describe any difficulty. He reported transient dizziness on stopping after a modified circular walking test (six circles), there was severe (though short-lived) antero-posterior sway. This occurred on clockwise and anticlockwise circles.

- M had difficulty with vertical VOR testing, needing to move slowly to keep the target in focus. He could only cope with slow optokinetic stimuli and this was more apparent in the vertical plane than in the horizontal.

Vision

- M reports no visual difficulties (other than the loss of his right eye) since the injury. Even allowing for the lost eye I felt that there was a possible slowness to acknowledge stimuli presented to the right field of the left eye. On smooth pursuit testing, I was not convinced that range towards the nose was full. He had difficulty keeping his head still during horizontal saccades but this may represent a habit developed in compensation for the loss of his right eye.

Tactile and proprioceptive sensation

- In general, M's responses to stimuli were prompt and accurate. Initially, however, there was a suggestion of difficulty in acknowledging two concurrent stimuli on the right arm and leg and a particular difficulty in discriminating different stimuli distally on the left arm/hand.

Other findings

- Even at speed M's gait pattern appeared stilted and two-dimensional. There was a tendency to throw the left leg and some high-level incoordination of the left arm.

Opinion

- Although M is well controlled in static balance testing he has clear limitations of functional balance. His self-report does not hint at any functional problem and even when balance was compromised during assessment he did not seem to regard this as an issue. Taken positively this could be interpreted as an acceptance of functional difficulty and that he is coping well. On the other hand, his failure to indicate that he was aware of his potential vulnerability could be seen as a problem of awareness or even denial, which could raise questions of safety. It would seem important for the treating team to try and establish which of these interpretations are correct.
- There was a hint of slowed attention / processing of complex sensory stimuli on the right. As this was not confined to the visual system (which may be explained by the

loss of the right eye) but also appeared to include tactile sensation it would also seem worthwhile to investigate this further.

- In clinical management terms high-level dizziness provoking work should help drive any further available change and it would be helpful to combine this with specific work to improve left-sided control during movement execution. I would also want to include work that encourages integration between both sides of the body. From an academic point of view I would be interested to know if peripheral vestibular dysfunction could be excluded by laboratory testing.

SECONDARY REVIEW

Injury history

Depressed skull fracture, diffuse traumatic subarachnoid haemorrhage. Facial fractures, glass in right eye. Meningeal repair, eye surgery (right eye removed) and facial repair.

Synthesis of presenting problems

Subtle ocular motility problems in remaining eye and suggestion of right inattention (also initially on testing peripheral sensation, which was otherwise generally prompt and accurate) but seemed to improve when 'tuned in'. Head resting position, rotated to right, with left shoulder elevation. Abnormal response to optokinetic stimulation, particularly in the vertical. Slight limb ataxia in both left limbs. Subtle left-sided suggestion of vestibular dysfunction, physical reaction to the left Dix-Hallpike, left side rotation (and significant forward movement) on Fukuda. Noticeable absence of any postural movement / adjustment in sitting and standing, even with eyes closed (was martial arts enthusiast prior to injury and expressed keenness to demonstrate his ability to be still). 'Dizziness' elicited on neck extension and on modified circular walking test (added to explore dynamic postural stability, given the subject's report of dizziness and loss of balance and the apparently excellent static postural control). Subject's report of dizziness is a feeling of his head being left behind. Significant A-P sway immediately on stopping circular walking, very quickly brought under control. Gait stilted and two dimensional, even at speed, with a tendency to throw the left leg.

Issues raised by presenting problems

Impairments patterns and minor injuries (as measured by GCS). Symptoms suggesting vestibular involvement that are not obviously attributable to (horizontal) semi-circular canal dysfunction. Influence of pre-injury skills.

Subject 12:

47 year old male, 70 weeks post injury, lowest GCS 15, motorcycle RTA

CLINICAL SUMMARY

Pre-injury influencing factors

J has worn glasses since his early 30's, using them for both distance and close work. In recent years he has worn varifocals. I am not aware of any other pre-injury factors likely to influence the assessment findings.

Notable findings

- J has recently commenced a programme of intervention (delivered by a Locum physiotherapist) to tackle suspected balance disorder. He reports that during this period targeted symptoms have reduced in frequency and intensity.

Visual issues

- J reports blurred vision, particularly for close work, which he had presumed meant that he needed new glasses. Testing by his optometrist had not identified any significant change in prescription. Brief convergence testing during this assessment produced visual blurring at 8".
- J experienced subjective difficulty on tests of smooth pursuit and, although he appeared to have good range, there was a suggestion that the left eye momentarily lost track but was also quick to regain the target. Looking for a target on the right frequently required a second saccade and he asked if the assessor had moved the target further away. Vertical saccadic movements were performed on the diagonal, with upward gaze deviating to the left.
- Response to horizontal optokinetic stimulus applied to both eyes together was abnormal in both directions. Vertical was within normal limits.

Cervical spine and headaches

- J is not documented as having any specific neck injury although his vertebral column may be presumed to have been affected by the impact of the injury that caused a burst fracture of L4 with significant lateropulsion of fragments. He has a post-injury history of frontal morning headache, mostly on the right. Complaints of cervico-thoracic pain and stiffness have been addressed with some success by recent physiotherapy. Headaches still occur after periods of intense concentration or in noisy environments.

Vestibular issues / integrative ability

- J reports two major falls, one from a ladder (necessitating hospital admission) and one from the top of an external set of stairs. Both falls were instantaneous and may have followed sudden head movement. He reports frequent episodes of stumbling, especially when negotiating kerbs and during similar activities. He had recently been advised by his physiotherapist to wear standard distance glasses and has noticed increased frequency of stumbling since mislaying these glasses and having to again wear his varifocals. J reports frequently feeling unsteady and that he experiences sensations of dizziness, usually after sudden movements.
- On examination, simple neck movements in sitting induced a "slightly swimmy" sensation. This resolved quickly. Side flexion was restricted to both sides by pain and stiffness and movement to the left was produced in combination with unwanted neck extension. There was some lumbar discomfort on maintaining an upright sitting position and a slight left-sided drift of the head into side flexion/rotation when trying to maintain this position with closed eyes. J also reported a sensation of being slightly light-headed.
- In standing with open eyes, as in sitting, a balanced position was maintained without difficulty. On eye closure J perceived a feeling of head and body rotation while a visible antero-posterior sway was observable to the assessor. J was unable to sustain eye closure (because of the rotatory sensation) and on a second attempt both his sensation of rotation and the observable sway increased. He had to sit to recover and continued to feel "swimmy" for a couple of minutes. Fukuda stepping test produced forward progression and 45° rotation to the left. Dix-Hallpike to the left produced latent dizziness with recovery within one minute but no nystagmus. Repetition produced the same pattern of symptoms but to a lesser intensity.
- Horizontal VOR testing also produced dizziness after 40 secs. This was a stronger response than has been achieved during recent therapy sessions but it should be noted that dizziness had already been induced several times during the assessment.

Opinion

- Findings are suggestive of left vestibular hypofunction with or without central processing elements. J appears to use his vision to compensate for his poor vestibular function and therefore to be at risk when vision is absent or unreliable.

While some of the observed visual system abnormalities may be linked to vestibular function he also appears to be experiencing specific accommodation/vergence difficulties and this should be assessed by a specialist orthoptist to fully define the problem.

- Given that J is intent on returning to working at heights it may be prudent to obtain an objective evaluation of his vestibular function to quantify the level of function available. This, along with the advice gained from the specialist visual assessment will allow more specific targeting of intervention and safety guidance. In the meantime work should continue to increase pain-free range of cervical movement and include a stretching regime to minimise soft tissue adaptation secondary to the left-sided head drift.

SECONDARY REVIEW

Injury history

Burst fracture L4, fractured distal right humerus (fixed) and 4th and 5th metacarpals. Reported tinnitus in right ear early in recovery period. Further A&E admission following fall from ladder 4 months after injury. Has begun a period of physiotherapy targeting balance issue problems that has diminished symptom levels.

Synthesis of presenting problems

Two witnessed episodes of sudden, serious loss of balance (up ladder, down several stairs) and reports of others. Frequent stumbling, for example, while negotiating kerbs (improved following advice not to wear varifocals). Cervico-thoracic stiffness and right frontal headache most mornings. Headache also associated with periods of concentration or when having to deal with noisy environments. Visual blurring during everyday activities, particularly during close work. Limitations of the occulomotor system affecting motility (momentary loss of target with left eye, abnormal saccadic movement upward and right going) and vergence. Reports dizziness on sudden movement, became very dizzy on VOR testing and to a lesser degree during neck mobility examination. Postural drift, slight left neck side flexion and rotation on eye closure in sitting. In standing, perception of rotational movement, while actually swaying back and forward and subject was fearful of maintaining eye closure. A second attempt produced an increased response of both perceived and observed postural dyscontrol. Symptomatic left Dix-Hallpike and forward and left rotation on the Fukuda.

Peripheral sensory system intact although did initially adopt a supine position with the legs angled significantly to the left.

Issues raised by presenting problems

Impairments patterns and minor injuries (as measured by GCS). Visual substitution for vestibular loss in the presence of visual dysfunction. Risks to safety during demanding activities.

Subject 13:

58 year old male, 72 weeks post injury, GCS 14, assault.

CLINICAL SUMMARY

Pre-injury influencing factors

F had a Bell's palsy in 1995, which can result in some residual symptoms such as tearing and abnormal blinking. He has worn glasses for many years, initially for close work (precision welding) and then for distance too. In the past he has worn bi-focals but at present he has separate sets.

Notable findings

Visual

- F reports that his eyes seem to water easily since his injury and that they often feel itchy, especially after concentrating. He also reports misreading words in English, usually getting the first letter right. During the assessment it was noted that he did not hold a central gaze position but had a tendency to look to the right of straight-ahead. This was accompanied by a left tilted and slightly right rotated head position.
- On confrontation testing, his first response was to back away from the stimulus. Voluntary saccades produced two pulses on each occasion looking to the left target. F expressed a dislike of looking up on testing vertical saccades and also some discomfort in performing smooth pursuit movements, although these appeared full and smooth on testing.

Balance

- F described feeling like "a puppet on a string". He said that he frequently stumbled and that he can feel quite unsteady at times. He also described a sensation of feeling like he has a "bobbing cork" inside his head and that he also experiences sudden, short-lived "whooshes of dizziness". He felt that the latter occurred mostly in lying and occasionally in sitting.
- Sitting with eyes closed produced a feeling that he was vulnerable to falling to the left. In standing, again with a slight left tilt of the head, he was uneasy with eyes open, worse with eyes closed and displayed a sudden loss of balance backward. Following this F experienced the previously reported watery/itchy eye sensation. He reported transient discomfort when lying on the left side and a much increased blink rate was noted.

- The Fukuda stepping test produced a 90° turn to the left. Dix-Hallpike: no nystagmus but disliked the sensation to both sides, worse coming up form left , lots of blinking observed again. Nil remarkable observed on VOR testing or on optokinetic testing. ?VORc a problem: dysmetric on passive testing and eye movements did not follow head movements on testing range of active neck movement.

Cervical spine

- F reported difficulty with activities that require him to look over his shoulder. This is particularly a problem on looking to the left but he reports pain to both sides. Range is limited (½ to ¾) with no visual follow through and the eyes held predominately to the right. There was virtually no voluntary extension.

Tactile and proprioceptive sensation

- Diminished "volume" of light touch and sharp stimuli throughout left limbs. Hesitant in tests of discrimination.

Other findings

- F reported that he easily becomes out of breath and it sounded as if this might be related to breath holding associated with feeling vulnerable to falling. His gait was very slow with no rotation and a lot of co-contraction. Other movements were suggestive of a slight decrease in co-ordination.
- F described hearing infrequent added noises (more of a problem initially).

Opinion

- Overall, F appeared to deal with information only slowly but he did not appear to have great difficulty in performing the rapid movements required for VOR testing (within his small chosen range of neck movement). There were a number of subtle left-sided sensory symptoms and a consistently presented appreciation of vulnerability to fall, especially with vision removed. Although the picture is somewhat confusing there are some indicators of gravity-linked difficulties and I would want to investigate further the role of the cervical spine and also to consider Otolith dysfunction (+/- BPPV). In parallel to this, a cognitive-behavioural approach to diminish co-contraction, reintegrate normal breathing patterns during function and loosen/speed-up physical movement should help drive any available change.

SECONDARY REVIEW

Injury history

Fractured base of skull, fractured nose. Little known about immediate management but clinic note two months later describes reports of dizziness and unsteadiness, diminished concentration and memory, and troublesome headaches.

Synthesis of presenting problems

Unusual descriptions of visual difficulties and postural instability: eye watering, sensations of itchiness when trying to concentrate, misreading words but always gets the first letter right, feeling like a puppet on a string, feeling like he had a cork bobbing from side to side in his head, occasional whooshes of dizziness. Examination revealed a consistent (subtle) apparent aversion to the left side: eyes appeared almost consistently fixed with a tendency to look to the right of straight ahead with eyes and head (resting head position was also with a degree of left tilt), required two saccades each time to find the left visual target (with a suggestion of a rebound). Eye closure in sitting produced feeling of vulnerability of falling to the left but previous posture and rotated /tilted head position was maintained. Holding a steady standing position immediately produced a feeling of unease, increased with eye closure and resulted in a sudden fall backwards (onto plinth placed behind). Sensory awareness on the left side was reduced, left side lying was perceived as unpleasant (lots of blinking) and Fukuda produced a large rotation to the left. Dix-Hallpike was perceived as unpleasant on both sides, moreso on the left. Passive VOR produced jerky, dysmetric eye movements, however, VOR gain on active testing was within normal limits (within a small range). Eye movements did not follow head movements on testing neck range, especially on rotation to the left. Range was restricted, with virtually no voluntary extension. Gait was slow, with no rotation and everything fixed. There were reports of breathlessness which may have been related to breath holding. While there was the overall picture of fixation and co-contraction, there was a degree of upper limb ataxia evident on finger-nose testing.

Issues raised by presenting problems

Subtle left-sided symptoms, consistent with each other. Unusual descriptions of sensory disorientation. Differentiating between primary impairments and secondary compensations.

Subject 14:

27 year old male, 140 weeks post injury, GCS 13, mechanism not recorded

CLINICAL SUMMARY

Pre-injury influencing factors

M is an insulin dependent diabetic and was known to have diabetic retinopathy prior to his injury. He has had some laser treatment on the right eye.

Notable findings

Visual symptoms

- M feels that his vision has deteriorated since the injury and now has glasses. His describes the problem as "blurry vision" which is worse on some days than others. He is also affected negatively by bright lights, for example having difficulty with glare in some supermarkets.
- On examination visual acuity was 9/6 on the right with glasses. Convergence testing produced an asymmetrical motor response and there was difficulty maintaining left abduction on vertical pursuit. The same medial deviation was evident on vertical saccadic movements. M initially appeared to extinguish left visual stimuli on bilateral testing but seemed to 'tune-in' and subsequently made no more errors.

Vestibular issues

- Sitting eyes open produced a slight head tilt to the left over time and with eyes closed this was accentuated (and perceived by M), with intermittent partial corrections. A side-to-side sway was observable with eyes closed. A similar pattern occurred in standing with left deviation and backward sway being observable with eyes closed and possibly some rotation of the head to the left. M felt very threatened in this condition and was unable to attempt the Fukuda stepping test.
- On questioning M revealed that he could not lie down to sleep and this was confirmed on examination by the experience of immediate dizziness on moving into supine. Movements into right and left side lying also produced transitory dizziness.
- M experienced dizziness (but no nystagmus) on Dix-Hallpike to both sides. Intensity of dizziness and speed of recovery decreased with repetition (R,L,R). VOR gain was reduced, to a greater extent in the vertical. I was unsure of his response to the Halmagyi but did not repeat as M was tiring. Horizontal optokintetic stimuli

produced a normal response but made him feel nauseous, vertical response was abnormal.

Neck

- There was some limitation in all movements, slight dizziness on right rotation and spinning dizziness on extension. This movement was carried out with a degree of left tilt.

Gait and function

- M's gait was rigid in style and he was clearly 'unstable' on stopping and turning (small sway observable). He felt better walking at a slightly increased speed but was unable to sustain and more threatened at reduced speed.

Opinion

- M has fatigable dizziness which should respond to treatment by repeated, graded exposure. The clinical signs are suggestive of a left vestibular problem but I am unsure that all of his visual symptoms are accounted for by this alone. It would be useful to monitor these signs as treatment progresses and if they remain, a specialist orthoptic assessment would then be of assistance.

SECONDARY REVIEW

Injury history

No fractures, PTA estimated between 5 and 7 days. Early reports of frontal headache, nausea and dizziness. Insulin dependent diabetic with pre-injury retinopathy and laser treatment on the right eye.

Synthesis of presenting problems

Reports deterioration in vision post injury, fluctuating 'blurry' vision and difficulty dealing with bright lights and surroundings, such as supermarkets. Tendency to nasal deviation of the left eye (especially on vertical movements) and initial difficulty identifying stimuli in the left visual field. Head tilt to the left in quiet sitting (maintained through neck range testing), increased with eye closure (intermittently corrected) and accompanied by a visible side to side sway. Similar postural instability in standing, with increased left and backward drift of trunk and head. Extremely uncomfortable in eyes closed condition and couldn't attempt the Fukuda. Immediate dizziness on attempting to lie supine and transitory increase in intensity turning to right and left. Dizzy (fatigable) on Dix-Hallpike (both sides), dizzy on neck extension, reduced VOR gain, especially in the vertical, abnormal vertical optokinetic response and nausea induced by horizontal testing (though apparently normal response). Rigid gait, unstable (visible sway) on stopping and turning. Felt better (less unstable) when encouraged to walk at an increased speed, but was unable to sustain.

Issues raised by presenting problems

Postural alignment with respect to gravity. Inter-related signs and symptoms and pragmatic prioritisation in planning interventions. Balance organ function and gait.

Subject 15:

20 year old male, 20 weeks post injury, GCS 15, fall from moving van

CLINICAL SUMMARY

Pre-injury influencing factors

N has worn glasses since childhood.

Notable findings

Early history

- N was not taken to accident and emergency in the immediate period post injury. He is reported to have taken to bed at home because of a mixture of headache, dizziness and nausea. When he was medically assessed a right occipital fracture was found.

Vision

- N reports a slight hazy affect on his vision. He also experiences a fairly consistent feeling that there is something in his eyes which he feels is disrupting his clarity of vision. Throughout the assessment both eyes were aligned to the left of centre (along with head rotation to the left and slight right side flexion) and he had difficulty achieving/maintaining a forward gaze. Smooth pursuit and saccadic movements were unremarkable. There was a suggestion of asymmetrical activity on convergence testing with the left eye travelling a greater distance than the right.

Cervical spine

- N described his neck as stiff but not sore. Voluntary movements were reduced in range and performed with some reticence. N reported previous episodes of muscle fasciculation following movement pushing into the 'stiff' range but this was not observed. There was muscle resistance to passive head movement especially to the right and initially into extension. However, trunk rotation in an office chair with a fixed head was free.

Vestibular/integrative function

- N rotated 45° to the right and gravitated forward over one minute during the Fukuda stepping test. No dizziness was elicited during the assessment but he avoided any forward leaning component in functional movement (standing from sitting, walking). There was a visible antero-posterior sway in standing with the eyes closed (which he was aware of) and the previously noted left rotation of the head was again evident, this time also accompanied by forward flexion. In contrast, when walking N appear to look to the floor on the right as a reference point. He had a tendency to lean to right at the trunk, which fits with his report of veering to the right in day to day function. His base of support, even after self-correction, was at all times small with the left leg crossing midline during gait. VOR gain was reduced in both horizontal and vertical planes.

Sensory perception

- N has difficulty interpreting /discriminating sensory stimuli (two-point, sharp/blunt) and although accurate was slow to interpret multi-joint movement/positions. He described feeling like his head will fall off - although he knows this will not occur. Although not formally a part of the assessment it would appear from discussion with N that he has some altered perception of the vertical/horizontal alignment of his environment. His description also suggested that he was having some difficulty processing/resolving some of his visual impressions.

Opinion

- Although there is a clear early history of dizziness, avoidance of forward-lean movements and a borderline performance on the Fukuda stepping test, there is no strong clinical evidence of peripheral vestibular dysfunction. Some of the right drift and apparent avoidance of movement may be explained by a combination of left-sided motor co-ordination problems, right-sided sensory dysfunction and abnormal visual perception. However, the combination of head rotation and tilt is sometimes seen with otolith dysfunction although I did not observe the sometime associated vertical deviation of the eye.
- It would seem important to examine further the question of visual perception, even to exclude this as a primary source of the abnormal head posture/eye position.

SECONDARY REVIEW

Injury history

Although an ambulance was called to the scene, this subject was not taken immediately to A&E, but to his home where he took to bed for several days complaining of headache, dizziness and nausea. He was subsequently found to have a fractured right occiput.

Synthesis of presenting problems

Reports diminished clarity of vision. Sensory disorientation described now as being more like light-headedness rather than dizzy, usually associated with movement. Also reports a strong sensation that his head will drop off (though intellectually knows it won't). Avoided forward leaning throughout the assessment. Head resting position rotated to the left with slight right side flexion, eyes also held to the left of centre. Had access to full range conjugate eye movements but had difficulty adopting/holding central forward gaze. Reflex increase in neck muscles on passive VOR testing with particular resistance to right head rotation. Free movement of trunk on body in the office chair. Head resting posture accentuated on eye closure in sitting (and standing). Maintained the eyes closed condition but was unable to be completely at rest. A-P sway evident when eyes closed in standing with increasing forward/side head flexion. In contrast, uses a right of centre ground reference point when walking and tilts to the right from the waist. Adopts a narrow base of support and the left leg often crosses the midline. Reports veering to the right in day to day functioning. Rotated to the right and travelled forward during the Fukuda stepping test. Demonstrated significant upper limb ataxia on testing, especially on the left. In addition to slowness of response on sensory testing with a cognitive load, this subject had some altered perception of the vertical and horizontal alignment of his environment and difficulty processing/resolving some of his visual impressions.

Issues raised by presenting problems

Head tilt. Gaze stabilisation. Functional outcome of combined sensory and motor impairments. Reflex increase in neck tone, absent in head fixed condition. Symptoms suggesting vestibular involvement that are not obviously attributable to (horizontal) semi-circular canal dysfunction.

Subject 16:

47 year old female, 69 weeks post injury, GCS not recorded, RTA

CLINICAL SUMMARY

Pre-injury influencing factors

T previously experienced fainting/blackouts (1988) which it was thought might have their basis in hyperventilation. This was not an active problem at the time of this injury. She has worn glasses since childhood.

Notable findings

Visual symptoms

- T reports visual problems from day 1 of the injury. In the main this has been difficulty with focus/blurring of vision and only occasional diploplia. She also reports visual illusions, primarily a shimmering of the environment but also describes one incident when she grabbed hold of another person because she thought they were falling.
- Visual acuity on the right (wearing current prescription lenses) appears to be diminished and she performed poorly on field confrontation testing on this side. T had difficulty maintaining static gaze especially straight-ahead and to the right. Smooth pursuit was apparently full range (but produced nausea and reflex swallowing) and saccadic testing was abandoned because of complaints of nausea. Horizontal optokinetic response was much reduced, especially to the right.

Falls and dizziness

- T reported avoiding activities because of previous falls and frequent episodes of stumbling. She described a sensation of tilting to the right that she is aware of in standing.
- She was observed to drift to the right in sitting, moreso with eyes closed. She made slow but accurate correction based on her perception of changes in weight distribution through her buttocks. The right-side drift was also evident in standing and T was able to keep her eyes closed for only a short time as she felt very threatened by what she perceived as a push/pull to the right. Unlike in sitting she had not identified a feedback method to counteract the destabilising sensation. None of the standard clinical vestibular tests were positive but she simply fell to one side and then the other when attempting the Fukuda stepping test. T reported dizziness on

return to midline after right neck rotation and to a lesser degree to the left and after right side flexion.

Sensation and other issues

- While joint position and movement sense appeared intact, T had problems identifying tactile stimuli throughout the right limbs. She was also a little clumsy on finger/nose testing on the right. Her gait was reticent, unsteady and characterised by stepping only from the knee thus producing a creeping movement. T also reported hyperacusis and intermittent awareness of high-pitched additional noises.

Opinion

- T's clinical presentation is similar to a previous client who was found to have a mixture of unilateral vestibular hypofunction and "cervical vertigo". The tilting sensation and description of being pulled or pushed is consistent with both cervical spine and otolith pathologies. The combination of staggering gait, ataxia and sensory deficit has been linked with upper cervical spine pathology. There is clearly an issue of visual degradation on the right.
- Initially I would investigate further the cervical spine, treat any joint malalignment/stiffness and any associated proprioceptive sensitivity. If there was positive progress I would then promote increased function via graded exposure/cognitive behavioural programme. If there is limited progress it may be worth obtaining a formal assessment of peripheral vestibular function.

SECONDARY REVIEW

Injury history

Fractured left clavicle, lateral malleolus right ankle. Whiplash type symptoms noted in hospital, had a collar for about a month.

Synthesis of presenting problems

Reports difficulty in focusing, problems of blurred vision and perceptions of the environment shimmering. Diminished acuity (right), difficulty maintaining static gaze (especially forward and to the right) and reduced optokinetic response (especially horizontal to the right) observed. Reported nausea (and was seen to swallow repeatedly) on eye movement testing (though movements appeared full). Reports numerous falls, episodes of stumbling and perception of others falling. Reports a strong sensation of tilting to the right in standing. Instability evident on examination: drift to the right in sitting, increased with eye closure (described making corrections via awareness of change in the level of pressure through the buttocks), drift also apparent in standing and not able to maintain eye closure due to the strong sensation of being pulled to the right and the absence of an alternative reliable feedback mechanism. Described Dix-Hallpike to the left as 'feeling weird', tried the Fukuda (briefly), falling to one side and then the other. Diminished awareness of tactile stimuli on the right as compared to the left, hesitant on both sides, unable to differentiate between sharp and blunt stimuli on the right. Accurate, with normal speed of response for proprioception. Slight ataxia in the right upper limb. Cervical range reasonably good except for right rotation. Significant levels of dizziness reported during and after neck range testing. Reports, hyperacusis and intermittent tinnitus, especially in certain rooms at home. Reticent and apparently unsteady while walking, fixes thighs together and only steps from the knees.

Issues raised by presenting problems

Mixed vestibular and cervical symptoms. Cervical vertigo. Autonomic symptoms. Impact of peripheral sensory impairments. Cumulative effect of multiple impairments.

Subject 17:

26 year old male, 102 weeks post injury, GCS 4, driver RTA

CLINICAL SUMMARY

Pre-injury influencing factors

D sustained a whiplash in 19??. He reports this as resulting in neck soreness/stiffness but not any referred arm pain. It did not cause him to have any time off work.

Notable findings

- D has had surgery to lengthen his tendo-achilles bilaterally, indicating that he sustained a period of high extensor tone post injury.

Vision/visual signs

- D denies any problems with vision before or since his injury although a few subtle signs were observed on assessment. For example there appeared to be a slight wavering of the eyes when trying to hold static gaze and convergence testing produced an asymmetrical response with the left eye converging first and the right subsequently diverging. He appeared to acknowledge visual stimuli presented to the left hemi-field before the right and he also had difficulty sustaining the performance of smooth pursuit movements. This deteriorating performance was also noted during saccadic movements, which started without difficulty on horizontal and vertical planes but broke down firstly in terms of requiring two pulses and secondly in being perceived as too tiring to continue.
- D had difficulty with other aspects of volitional eye movement (see balance/dizziness) and his response to optokinetic stimulus was abnormal in both horizontal and vertical planes.

Balance and dizziness

- D describes diminishing problems of balance control and says he is now much less aware of feeling unsteady. For example, he recalls feeing that "everything was still moving" any time he stopped doing an activity that challenged his balance at speed but now he can use the treadmill and the steppa machine in the stamina and co-ordination group with little subsequent ill-feeling. He still has problems with whole-body co-ordination and dual tasking, for example carrying drinks while walking but feels he is much less likely to stumble.

- In sitting and standing he had the tendency to drift to the right, more noticeable with eyes closed. In standing and during positional change he maintained a backward inclination, moreso on the right. A definite backward sway was observable on standing from sitting, but this was soon brought under control. When not under direct instruction he would adopt various strategies to fix with the lower limbs. He had to be encouraged to relax into his base of support, even in lying.
- While D experienced no problems with the Dix-Hallpike manoeuvre or the Halmagyi head thrust, he rotated a full 180° to the right (on the spot) on the Fukuda stepping test. D experienced a number of difficulties in performing visual reflex tests. For example, he could not reliably accompany passive head rotation with appropriate eye movements, he could not hold his eyes steady on VOR testing without bracing his neck muscles and he also had problems holding his eyes steady during COR testing.

Tactile/proprioceptive sensation

- D had difficulty discriminating between one and two distinct simultaneous stimuli when applied to either of the right limbs.

Other

- D's neck range of movement was restricted in all directions with tissue shortening, especially in the neck extensors. He walked with his weight held back giving the appearance of a creeping quality. Although in the main there was little spiral or rotatory components of movement, D occasionally attempted to introduce upper trunk rotation. He was unable to maintain any increased speed of walking but this and the trajectory of his gait were both improved by looking straight ahead rather than using the ground as reference as was his normal practice.

Opinion

- The most striking impression is D's difficulty in breaking down any individual component of movement of the trunk, head or eyes. Functionally he has a clear preponderance to the right and the 180° rotation on the Fukuda was striking. However, whether his postural imbalance is secondary to a peripheral or central vestibular imbalance is difficult to say from purely clinical assessment. He certainly still displays signs of a period of high post-injury muscle tone, both in the lack of head flexion and the difficulty accepting support.
- He has responded to intervention and is now less disorientated after challenging exercise. Functionally he needs to add the third dimension to his movement: forward

weight transference, rotational components, isolated components of movement, and to increase speed of action. Whereas little further may be added to the clinical programme by formal vestibular assessment I think that a specialist opinion concerning his visual signs would be useful.

SECONDARY REVIEW

Injury history

Subject 17 was initially treated in another region and full notes were not transferred. However, he is known to have undergone surgery to lengthen both tendo-achilles.

Synthesis of presenting problems

This subject denied any visual problems but there were a number of notable findings on examination: difficulty holding static gaze, asymmetrical response to convergence testing, diminished awareness of stimuli in the left visual field, difficulty sustaining smooth pursuit and saccadic movements ("too tiring"), abnormal optokinetic response. He was aware of balance instability and difficulty dual tasking, for example, carrying drinks while walking. Sensory disorientation, feeling movement continuing when motion has stopped, was reported as lessening. Postural instability was apparent in quiet sitting (drift back and right), in standing and when moving into standing from sitting. Head and trunk drift increased on eye closure, in sitting and standing. He habitually adopted various fixation strategies with the lower limbs, sometimes also clasping hands together. In supine, he adopted this co-contracting behaviour throughout trunk and limbs, crossing legs and having great difficulty accepting the support surface. Tests of peripheral vestibular function were not symptomatic but he rotated a full 180° to the right (on the spot) during the Fukuda stepping test. He had significant difficulty on visual reflex testing, being unable move his eyes with passive head rotation, to hold his eyes steady during active head rotation or when his body was rotated away from a fixed head in the office chair. Cervical range was much reduced with significant tissue adaptation, particularly in the neck extensors. He was unable to discriminate between two distinct stimuli in both right limbs. Gait was with backward inclination of head and trunk, with visual reference to the ground and with no rotational components of movement, giving a creeping appearance. Speed and quality of movement could be momentarily improved by prompting to look ahead, but this could not be sustained.

Issues raised by presenting problems

Influence of early high tonal states on subsequent movement patterns. Defining central vestibular dysfunction. Fractionation as a prerequisite for successful functional movement.

Subject 18:

26 year old male, 98 weeks post injury, GCS 13, RTA

CLINICAL SUMMARY

Pre-injury influencing factors

Incidental finding of spina-bifida occulta 4 years prior to injury, asymptomatic.

Notable findings

- Vision
  - Difficulty maintaining central gaze, with gaze nystagmus to both sides
  - Build of visible nystagmus over the period of the assessment
  - Reported visual degradation associated with movement and illusory movement of the visual horizon while walking (wavy movement)
  - Difficulty focusing to read, using glasses for first time in life
- Vestibular system (in addition to the above)
  - Does not report classic dizziness but feelings of heaviness in the head and perceptions of tilting (can be to either side)
  - Non fatigable nystagmus to both sides on Dix-Hallpike manoeuvre, accompanied by the previously reported feeling of heaviness in the cranium
- Postural stability
  - Perception of A-P sway in sitting, larger that seen by the assessor
  - Perception of S/S sway in standing, while observation revealed A-P sway and increasing tendency to lean back
  - Perception and actual movement worse in standing, barely able to maintain eye closure for one minute and managed only because of continuous verbal feed back
  - Unable to attempt the Fukuda Stepping Test
- Other
  - Increasing levels of nystagmus following head on neck and body on head movement
  - Diminished levels of co-ordination/ control in right limbs
  - Reduced speed and accuracy of response to tactile stimuli requiring discrimination
  - Lean-back posture during gait, worse at slower rates, eyes to ground throughout

Opinion

- Some of C's presentation is suggestive of bilateral vestibular dysfunction but I have limited clinical experience in this area. Equally, there is a suggestion of cerebellar involvement. However, his lowest recorded GCS is only 13 and in itself wouldn't immediately suggest significant structural damage. I would like to exclude any contribution of his pre-existing, supposedly asymptomatic, spina bifida occulta.

Suggested Action

- Medical referral for review of current symptoms and exclusion of additional factors. Subsequent intervention would be dependent on the results of this review.

SECONDARY REVIEW

Injury history

Scalp laceration, degloving injury right calf. PTA estimated at 9 hours. Asymptomatic spina bifida occulta diagnosed on x-ray 4 years prior to injury.

Synthesis of presenting problems

Dominant symptoms were difficulties of gaze fixation and increasing levels of visible fine nystagmus observed during the assessment, particularly associated with rotational (head on body, body on head) movements. Significant levels of illusory movement with eyes open and increased with eye closure. Postural instability also present (but not in the direction perceived by the subject). Reduced speed of response for sensory testing with cognitive load (in addition to local sensory loss associated with degloving injury). Sway-back orientation of trunk during walking, instability increasing with decreased speed. Slight ataxia in both right limbs. No other lateralising signs.

Issues raised by presenting problems

Gaze stabilisation and bilateral signs. Functional outcome of combined sensory and motor impairments. Active movement as a form of sensory substitution.

Subject 19:

33 year old male, 122 weeks post injury, GCS 3, RTA

CLINICAL SUMMARY

Pre-injury influencing factors

D wore glasses for five to ten years prior to his injury for reading and while watching TV.

Notable findings

- D had corrective eye surgery in November 1998.

Vision

- On initial questioning D said he had no problems with his vision but then went on to describe double vision in the vertical plane. He says that the lower image is stronger and that he can achieve one image when his head is a high degree of extension. He says he has no other visual difficulties.
- Although D has had corrective surgery, the right eye is still slightly medial and below the horizontal at rest. The left eye only seemed to move on convergence testing and D denied any blurring of the object. Left eye occlusion produced a correction to the mid line of the right eye with the covered eye deviating up and out. D could make it to the midline on smooth pursuit and performed saccadic movement well within the limitations. I felt that he achieved better elevation on saccadic movements. Vertical optokinetic stimulus seemed to produce a horizontal response

Balance

- D initially said that his balance was only a problem when he was tired but then went on to describe a lack of control of his right side after a short distance. He denied any episodes of dizziness but mentioned that sometimes he has the sensation of being pushed backwards. He was fairly stable in sitting but gained extra stability by adopting fixing positions with both the upper and lower limbs. There was a suggestion of left head rotation drift over time with eyes closed.
- D had difficulty maintaining a standing eyes closed position as he was repeatedly distracted by hyper-awareness of the right leg. This noxious sensation has been an ongoing problem but is thought to be diminishing. D said he felt he would fall and thought probably to the right but could not be sure.

- There was 90° rotation to the left and forward progression on the Fukuda stepping test. Dix-Hallpike was negative. D managed 30 seconds of active VOR testing without reported problems but he lost the target on passive testing.

Tactile and proprioceptive sensation

- D was hyper sensitive to light touch stimuli on the right and this was greater in leg. He had difficulty discriminating between sharp and blunt in the same pattern.

Neck

- D initially denied any difficulties with his neck but subsequently referred to stiffness which he reported could be relieved by stretching. His preferred resting position was in substantial extension and it became clear that this was dictated by trying to achieve single vision. Range of movement was generally restricted and influenced by the habitual neck extension.

Opinion

- D's self report was inconsistent and he gave a general impression of underreporting. His motor function is strongly influenced by his right-sided sensorimotor deficits and by the awkward position he has to adopt to achieve single vision. I think that the positive Fukuda test may be due to a combination of the right weakness and the pull of the extended and left-rotated position of the head. It will be important to establish what further intervention may be planned by the ophthalmologists as D's current visual status is having a negative impact on his overall function.

SECONDARY REVIEW

Injury history

Fractured base of skull, left extradural haematoma and intravenous blood. Left carotid cavernous fistula. Pulmonary contusions. Corrective eye surgery carried out while under the care of a previous service at 12 months post injury (16 month prior to this assessment), details not known.

Synthesis of presenting problems

Evidence of underreporting of limitations, within the assessment and in seeking corroborative reports. Continuing difficulties with binocular single vision (two images in the vertical plane) despite surgical intervention. Residual abnormal resting eye position and limitation of eye movements. Preferred resting neck posture in overextension (brings stronger of the two images to central vision), neck movements restricted by associated soft tissue adaptation. Right-sided hemiplegic type gait with heightened muscle tone distally in the lower limb and retracted shoulder girdle and upper trunk. Difficulty stabilising while walking at slower speed and unable to achieve fluidity of movement as pace increased. Hyper awareness of the right side (often verging on pain) while at the same time being unable to discriminate between competing stimuli. Head drift towards left rotation in eyes closed condition. Subject described fear of falling to the right in standing during assessment but reports sometimes feeling like he is being pulled backwards (not provoked during assessment). Full 90° turn to the left (with forward movement) during Fukuda stepping test.

Issues raised by presenting problems

Binocular single vision – fusion, influence of vision on head position. Influence of head position on postural stability. Factors determining postural drift. Co-existing presence of heightened muscle tone and proximal dyscontrol. Carotid cavernous fistula and local blood flow.

Subject 20:

30 year old male, 151 weeks post injury, GCS not recorded, RTA abroad

CLINICAL SUMMARY

Pre-injury influencing factors

A first wore spectacles around age 12 and has worn them consistently since age 16. Previously, he had corrective surgery, possibly on both eyes. *A* reports that before the current injury he still experienced momentary eye drift at times when tired. He says he never experienced double vision.

Notable findings

- *A*'s injuries included an initially untreated fracture dislocation of C6/7, a fractured right wrist and right clavicle.
- At the time of this assessment *A* had not had his eyes tested since the injury although he had consistently intended to do so as his glasses were damaged.

Eyes and vision

- *A* reported posterior eye pain, associated with migraine type headaches. Resting eye position was unremarkable other than an increased rate of blinking. Visual acuity with glasses was 6/6 and there were no field deficits. Occlusion testing produced drift of both eyes and convergence was asymmetrical.
- Pursuits were reasonably full but he had difficulty sustaining the activity. The right eye had a tendency to bounce back to the primary position and the left though observably better was described as painful. Saccadic movements to the right were initially short of target but improved with practice. *A* seemed unable to attempt these eye movement tests without holding his breath. Optokinetic response was diminished in the right eye.

Neck

- *A* reported a constant dull ache throughout his neck and specific pain and stiffness around T2-T4. ROM was restricted to less than half normal in all movements with minimal extension and only slightly greater side flexion. *A* was very anxious to avoid additional head extension although his resting position was in upper cervical extension. He described the onset of a headache after rotation to the left.

Balance

- *A* reported stumbling and falling, mostly in a backward direction. He also described episodes of dizziness following quick and/or rotational movements although he was unable to describe the quality of his dizziness. In quiet sitting he perceived himself as rocking in left/backward, right/forward diagonal. This was not observable to the assessor, even when his vision was removed. In standing he described a strong feeling of being seasick on eye closure, feeling "waves of bobbing". Repeated upper limb balance reactions were observed and attempts to persevere made him increasingly agitated. He felt unable to attempt the Fukuda stepping test after an eyes open trial again produced the seasick feeling.
- He walked with a stiff gait and wide base and was unsteady on turning. When he stopped after a few trials he experienced a sensation of the room spinning and had to sit down. There was no nystagmus on Dix-Hallpike but *A* described a light-headed, cotton wool sensation to both sides. This sensation decreased with repetition. Active VOR was reduced in speed and he had difficulty sustaining the movement. He complained of neck pain on the horizontal and nausea on vertical. COR testing was limited by neck pain and increased muscle tone.

Other sensory/physical issues

- *A* described abnormal juddering sensations and intermittent paraesthesia in both upper and lower left limbs and occasional flashing pains in the right thigh. Tactile and proprioceptive sensation was grossly intact with some slowness of interpretation of multi-joint movements.
- *A* was initially slow to appreciated left auditory input but fine once apparently 'tuned-in'. He described disturbing episodes of offensive olfactory illusions and was not clear whether his taste for food was the same as prior to this injury.

Opinion

- Although there was a number of abnormal visual findings these are likely to be due to pre-injury factors. Whilst vestibular deficits cannot be excluded on the basis of a clinical assessment alone, I believe that *A*'s primary symptoms are likely to emanate from the injuries to his cervical spine and his subsequent postural habits and movement limitations. Although the visual difficulties may not be new, their presence is likely to have influenced, and be continuing to impact on, the clinical picture. Dizziness of cervical origin responds well to interventions aimed at normalising pain free range of movement combined with a cognitive behavioural approach to steadily increase the scope and level of physical activity.

SECONDARY REVIEW

Injury history

Fracture dislocation of C6/7 diagnosed and surgically stabilised *after* transfer from India to the UK by air ambulance. Fractured right clavicle, fractured right wrist. Had corrective eye surgery as a child, details unknown, possibly involving both eyes.

Synthesis of presenting problems

Possible rebound nystagmus and diminished optokinetic response (lateral and upgoing) in right eye. Problems with convergence and drift on cover testing (probably related to childhood visual problems). Reasonable range of eye movements but had tendency to hold his breath and also complained of fatigue. The resting head position was in upper cervical extension and yet he was anxious about active extension. All voluntary neck range was 50% or less with a complaint of headache following left rotation (also reported posterior eye pain with severe headache as an ongoing problem). The subject described regular stumbling and falling, mostly backward, and dizziness following quick or rotational movements. In quiet sitting there was a self-perception of rocking diagonally (left/back-right forward), which was not visible to the assessor. In standing he described a strong sensation of feeling seasick on eye closure, feeling "waves of bobbing". Repeated balance reaction responses in the upper limbs were seen (although no core postural instability), and increasing agitation when attempting to maintain eye closure for one minute. An eyes-open trial of the Fukuda stepping test produced a similar sensation of seasickness and he preferred not to proceed with the full test. Dix-Hallpike produced a light-headed/cotton wool sensation on both sides, which lessened with repetition. Lack of adequate speed on active VOR testing limited assessment of horizontal response (complained of neck pain), vertical testing resulted in a feeling of nausea. Rotation of body on head in the office chair was limited by complaints of neck pain and reactive increase in muscle tone. Tactile and proprioceptive testing was grossly intact, though interpretation of multi-joint movements was slow. The subject reported experiencing juddering sensations and intermittent paraesthesia in both left limbs. He also described disturbing episodes of offensive olfactory illusions. He was slow to turn while walking and reported the room as spinning (had to sit to recover) after a few directional changes.

Issues raised by presenting problems

Sensory disorientation of cervical origin and patterns of postural response.

Subject 21:

47 year old male, 69 weeks post injury, GCS not recorded, hit on head by scaffolding

CLINICAL SUMMARY

Pre-injury influencing factors

R had right eye surgery as a child (possibly several operations) to correct a squint and ?enable improved vision. He says that the vision in his left eye has always been excellent and that he has never worn glasses.

Notable findings

Eyes and vision

- R reported varying levels of visual blurring when reading. He did not think that it was related to fatigue. He recalled having double vision early in his recovery but that this was now rare and probably only occurred during close work. R described some difficulties in the immediate recognition of people he ought to know. He denied any problems while driving.
- He was able to bring both eyes to the primary position but experienced difficulty holding the position to achieve forward gaze. He appeared to have a good range of conjugate eye movements and there were no problems with saccadic movements. There was a small adjustment on the right on left occlusion, limited right convergence and some divergence on brisk testing. Fields appeared full. There was a normal optokinetic response but both horizontal and vertical testing induced dizziness.

Balance/functional movement

- R described himself as wary and having learned to avoid a number of activities to limit accidents. He said he still stumbled from time to time and admitted to falling (at night going to the toilet). He described particular anxieties about dealing with machinery at work, disliking climbing up onto a raised staging and more so climbing down. He thought that forward movements probably made him dizzy. R tried to describe a pulling type sensation that was also troublesome. He also described episodes of 'blanking-off'.
- He sat with a kyphotic posture, leaning slightly to the left. He liked to maintain upper limb support and found sitting with eyes closed stressful, fearing that he would

fall. He moved slowly into standing, again using arm contact with thighs. In standing there was a visible antero-posterior sway even with eyes open. He was very anxious on eye closure, feeling he was falling backward and the left. He walked slowly with left trunk side flexion. His gait improved when persuaded to walk at a slightly increased speed. He clearly led with the right leg and there was evidence of some inco-ordination in both left limbs.

- I did not ask him to perform a Fukuda and he found past pointing in sitting difficult, losing balance backwards. There was no nystagmus on the Dix-Hallpike but he experienced odd sensations on return to sitting from both sides, worse on the left. He could not attempt active VOR due to a build up of dizziness. He experienced visual blurring and dizziness on COR testing.

Neck

- R denied any problems with his neck but his active movements were limited and performed in a protective fashion. He was less willing to turn to the left and adopted a left tilt on return to midline from extension. He described dizziness on flexion and was very reticent to perform this movement at all.

Tactile and proprioceptive sensation

- R experienced stimuli applied to right and left sides of the body as different. He felt right stimuli more than left. Overall his speed of response was good but he had difficulty and was slow when asked to discriminate between different types of stimuli.

Additional information

- From the treating team: some of R's symptoms have become more apparent over the period of contact (including dizziness), for example today's assessment results are more severe than would have been the case several months ago. The results of the team assessment, including observations of R's performance within the rehabilitation setting also raise concerns about his ability to undertake work duties and associated issues of safety. R remains keen to hold on to his job and there have been no adverse reports from work (it may be relevant to note that his accident was in the workplace).

Opinion

- The only primary visual problems identified on assessment may be attributed to his childhood visual history. On today's assessment there is striking evidence of balance system dysfunction affecting both visual and postural stability. His subjective symptoms and tonal imbalance suggest possible involvement of both the canal and otolith function. Functionally, R appears to try and compensate with vision and there is a suggestion of increased sensitivity of the cervico-ocular reflex, which may indicate that this is being used as a compensatory strategy. There is some evidence of brainstem/cerebellar loop involvement and difficulty dealing with information at speed.

- From clinical experience I would suspect that today's poor performance and R's deteriorating symptomology may well result from a build up of fatigue brought about by the unceasing demands of trying to maintain performance at work. Essentially he needs a break from the consistent level of demand so that baseline symptoms can be established as they present within a more manageable daily programme.

SECONDARY REVIEW

Injury history

Work injury, attended A&E but not admitted. Returned two weeks later complaining of headaches. First attempt at work return within a month of the injury failed. Subsequently returned to work but referred to follow-up with ongoing difficulties. Surgery on right eye as a child.

Synthesis of presenting problems

Reports of visual blurring while reading and some difficulties in immediate recognition of people he ought to know. No major visual impairments detected that could not be attributed to his early visual history. Optokinetic testing produced a normal response but also induced dizziness in both horizontal and vertical planes. Reports of stumbling and falling (visiting toilet at night), reports of activity avoidance to "limit accidents". However, also describes being anxious about operating machinery at work and when climbing up onto, and more so down from, raised staging. He thinks forward movements probably make him dizzy, is aware of experiencing an intermittent pulling sensation and of being aware that he may have on occasion "blanked-off". His resting position in sitting was kyphotic and with a slight trunk tilt to the left. On eye closure there was a perception of falling back and left although no movement was seen. Balance was lost in a backward direction when asked to raise the arms while maintaining eye closure. There was a visible A-P sway in standing and the subject was very fearful of falling back and to the left on eye closure. Neck movements were performed in a protective manner and a left tilted head posture was adopted as central following head extension. Slight dizziness was reported on flexion. Gait was initially slow with a slight left trunk tilt, improved a little at increased speed, but he clearly led with the right leg and there was a degree of inco-ordination in the left leg. Similar ataxia was observed in the left upper limb. Tactile stimuli were perceived more on the right than the left and speed of response was reduced for discrimination. The Fukuda stepping test was not attempted. "Odd sensations" were reported on returning to the starting position after the Dix-Hallpike manoeuvre and this was worse on the left. VOR was abandoned due to increasing feelings of dizziness and further visual blurring and dizziness was experienced on body on head rotation in the office chair (following a short rest). The level of dizziness was described by the local therapist (after the assessment) as increased from her assessment a couple of months earlier.

Issues raised by presenting problems

Absence of anticipatory postural adjustments. Postural alignment with respect to gravity. Monitoring of postural drift. Impact on symptoms and functional performance of continued high level demands. Symptoms suggesting vestibular involvement that are not obviously attributable to semi-circular canal dysfunction.

Subject 22:

52 year old female, 21 weeks post injury, GCS 15, assault (pushed downstairs)

CLINICAL SUMMARY

Pre-injury influencing factors

Prior to her injury J had worn reading glasses for 3 years. She reported that a previous serious back injury had caused a change in movement style but that she did not experience any problems with stumbling or falling. J also reported that she had a neck problem 8 years previous that was successfully treated by physiotherapy. She has not experienced any further symptoms.

Notable findings

Vision

- J complained of deterioration in vision of the right eye in that her current vision while wearing glasses was not as clear. On testing, right visual acuity was reduced to 9/6. No other deficits were noted except for a suggestion of slight limitation of upward gaze.

Balance and functional movement

- J complained of problems when walking, with particular difficulty in looking forward and around especially when people are approaching. J also described feeling unsteady first thing in the morning, being light-headed and feeling wobbly in the legs. She reported dizziness provoked by lying down and occasionally on turning quickly.
- On examination, the preferred sitting position was with a narrow base and a slight tilt of the head to the left. J did not experience any problems on eye closure. In standing, she again adopted a narrow base. On eye closure, there was a small amplitude observable sway and this was also perceived by J. On the Fukuda steeping test J moved several feet while first rotating to the right and then to the left. Dix-Hallpike to the right provoked dizziness but no nystagmus. To the left, nystagmus was seen and there was fatigable dizziness. Active VOR was performed at diminished speed and was associated with increased neck muscle tone. On passive testing, J had difficulty maintaining forward gaze on rotation to the right.

Neck

- J reported occasional neck stiffness but said this was not a problem. She had reasonable range on examination but reported a feeling of light-headedness on return to the upright position following neck flexion.

Other observations

- J leaned slightly to the left form the waist when walking and deviated to the left with each step. The right leg was repeatedly placed towards and sometimes across the midline. Although she habitually looked at the floor when walking she was able to look ahead on request. She reported greater subjective difficulty when walking towards the wall that holds the wall bars compared to when walking towards a plain painted wall. There was evidence of inco-ordination in the left arm and some diminished appreciation of sensation in this limb also.

Opinion

- Some of the assessment findings are suggestive of peripheral vestibular pathology (possibly bilateral, L > R) but there is also evidence of brainstem/ cerebellar loop signs. It would be reasonable to adopt a two pronged approach to intervention, targeting the dizziness by repeated exposure to provoking movements, progressing to specific work to improve VOR performance, while at the same time addressing issues of postural symmetry and left-sided co-ordination. With progress in both areas, treatment objectives would then progress to driving functional interaction of limbs and vision.

SECONDARY REVIEW

Injury history

Admitted for observation overnight. Returned to A&E five days later complaining of headache and recurrent vomiting. Very small right temporal subdural. Lost almost two stones in weight since injury (no sense of smell and minimal taste). Previous back injury and reported stiff gait prior to this injury.

Synthesis of presenting problems

Diminished visual acuity in the right eye and slight restriction of upward gaze. No problems on optokinetic testing. Reported difficulties of dealing with the visual environment (especially the moving environment) while walking, dizziness provoked by lying down or turning quickly, feels unsteady, light-headed and "wobbly in the legs" first thing in the morning. In quiet sitting she had a noticeably narrow base and a slight head tilt to the left but maintained stability, even with eyes closed. The narrow base was again evident in standing, this time with an A-P sway on eye closure. There was a small initial rotation to the right on the Fukuda stepping test, followed by a larger rotation to the left, accompanied by forward travel. Dix-Hallpike to the right produced slight dizziness but no nystagmus, to the left fatigable dizziness and nystagmus. There was reactive increase in neck muscle tone on active VOR (with reduction in speed) and difficulty with VORc on right head rotation. Cervical range was within normal limits, with a report of light-headedness on return from forward flexion. There was left trunk inclination during gait, right central and midline crossing placement of the right leg and overall left deviation. Preferred pace was slow with habitual eye reference to the ground. The subject could walk with a straight ahead gaze but expressed a preference to walk towards the plain gym wall rather than the one with parallel bars. There was slight ataxia of the left upper limb and diminished discriminatory sensation in this limb with a slow response rate.

Issues raised by presenting problems

Mixed peripheral and central signs in an apparently mild injury. Maintaining safety by limitation of activity. Influence of time since injury on observable findings.

Subject 23:

53 year old male, 20 weeks post injury, GCS 3, RTA

CLINICAL SUMMARY

Pre-injury influencing factors

J required reading glasses prior to his injury but denied any other visual difficulties. He reports that he was actively playing sports until three years prior to this injury when he sustained a ruptured Achilles tendon.

Notable findings

Vision

- J complained that his vision was "not as effective" in the immediate period after emerging from coma, but he felt that this was improving. He described blurring of vision but no double vision.
- On examination there was a question around J's right visual field with some initial extinction of the right image on bilateral stimulus. Visual acuity in this eye was also slightly reduced at 9/6. The left eye diverged on convergence testing but J could control this to some extent when asked to keep the stimulus in focus. Range of smooth pursuit appeared full although it required effort to move the eyes independently of the head.

Balance and functional movement

- J described his right side as "not as effective" as it should be. He reported catching the right foot and stumbling. He denied any dizziness or nausea.
- J's sitting posture was kyphotic. He gained extra stability by fixing with his arms and gripping the plinth with his legs. He had no difficulty maintaining a stable sitting position even with eyes closed although he reported an initial "circular feeling" on eye closure. In standing he adopted a wide base. The right side was slightly retracted and a slight antero-posterior sway was visible. J reported experiencing the same brief sensation of circular motion on eye closure but there was no deterioration in his stability. J was also able to stand with a more standard base without undue effect.
- The Fukuda Stepping test had to be abandoned because J had moved so far forward across the room. He described feeling that he was swaying but he was not aware of moving forward. The Dix-Hallpike was limited by neck pain and diminished range

of movement. J's treating therapist reported a recent episode of dizziness in the course of intervention to improve neck mobility. VOR gain was reduced and there was a suggestion of specific sluggishness in the right eye.

Tactile and proprioceptive sensation

- J reported a lack of feeling in his right limbs. On examination there was diminished appreciation of light touch in the right lower limb and J had problems with two point discrimination in both right limbs. He also had difficulty discriminating sharp stimuli from blunt, being inaccurate throughout the right limbs and accurate, though hesitant, on the left. Joint proprioception was slow and inaccurate, J used movement to improve his awareness of position. When asked to adopt a supine position he was not aligned and was unaware of this until it was pointed out to him.

Neck

- Neck range of movement was reduced and limited by pain and stiffness. Movements to the right provoked right-sided pain and to the left provoked both right and left-sided pain. J reported left posterior headaches, which he associates with times when his neck is particularly troublesome.

Other observations

- There was evidence of co-ordination deficits in both arms for brisk, precise movements. Balance reactions were observed in the right arm during gait at J's chosen speed and this increased when asked to reduce gait speed. In contrast, the reactions reduced at increased walking speeds and the gait pattern also improved in terms of trunk rotation and arm swing. He did not maintain fluidity when required to turn, choosing to stop and turn rather than incorporate a gradual adjustment and maintain progression. J did not maintain a normal visual horizon.

Opinion

- J displays a combination of a high level hemiparesis, possible cerebellar loop signs and the impact of a symptomatic neck. Although he does experience some sensory disorientation on eye closure, there are no strong signs suggestive of peripheral vestibular pathology. It should be noted, however, that the clinical testing of the peripheral vestibular system was limited on this occasion by neck pain and stiffness.

SECONDARY REVIEW

Injury history

Five weeks of intensive care, recovery complicated by pulmonary embolism. Tendo-achilles rupture three years prior to injury while playing badminton. Post injury neck x-ray reported as generalised degenerative changes.

Synthesis of presenting problems

Awareness that vision was "not as effective": reduce right visual acuity, possible extinction of right stimuli on bilateral presentation, left divergent drift on convergence testing, had to work hard to move eyes only during eye movement testing. Awareness that the right limbs were "not as effective": bilateral slight upper limb ataxia, significant right-sided balance reactions in upper limb during gait (decreased with increased speed but unable to maintain fluidity on turning), diminished accuracy for discrimination on peripheral sensory testing on the right and hesitant on the left, difficulty with multi-joint proprioception, unable to accurately align body in supine without external prompting and visual checking. Reduced range and bilateral pain in the neck (greater right than left). Denies dizziness and only brief circular sensation reported on eye closure during assessment (but Dix-Hallpike limited by neck pain). Treating therapist reports one previous episode of dizziness during neck treatment. Kyphotic posture in sitting with upper and lower limb fixing. Maintained stability in eyes open and closed conditions. Wide-based standing, slight right retraction and slight A-P sway, not increased by eye closure. Similar picture when asked to stand with standard base. Moved forward the full width of the gym during Fukuda stepping test (with slight left deviation) but only perceived a side to side sway. Unable to achieve adequate speed to fully test VOR, right eye appeared sluggish. Right reflexive movement of the head to the right when body rotated to the left in the office chair. No problems on optokinetic testing.

Issues raised by presenting problems

Functional outcome of combined sensory and motor impairments. Fractionation as a prerequisite for successful functional movement. Central vestibular signs.

Subject 24:

53 year old male, 62 weeks post injury, GCS 13, mechanism not recorded

CLINICAL SUMMARY

Pre- injury influencing factors

J has worn reading glasses for the last two years.

Notable findings

Vision

- J complained of blurred vision, which has reduced in frequency over the time since his injury. It remains a problem early in the morning and when he is tired. He does not report double vision.
- Although J has glasses for close work, his visual acuity at six metres was reduced to 18/6 [L] and 12/6 [R]. The rest of the visual screen was unremarkable except for a suggestion of weak convergence. Response to vertical optokinetic stimuli was difficult to visualise.

Neck

- J denied any pre-injury neck problems but was aware that he now had restricted movement and pain, especially on rotation to the left. He said that this had improved following physiotherapy intervention, which is ongoing. Resting position was in upper cervical extension with a slight deviation to the left. Left rotation was around half range and right three-quarters, both limited by end range stiffness as well as left-sided pain. Forward flexion produced the same pain and side flexion was negligible and mainly with rotation because of the upper cervical extension. The forward flexion movement was reticent.

Balance and movement

- J reported frequent stumbling and episodes when he "passes out". He described dizziness on rising from lying, in the morning and when getting up to the toilet (which he reports doing several times each night). Medical notes record early nausea and vomiting but J has had no recent problems with this.
- J gained some extra stability in sitting by fixing with his hands. He was able to maintain a stable position with eyes closed. While quiet standing was fairly stable, J became very anxious on eye closure which he described as like being in a vacuum. He became sweaty and experienced upper limb parasthesia. He was clearly

hyperventilating and was initially unable to accept reassurance. On questioning, he confirmed that this experience was very similar to those he experiences at night and following which he passes out. I did not ask him to perform the Fukuda stepping test. Dix-Hallpike was negative to both sides although his available neck range may confound this result.

- He performed better on active VOR testing than I would have anticipated from his general presentation and he was able to increase speed of head rotation with encouragement. Vertical movements were slower but this was influenced by neck stiffness and habitual head position. On passive testing there was immediate tonal increase in the neck muscles and breath holding.
- J relaxed over the course of the assessment and at the end I asked him to perform some fast walking around a chair, which he was able to do in both directions without provoking dizziness.
- J's gait was slow with a narrow base. He had a good stepping pattern but there was little forward weight transfer and no trunk rotation. On standing from sitting he also avoided leaning forward. He was unable to sustaining walking at an increased pace and he became breathless, probably due to breath holding.

Other observations

- J complained of headache, fatigue and needing to sleep a lot. However, it seems clear from his report of night-time habits that he has a very disturbed sleeping pattern. His performance on limb tactile and proprioceptive screening was hesitant and difficult to interpret. Although he denied any problems with hearing, he appeared to respond less to auditory input on the left.

Opinion

- J's performance improved over the course of the assessment as he became less anxious and following feedback that his dizziness was at least in part being caused by his hyperventilating.
- There is clear documentation of early dizziness and vomiting and of left-sided head lacerations. It would not be unreasonable to assume that a blow to the left side of the cranium would have caused vestibular concussion and disruption (overstretch) of the soft tissues on the left side of the neck. Much of J's movement avoidance and anticipation of noxious sensation could be explained by his early dizziness.

However, his most disabling symptoms are at present at least exacerbated by inappropriate breathing.

- I would recommend a cognitive-behavioural programme to re-educate movement habits and activity levels, incorporating awareness and control of breathing pattern combined with work to improve neck mobility. It may be of value later on to revisit the question of vestibular dysfunction if there are residual symptoms.

SECONDARY REVIEW

Injury history

Laceration left side of head, no fracture, negative CT scan. No recall of incident. Nausea and vomiting for a few days, headache, dizziness and increased need for sleep.

Synthesis of presenting problems

Blurred vision and reduced visual acuity, left worse than right, possibly abnormal response to optokinetic testing in the vertical plane. Head resting position with excess upper cervical flexion and slight left head tilt. Left-sided neck pain and generally restricted range. Denied hearing loss but appeared to respond more to auditory input from the right. Reported frequent stumbling and episodes of "passing out". Reported dizziness on rising from lying, problematic at night, with several toilet visits. Maintained postural stability in sitting, even with eyes closed but preferred to gain extra stability by fixing with upper limbs. Reasonable stability in quiet standing until eye closure when he described feeling like he was in a vacuum, became very anxious, sweaty and reported upper limb parasthesia (clearly hyperventilating), Fukuda not done. Negative Dix-Hallpike (though possibly restricted by neck range), apparently limited vertical VOR (but neck pain and stiffness), protective increase in neck tone and breath holding on passive VOR testing, no problems with body on head rotation. Narrow-based, slow gait lacking rotation and forward weight transference, breath holding when attempting to walk at a quicker pace, avoided forward lean movements throughout assessment. Following explanation of impact of abnormal breathing and reassurance, able to walk around a chair at reasonable pace, in either direction without provoking dizziness.

Issues raised by presenting problems

Anxiety, learned avoidance and hyperventilation.

Subject 25:

26 year old male, 52 weeks post injury, GCS not recorded, assault

CLINICAL SUMMARY

Pre-injury influencing factors

None

Notable findings

Vision

- J reports variable levels of blurred vision on the left side. This was previously more frequent but now occurs primarily when he is tired. He has recently had any eye test and has been told that he is slightly short-sighted. J reports that early in his recovery he misjudged door openings and physical negotiation of similar gaps and would bump into things on his left side. He said that this was no longer a problem.
- On examination visual acuity at six metres was OK although he was slower to read with the left eye. Other than perceiving convergence testing as hard, no other visual problems were noted.

Balance and functional movement

- J described early problems of veering to the right while walking. He now feels unsteady, especially when at the top of a flight of stairs. He describes himself as cautious, preferring to hold on. He does not, however, recall ever falling. J also described being made feel unsteady by objects or activities passing across his visual field.
- On examination, he sat with his head tilted slightly to the left and he fixed with his legs to achieve a feeling of security. On eye closure he perceived that he was swaying from side to side although this could not be seen. He described his right side as 'weightless' - knowing that it was there but experiencing no appreciation of pressure on the weight-bearing surface. In standing, he drifted to the left and an antero-posterior sway could be seen, with correction forward after significant drift back. On eye closure the A-P sway increased and then transformed into an erratic side to side movement. Although the movement was erratic, J did remain in control. He again described a dominant difference in sensory awareness between right and left.

- On the Fukuda stepping test, he progressed several feet forward. Dix-Hallpike was negative. Horizontal VOR testing produced only slow movement and J cited difficulty in maintaining the point of focus as the reason he could not increase the speed. He also identified the right eye as the 'problem'. The upward eye movement on vertical testing was perceived as odd but this could be accounted for by his habitual 'chin-up' head position.

Neck

- J reports that initially after the injury, he was sensitive to neck movement and was tender to touch. This is no longer a problem. On examination the resting head position was in upper cervical extension with a slight tilt to the left. All movements were carried out from this basis, and side-flexion with some rotation but, other than this, range was almost full and there were no complaints of pain or dizziness.

Other observations

- J had to concentrate hard to perform the finger-nose test with the right arm. He reported right facial sensitivity and diminished sensory awareness across modalities. He also reported decreased temperature awareness in both feet, although this was not tested. Although accurate for the modalities of touch and motion, his response was considered and hesitant.
- J describes two kinds of headaches, one of pressure that he associates with stress and fatigue and the second, which is accompanied by stabbing pains into the eye, ear and gums.

Opinion

- The dominant symptomolgy for J is the apparent weightlessness of the right side. In terms of functional balance, although there are no hard peripheral vestibular signs he is clearly vulnerable on the removal of vision and compromised by confusing visual information, which he has difficulty resolving in the time required to prevent a physical response.
- J has an abnormal (extended/tilted) resting head position. The functional examples of when he feels unsteady related to when he would have to move out of upper cervical extension. This movement was also described as feeling strange (and the corresponding eye-up movement) on vertical VOR testing. The stabbing pains with headache are consistent with upper cervical spine pathology. It would therefore

seem important to restore the normal biomechanics of the upper neck for both pain relief and improved balance function.

- I wonder whether his weightlessness, head position and apparent balance dysfunction without dizziness are indicative of otolith dysfunction.
- J report altered sensation in his feet (temperature) and it would be useful to assess peripheral sensation in more depth, at least to exclude it as a primary factor. It would also be of interest to explore J's report of visual degradation (left blurring, feeling of right eye lethargy during VOR) to gain more clarity. Similarly, the apparent conflict between the report of veering to the right and bumping into objects on the left. It is entirely speculative, but possible, that the right veering sensation emanated from disruption of the balance organ while the left visuo-spatial difficulties reflected a primary visual/visual processing deficit.

SECONDARY REVIEW

Injury history

Witnessed loss of consciousness of two to five minutes, no recall of the day of injury and patchy recall of subsequent few days. Occipital impact as fell to ground, bruising left side of face. No fractures.

Synthesis of presenting problems

Reported blurred vision on the left, now only occurring when tired. Reported problems early on in judging spaces within limited environments and bumping into things on the *left* side, now resolved. Also reported problems of veering to the *right* while walking, now much improved. Still feels unsteady, especially at the top of a flight of stairs and when objects or activities pass across his visual field, prefers to have something to hold on to. Although slower to read with the left eye and reporting convergence testing as difficult, no other visual problem observed. Quiet sitting was with slight left tilt/chin up head position and a preference for leg fixing. The subject perceived a side to side sway on eye closure, not seen by the assessor. He described his right side as weightless – knowing it was there but feeling no pressure against the weight bearing surface. A-P sway with some left-sided drift seen in standing with eventual correction after significant sway back. On eye closure the A-P sway increased and then transformed into an erratic side to side movement, although the subject did remain in control. Again he described a dominant difference in sensory awareness between right and left. No problems of accuracy with tactile stimuli, except across the right side of the face (which was hypersensitive), hesitant on discrimination. Reports reduced temperature appreciation in both feet (not tested). No problems with proprioception at single or multi-joint level. Negative Dix-Hallpike. Forward progression only on the Fukuda stepping testing. Slow horizontal VOR with loss of focus (reported as being in the right eye) on trying to increase speed. Upward eye movement on vertical testing was perceived as odd and upward optokinetic response was reduced in expected range. Slight right upper limb ataxia. Weight held back during gait and with a tendency to 'waddle' at slower speeds. Subject reports having to work hard to reduce width of base when walking (right leg especially). Preferred walking at a quicker pace.

Issues raised by presenting problems

Spatial and depth perception. Possible links between right-sided symptoms: otolith organs and central connections.

Subject 26:

28 year old male, 160 weeks post injury, GCS not recorded, fall from scaffolding

CLINICAL SUMMARY

Pre-injury influencing factors

None.

Notable findings

Vision

- P described early post injury problems of constant blurred vision, which resolved steadily over several weeks. He denied any double vision.
- One examination, gaze stability in the primary position appeared normal but there was a suggestion of difficulty maintaining left gaze. Some 'pulses' in the left eye were also observed towards the left, within the normal range of smooth pursuit movements and on voluntary saccades. (The slow component of optokinetic nystagmus was increased on vertical stimulation.)

Balance and functional movement

- P described occasional stumbling, nil recently. He was not sure whether he had fallen since the time of his injury. He described rare sensations of dizziness, which he perceived as the room moving round about him. He said he did not really experience nausea but sometimes felt "a bit spacey" after a hard day.
- In quiet sitting there was a slight rotation of the head to the right. Initially P used his arms to support him but he was able to sit without this assistance when asked. On eye closure he became aware of a slight side to side swaying motion and this could be observed. P held a good standing position but a small antero-posterior sway became evident on eye closure. He denied dizziness but his eyes could be seen to flicker under their lids and there was a distinct impression that he was very uneasy.
- P rotated 135° to the left on the Fukuda Stepping test. No symptoms were felt or observed on the Dix-Hallpike. Active VOR produced a feeling of heavy eyes and P was not quite able to get up to speed. Vertical testing was perceived as harder and P described the difficulty as “losing the focal point”.
- Preferred gait pattern was slow and with an eyes to floor reference point. When requested to walk more slowly, he shortened stride length and maintained the same period of weight-bearing. He had difficulty walking at an increased speed. P was

able to walk looking forward when asked to but he held his eyes fixed. A modified circular walking test provoked dizziness (spinning and nausea) but with relatively quick (10 seconds) recovery.

Neck

- P denied any problems with his neck. On examination, rotation to both sides was about ¾ of normal and right side flexion was performed with extension/rotation. There were no complaints of pain or dizziness.

Other observations

- Tactile and proprioceptive sensation was broadly accurate although response was slow and there was some difficulty in the discrimination of two stimuli within the same limb. Left upper limb co-ordination was obviously less than on the right but possibly within normal limits for a right-handed person.
- P recalls having ringing/buzzing in his ears in his early recovery but this has now resolved.
- P consistently referred to himself as being demotivated. However, the functional examples he gave of this appeared to relate to fatigue or to activities that required speed of movement or visual monitoring.

Opinion

- Whether or not P has a specific peripheral vestibular dysfunction, he has a clear disruption of the balance system. This is apparent on testing in:
  1. the rotation to the left during the Fukuda
  2. the provocation of dizziness by rotational movements or movement at speed ('speed' equalling normal velocity in several instances)
  3. difficulties of gaze fixation
  4. abnormal optokinetic and vestibulo-ocular function.
- Points 3&4 both represent difficulties in keeping the object of regard on the fovea, which is essential for clarity of vision. In my opinion it is not surprising that P experiences fatigue, given the demand of everyday activities on such a dysfunctional system. Coupled together with the experience of dizziness at speed or on rotation, his preference for inactivity is entirely understandable.
- I believe it would be worthwhile exploring P's ability to 'tune-up' each of the functional sub-components and to drive re-calibration to diminish the experience of dizziness.

SECONDARY SUMMARY

Injury history

Witnessed loss of consciousness around ten minutes. Post traumatic amnesia estimated at one week. Fractured left ileum and left triquetral. Bruising and swelling left temple.

Synthesis of presenting problems

Reports of visual blurring, now resolved, occasional stumbling and occasional episodes of dizziness (environmental spinning). Also reports of feeling "a bit spacey" after a demanding day. Observed difficulty with left gaze stability and occasional dysmetria during left eye movement. Quiet sitting was with slight right head rotation and initially with upper limb support. Stability could be maintained without arm support. Side to side sway was perceived and was visible on eye closure. In standing there was a small A-P sway on eye closure and the eyes were seen to flicker behind the lids but the subject denied dizziness or distress although he did appear quite uneasy. Negative Dix-Hallpike, 135° rotation to the left on the Fukuda stepping test, not quite able to keep up to speed on horizontal VOR (complaining of heavy eyes), vertical VOR more difficult with report of losing the focal point. Abnormal response to vertical optokinetic stimuli. Slow gait with visual reference to ground, able to increase speed with difficulty, able to look ahead when asked but with rigidly fixed gaze. Rotational dizziness experienced on modified circular walk test in both directions but with relatively quick recovery (10 seconds) and some latent nausea. Reduced speed of response for sensory testing with cognitive load. Initial impression given of having few difficulties but admits to fatigue, inability to play football and having to have a "break from work" on direct questioning. Chastising self for being lazy and demotivated.

Issues raised by presenting problems

Symptoms suggesting vestibular involvement that are not obviously attributable to (horizontal) semi-circular canal dysfunction. Defining central vestibular dysfunction. Head posture and vestibular imbalance. Inactivity and misattribution.

Subject 27:

29 year old male, 47 weeks post injury, GCS not recorded, motorcycle RTA

CLINICAL SUMMARY

Pre-injury influencing factors

None

Notable findings

Vision

- R has just (two weeks prior to this assessment) obtained glasses from his optician[1], which he thought included prism lenses. He had gone for a visual assessment because of some problems of the right eye 'clouding' and functional difficulty, for example, motorway signs looking misty.
- Without glasses, R had 6/6 vision [L] and 6/5 [R] and with the glasses 6/5 on both sides (Snellen chart). On bilateral field confrontation he named the left-sided stimuli first on each occasion (? influenced by slight left head rotation). On the first occasion of right eye occlusion the left eye deviated slightly outwards but this was not evident on subsequent testing. R had difficulty achieving and maintaining convergence and this affected both eyes, the left apparently more so. He was aware of having to make effort and of his eyes becoming tired. There was no obvious difficulty in clinical observation of smooth pursuit and voluntary saccades. The optokinetic drum produced increase length of slow phase on left going and upward stimuli.

Balance and functional movement

- R reported occasional stumbling but no falls. He said he felt unsteady only when he was also dizzy. He described a pattern of intermittent periods of dizziness, roughly of two weeks on and six weeks off. His dizziness is rotational in nature with a sense of upward and backward movement and a duration of about 15 seconds.
- Quiet sitting was unremarkable except for a drift of the head to the left, with some rotation. On eye closure, R perceived a wavy sensation of his body moving and his head correcting - there was no observable sway, just head drift as previously mentioned. In standing there was a slight rotation of the right upper trunk into

[1] R was not sure that he needed the glasses he was given and wasn't sure if he would wear them.

shoulder retraction along with the left drift of the head. R was aware of changes in pressure on the soles of both feet. On eye closure he felt he was moving back and forward over his feet but again there was no obvious movement to be observed.

- R's physiotherapist had previously looked at the Fukuda stepping test, which produced a 90°rotation to the right. On this occasion he first turned slightly to the left and then the right and then deviated left from the mid-line while consistently moving forward. On Dix-Hallpike to the right, his eyes filled-up and blinking rate increased, R experienced a momentary 'whoosh' sensation. On testing to the left, he felt slightly dizzy on return to the upright. Active VOR testing in the horizontal plane was tolerated only at reduced speed. On trying to increase speed, left head rotation produced an illusion of the visual target dipping. Vertical testing speed was still at reduced speed but performance was better than on horizontal.
- R walked with some retraction of the right upper trunk and the trunk as a whole was fixed and angled backwards. The same lack of forward movement of the upper body was evident in standing from sitting. When asked to walk faster than his chosen speed he experienced a brief sensation of continued motion on stopping. R also experienced dizziness during a short trial of circular walking (clockwise and anticlockwise) and significant after motion.

Neck and other observations

- Basic cervical range of movement was good. R described pressure at the cervico-thoracic junction on neck extension and side flexion to either side was performed with the head deviated to the left. He did not complain of pain or dizziness. R sustained fractures of three thoracic vertebrae in the course of his accident and continues to experience postural aching, specific pain and locally altered sensations.
- Although early in the interview he denied any problems with hearing or his ears, including a negative response to the question of whether he ever experienced any added noises in his ears R later described having experienced popping noises in his ears. He said that he had been sent for an ENT opinion but no abnormality was found.
- R performed finger/nose testing at great speed and, ?as a result of the speed, made several misses on the left.

Opinion

- It would be useful to examine the referring letter for, and the results of, the ENT opinion to get a better idea of the factors prompting referral, the areas covered, and the findings.
- R describes fluctuating levels of dizziness. This can be associated with different types of pathology, e.g Menieres Disease (which could exist separate to the TBI, but is usually accompanied by hearing loss) or Perilymph Fistula (which can result from direct trauma or straining and is often accompanied by popping noises within the ear but frequently also hearing loss). However, it may be that the 'fluctuations' result from changes in activity levels so that it appears to R that at times he is not dizzy. There may be a component of Benign Paroxysmal Postural Vertigo (which can be provoked by certain positions or movements) or simply an uncompensated vestibular loss. The difficulties described in maintaining clear vision while moving may be attributable to dysfunction of the vestibulo-ocular or optokinetic systems.
- R is also clearly having difficulty with the mechanisms involved in near vision. It would be useful to speak directly to the prescribing optometrist to establish the rationale behind R's glasses prescription, e.g. are they designed to assist convergence? It may be that a more specialist assessment by an orthoptist with experience of post-traumatic visual disorders could add to the overall picture and advise on management, including the prescription of special exercises.

SECONDARY SUMMARY

Injury history

Reports loss of consciousness but regained at scene. Fractured T6,7&8 with instability. Left facial bruising.

Synthesis of presenting problems

Reports right eye "clouding". Good acuity, and eye movements, problems of convergence, increased slow phase left going and upward stimuli on optokinetic testing. Reports stumbling and feeling unsteady when dizzy, reports fluctuating periods of intermittent dizziness. Dizziness is rotational with a sense of upward and backward movement. Quiet sitting produced left rotational head drift in both conditions and a perception of a wavy sensation of body moving and head correcting (only head drift seen). In standing there was backward rotation of the right shoulder girdle and left rotational head drift as before. On eye closure there was a feeling of moving back and forward over the feet but with no observable sway. He vacillated slightly to the left (rotation) then significantly to the right (rotation) and finally to the left (deviation) while all the time moving forward on the Fukuda stepping test. On Dix-Hallpike to the right he reported a momentary “whoosh” sensation and his eyes filled up and blink rate increased, he reported feeling slightly dizzy on return to sitting on from the left. Blink rate also increased in right side lying. Adequate speed for VOR testing was not achieved and he reported the visual target as dipping on left rotation when trying to increase the speed. The trunk was ‘fixed’ in backward inclination and slight right shoulder retraction during gait and a sensation of continuing motion was reported on stopping after walking at increased pace. Dizziness and after motion sensation also reported on modified circular walking test. Cervical movements were unremarkable except for the predominance of left rotation. Responses to stimuli on peripheral sensation testing were accurate and prompt. Slight ataxia was noted in the left upper limb. After initially denying any problems with hearing or added noise the subject mentioned he had been sent for and ENT opinion because of popping noises in his ear. He reported that no problems were found (referral had not been made known to the treating team and relevant notes were not available).

Issues raised by presenting problems

Functional effects of interacting impairments. “Corrective” movements and postural drift. Developing clarity in the clinical history.

Appendix 3:

Taxonomy of trauma related vertigo

Table A3.1

Site	Syndrome	Mechanism
Labyrinth	Otolith vertigo	Loosening of otoconia
	Benign paroxysmal positioning vertigo	Canalolithiasis
	Loss of labyrinthine function	Temporal bone fractures, concussion or haemorrhage
	Perilymph fistula	Round or oval window rupture, temporal bone fracture or haemorrhage
Vestibular nerve	Loss of vestibular function	Concussion or haemorrhage
Brainstem or vestibulocerebellum	All central vestibular vertigo syndromes (downbeat/upbeat nystagmus, ocular tilt reaction, central positional nystagmus/vertigo, etc.)	Concussion, haemorrhage, or stroke (e.g. vertebral artery dissection)
Cervical	Whiplash vertigo (not a clear entity) Cervical vertigo?	Not known (vascular compression?, neuromuscular?, neurovascular?)
Psychogenic	Phobic postural vertigo	Anxious introspection causes dissociation between efference and efference copy
	Secondary gain factors	

Taxonomy of trauma-related vertigo (Brandt, 1999)

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REFERENCE

Brandt, T. (1999). Head and neck injury. In T. Brandt (Ed.), *Vertigo: its multisensory syndromes* (2nd ed., pp. 345-350). London: Springer-Verlag.