Constraints on movement variability during a discrete multi-articular action

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ABSTRACT

The aim of this programme of work was to examine how the manipulation of organismic and task constraints affected movement variability during a basketball shooting task. The specific constraints that were manipulated included task expertise, state anxiety and dioptric blur (organismic constraints), and, shooting distance and attentional focus instruction (task constraints). The aim of Study 1 was to investigate the effect of shooting distance and task expertise on movement variability. Task expertise was characterised by decreased coordination variability and heightened compensatory variability between wrist, elbow and shoulder joints. However, no significant difference was found in joint angle variability at release as a function of task expertise. There was no significant change in movement variability with shooting distance, a finding that was consistent across all expertise groups. In Study 2, the aims were to examine the effect of induced dioptric blur on shooting performance and movement variability during basketball free-throw shooting, and, to ascertain whether task expertise plays a mediating role in the capacity to stabilise performance against impaired visual information. Significant improvements in shooting performance were noted with the introduction of moderate visual blur (+1.00 and +2.00 D). This performance change was evident in both expert *and* novice performers. Only with the onset of substantial dioptric blur (+3.00 D), equivalent to the legal blindness limit, was there a significant decrease in coordination variability. Despite the change in coordination variability at +3.00 D, there was no significant difference in shooting performance when compared to the baseline condition. The aims of Study 3 were to examine the effect of elevated anxiety on shooting performance and movement variability and, again, to determine whether task expertise plays a mediating role in stabilising performance and movement kinematics against perturbation from emotional fluctuations. Commensurate with the results of Study 2, both expert and novice performers were able to stabilise performance and movement kinematics, this time with elevated anxiety. Stabilisation was achieved through the allocation of additional attentional resources to the task. Study 4, had two aims. The first was to examine the interactive effects of practice and focus of attention on both performance and learning of an accuracy-based, discrete multi-articular action. The second was to identify potential focus-dependent changes on joint kinematics, intra-limb coordination and coordination variability. Support was found for the role of an external focus of attention on shooting performance during both acquisition and retention. However, there was evidence to suggest that internal focus instruction could play a pivotal role in shaping emerging patterns of intra-limb coordination and channelling the learners' search towards a smaller range of kinematic solutions within the perceptual-motor workspace. Collectively, this programme of work consistently highlighted the fundamental role that constraints play in governing shooting performance, movement variability and, more broadly, perceptual-motor organisation. For instance, task expertise was characterised by decreased coordination variability and heightened compensatory control. However, in light of the data pertaining to joint angle variability at release, general assumptions about expertise-variability relations cannot be made and should be viewed with caution. In addition, there is strong evidence to suggest that adaptation to constraints is, perhaps, a universal human response, and consequently not mediated by task expertise. Further research is needed to fully elucidate this proposition.

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At times I thought I would never get to this stage. I think the following two quotes by Winston Churchill and Thomas Edison respectively capture my PhD journey perfectly.

"Never give in! Never give in! Never, never, never, never – in nothing great or small, large or petty. Never give in except to convictions of honor and good sense."

"Many of life's failures are people who did not realize how close they were to success when they gave up."

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CHAPTER I

INTRODUCTION

Movement variability is an inherent movement phenomenon both within and between individuals (Newell and Corcos, 1993). Movement variability exists because of the vast number of biomechanical degrees of freedom available to the human movement system, a principle referred to as motor abundance. Traditionally, movement variability was considered detrimental to sporting performance and viewed as error or noise. The implication of this negative connotation was that invariance in the product or outcome i.e. motor performance, required invariance in the process i.e. the movement pattern. However, the emergence of dynamical systems theory as an alternative to traditional information processing perspectives has reconceptualised the role of movement variability during goal-directed behaviour and considers it to be an integral and functional characteristic of motor behaviour. These new theoretical insights into movement variability are allied to the growing evidence base that suggests movement variability is indicative of "normal, healthy function" (see van Emmerik and van Wegen, 2000; 2002), and can serve several purposes. For instance, movement variability reputedly affords motor system flexibility by facilitating the change between different modes of coordination, allows adaptation to changing environmental conditions, and permits the broader distribution of impact forces to attenuate possible overuse injury (for a review, see Bartlett *et al.*, 2007). The functional role of movement variability is further exemplified by the strong compensatory behaviour and covariance between interacting joints that develops with practice and is used to satisfy specific task goals (e.g. Arutyunyan *et al.*, 1969, Winter, 1984; Kudo *et al.*, 2000; Ko *et al.*, 2003b; Chiang and Yeou, 2007).

The constraints-led approach, pioneered by the framework proposed by Newell (1986), suggests that the constraints of the organism, task, and environment govern motor coordination and control. Furthermore, it has been postulated that the dimensionality of attractor dynamics is influenced by the confluence of constraints on action (Newell and Vaillancourt, 2001). Vaillancourt and Newell (2002, p. 1) argue that: *"The specific direction of change in complexity is dependent on the nature of the intrinsic dynamics of the system and the short-term adaptive change required to meet an immediate task demand."* Importantly, the magnitude of movement variability also appears to be dependent on the specific constraints on action (see Newell and James, 2008). However, there is currently limited empirical evidence pertaining to movement variability under certain constraints, such as those concerning target distance (e.g. Robins *et al.*, 2006), anxiety (e.g. Higuchi *et al.*, 2002), dioptric blur, or, focus of attention (Lohse *et al.*, 2010). Instead, research within these fields of study typically focuses on performance outcome measures, rather than exploring the movement kinematics and associated variability. In addition, there is a distinct lack of research into whether the change in movement variability under specific constraints is mediated by task expertise. It is important to ascertain whether the change in movement variability with, for example, elevated anxiety or changing target distance is homogeneous across different expertise groups. As surmised by Newell and James (2008, pp. 102): *"A theory of movement variability needs to be able to generalise across the changing constraints to action."* Therefore, the aim of this programme of work was to examine how the manipulation of organismic and task constraints affected movement variability during a basketball shooting task.

1.1 STRUCTURE OF THE THESIS

The structure of the thesis is as follows. Chapter 2 provides an extensive, critical review of the pertinent research. Specifically, Bernstein’s “degrees of freedom problem”, the dominant motor control theories e.g. information processing theory, dynamical systems theory and constraints-led approach, and the historical development of movement variability as an inherent movement phenomenon are detailed. Moreover, the functional role of movement variability is outlined and several lines of scientific enquiry documented. Chapters 3-6 inclusive relate to the experimental studies, the titles of which are:

Chapter 3: Distance and Task Expertise as Constraints on Movement Variability during Basketball Shooting.

Chapter 4: Dioptric Blur as a Performance Perturbation during a Discrete Multi Articular Action.

Chapter 5: Effects of Expertise and Anxiety on Attentional Strategies and Joint Kinematics During a Discrete Multi-Articular Action.

Chapter 6: Focus of Attention and Discrete Action Performance: A Process-Oriented Approach.

Finally, Chapter 7 synthesises the key findings from the programme of work and provides a general discussion in relation to pertinent, past research. The findings are also interpreted using dominant theoretical paradigms. The limitations of the programme of work are then acknowledged and future recommendations proposed.

1.2 LIST OF ABSTRACTS

Conference Abstracts

Robins, M.T., Davids, K., Bartlett, R.M. and Wheat, J.S. (2007). Effects of attentional strategies, task expertise and anxiety on coordination of a discrete multi-articular action. In H.-J. Menzel and M.H. Chagas (Eds.) *Proceedings of the XXVth International Symposium on Biomechanics in Sport*, 274-277.

Robins, M.T., Davids, K., Bartlett, R.M. and Wheat, J.S. (2008a). Expertise and distance as constraints on coordination stability during a discrete multi-articular action. In Y.-H. Kwon, J. Shim, J.K. Shim and I.-S. Shin (Eds.) *Proceedings of the XXVIth International Symposium on Biomechanics in Sport*, 408-411.

Robins, M.T., Davids, K., Bartlett, R.M. and Wheat, J.S. (2008b). Changes in compensatory variability as a function of task expertise and distance during basketball shooting. In Y.-H. Kwon, J. Shim, J.K. Shim and I.-S. Shin (Eds.) *Proceedings of the XXVIth International Symposium on Biomechanics in Sport*, 473-476.

CHAPTER II

REVIEW OF LITERATURE

2.1 INTRODUCTION

Motor control is broadly defined as:

> *"…a sub-discipline within the field of motor behaviour that is concerned with neurological, mechanical, and behavioural explanations of how humans control movements."*
>
> (Fairbrother, 2010, p. 7)

The scientific sub-discipline of motor control initially developed from the synthesis of two scientific fields; neurophysiology and psychology, and is concerned with the study of perception, cognition and action, as well as the formulation and empirical testing of theories (Utley and Astil, 2008). Although perception, cognition and action are inherently interwoven, of particular relevance to the current programme of work, and one that has received extensive appraisal from the human movement sciences (e.g. Turvey, 1990; Newell and Vaillancourt, 2001; van Emmerik *et al.*, 2004), is the study of action.

One of the seminal questions explored within this field of scientific enquiry is how complex, neurobiological systems, such as human beings, are able to coordinate and control the vast number of biomechanical degrees of freedom at their disposal. Biomechanical degrees of freedom refer to the many different joints and limb segments that are free to vary in both position and velocity (Davids *et al.*, 1994). It is important to note that biomechanical degrees of freedom do not equate to, and should therefore not be confused with, active (dynamical) degrees of freedom. Active degrees of freedom are the number of first order, autonomous, differential equations needed to fully capture a system's evolving behaviour (Mitra *et al.*, 1998). Consequently, many biomechanical degrees of freedom could, potentially, be used for the maintenance of a small number of active degrees of freedom. For example, the maintenance of a limit cycle (active degree of freedom) can be achieved by means of interacting trunk and leg movements (numerous biomechanical degrees of freedom) during upright stance (see van Emmerik *et al.*, 2005). However, Newell and Vaillancourt (2001) postulate that there is no obvious correlation between the number of biomechanical degrees of freedom and the dimensionality of an attractor.

This challenge to assemble and organise functional, coordinated behaviour, referred to as Bernstein's (1967) "degrees of freedom problem", is exemplified by the circa 100 biomechanical degrees of freedom available to the human movement system (Turvey, 1990), thus highlighting its tremendous complexity. Complexity can be operationally defined as the number of constituent parts that comprise a system (see Davids *et al.*, 1994). Traditionally, complexity was viewed negatively, and deemed to be a "curse" that should be overcome if functional, coordinated behaviour was to emerge. However, this view has been reconceptualised, and complexity is now seen to be a blessing, affording the movement system flexibility and the ability to adapt to changing task and environmental conditions (see Latash *et al.*, 2005; Latash, 2012).

The change in conceptualisation from "curse" to "blessing", or, "problem" to "bliss" (see Latash, 2012) is paralleled by the change in terminology used within the literature, and reflected the need to develop adequate language within the field of motor control (see Gelfand and Latash, 1998). Historically, Bernstein's (1967) "degrees of freedom problem" was also referred to as the problem of motor redundancy and proposed that the elimination of redundant degrees of freedom was essential during initial stages of motor skill learning and for the development of appropriate modes of coordination. However, redundancy implies a surplus to requirements, and although the term still pervades the literature (e.g. Todorov and Jordan, 2002; Todorov *et al.*, 2005; Braun and Wolpert, 2007; Guigon *et al.*, 2007), the scientific principles of motor abundance (Latash, 2000; Latash, 2012) and degeneracy (Tononi *et al.*, 1999; Edelman and Gally, 2001; Price and Friston, 2002; Friston and Price, 2003) have now been promoted. Specifically, Latash (2000, p. 260) argued that biomechanical degrees of freedom "*find their own place within a task*", and consequently could be modulated, explored or limited, but never eliminated. Latash (200) further argued that elimination could only ever be achieved through surgical procedure. As such, motor abundance was considered a more appropriate term to capture the notion that more degrees of freedom than perhaps are needed are used to form structural units (i.e. synergies) during goal-directed behaviour.

The term degeneracy has been imported into the human movement sciences (e.g. Davids and Baker, 2007; Glazier and Davids, 2009a; Davids, 2010; Davids and Glazier, 2010) from neurobiology and was pioneered by the work of Edelman and co-workers (e.g. Tononi *et al.*, 1999; Edelman and Gally, 2001). Degeneracy is defined as: "*the ability of elements that are structurally different to perform the same function or yield the same output*" (Edelman and Gally, 2001, p. 13763). The key difference between degeneracy and redundancy is that redundancy means that the same function is performed by identical elements. Conversely, degeneracy relates to structurally different elements performing the same or different function, depending on the context i.e. the specific constraints on action (Edelman and Gally, 2001). The difference between redundancy and degeneracy is further exemplified by the following quote that clearly captures the distinction:

"Waving goodbye with both hands is redundant, because either hand alone would suffice. Note that this redundancy can only be expressed with (a degenerate set of) two hands."

(Friston and Price, 2003, p. 152)

Degeneracy has been reported within genetic and immune systems as well as cognitive anatomy (see Tononi *et al.*, 1999). For instance, Price and Friston (2002) acknowledge the role of degeneracy within neurophysiology when the brain is subjected to physiological lesion. From a human movement perspective, degeneracy affords motor system flexibility because the same outcome can be achieved by a variety of equally functional kinematic solutions. Moreover, the biomechanical degrees of freedom can adopt the same or differing roles depending upon the specific situational context. The use of differing kinematic means to achieve the same outcome is also referred to as (sensori)motor equivalence[1] (see Scholz *et al.*, 2000).

In trying to understand how complex neurobiological systems coordinate and control these abundant degrees of freedom during goal-directed behaviour, and ultimately acquire skilled motor performance, numerous motor control theories have been developed. Anson *et al.* (2005) argue that although human movement scientists have devised numerous methods to quantify both the coordination and control of movements, an empirically tested and unified theory governing these processes has yet to be ascertained. The dominant theories relating to human movement include; information processing theory (Fitts, 1954; Adams, 1971; Schmidt, 1975; Masson, 1990), dynamical systems theory (Kelso *et al.*, 1981; Kugler and Turvey, 1987; Kelso and Schoner, 1988; Kelso, 1995), the constraints-led approach (Newell, 1986; Newell and Valvano, 1998;

[1] The use of a variety of comparable terms i.e. redundancy, abundance, motor equivalence, degeneracy etc., highlights the apparent tautology that exists within the field of motor control (see Savelsbergh, 2003).

Newell and Jordan, 2007), ecological dynamics (Araújo *et al.*, 2006; Vilar *et al.*, 2012; Vilar *et al.*, 2013), neuronal group selection theory (also referred to as neural Darwinism) (Sporns and Edelman, 1993; Hadders-Algra, 2000; Heineman *et al.*, 2009; McDowell, 2010), and the modular selection and identification for control (MOSAIC) model of movement control and learning (Wolpert and Kawato, 1998; Wolpert *et al.*, 2003). Although dynamical systems theory, constraints-led approach and ecological dynamics have been stated separately, it is important to note that these three theories are complementary and share numerous theoretical commonalities i.e. principle of self-organisation. The central tenets of the more dominant theoretical paradigms will now be discussed to provide an overarching historical perspective.

2.2 DOMINANT THEORETICAL PARADIGMS

2.2.1 INFORMATION PROCESSING THEORY

Information processing theory, also referred to as the traditional cognitive approach, is predicated on the work of Adams (1971) and Schmidt (1975). The key principles of information-processing were aligned with those from computer sciences, such as the computational decoding and processing of information, referred to within the human movement science literature as indirect perception, and motor programs (see Handford *et al.*, 1997). The theory of indirect perception considered sensory information e.g. visual information, to be impoverished, and in need of interpretation before use. The raw sensory information would enter into a series of computational stages before the relevant motor programme could be initiated. This led to the formulation of the five stage information processing model: stimulus, stimulus identification, response selection, response programming, and response (Schmidt and Wrisberg, 2004). In light of these computational stages, information processing theory is commonly known as the "computer metaphor". In addition, from a philosophical perspective, information processing theory promoted a dualist or separatist approach. A dualist approach argued that the mind and body were, in essence, two separate entities and that the mechanics of the musculoskeletal system were enslaved to higher order, mental processes (Davids *et al.,* 1994).

The initial work of Adams (1971) placed the emphasis on two distinct memory states, something which Schmidt (1975) later adapted when devising the schema theory of discrete motor skill learning (for a review, see Schmidt, 2003). Adams (1971) postulated the existence of two memory states; the memory trace and the perceptual trace. The function of the memory trace was to select and initiate a response, whereas the perceptual trace acted as a "reference of correctness" by which movements were prospectively compared to a representation of past movements as the action progressed, and retrospectively used to inform future behaviour. Support for Adams' (1971) closed-loop theory was obtained from numerous learning studies that involved the manipulation of knowledge of results, and investigated its affect on performance error during acquisition of precision-based movement tasks (e.g. Schmidt and White, 1972).

Schmidt (1975) integrated several of the ideas embraced by Adams (1971) within the proposed Schema Theory, which Newell (2003, p. 384) argues is a "*schematized version of Adams' (1971) closed-loop theory*". The central tenets of Schema Theory include: (1) the introduction of schema, defined as the relationship between the outcome (e.g. throwing distance) and the parameters (e.g. force) of an action, (2) the role of recall and recognition memory for governing rapid, ballistic movements (open-loop process) and slower, self-paced movements (closed-loop process) respectively, and, (3) generalised motor programs (see Schema, 2003). The promotion of generalised motor programs deviated from past theories, and argued that coded or prearranged information, in the form of generalised motor programs, was used to govern a *class* of actions e.g. throwing, kicking etc. (Vanberg, 2002). This contrasted with previous views that hypothesised a bespoke motor program for each individual motor action variant.

Motor skill learning was therefore characterised by the development of these motor (recall and recognition) schema with practice and experience. Incorporation of schema and generalised motor programs within the theory provided a valid theoretical explanation for the human movement system's complex repertoire of movements and ability to scale and adapt movement parameters to satisfy changing environmental conditions. A strong theme within Schema Theory was also that for certain movement tasks, action events were pre-programmed. Consequently, closed skills that were fast and of short duration e.g. golf putting or basketball free-throw shooting, were considered to be pre-programmed in advance, with the necessary motor commands "primed" once the required sensory information had been extracted, interpreted and processed.

Empirical support for this contention has been found from the work pertaining to the "quiet eye" (e.g. Vickers, 1996a; 1996b; Adolphe *et al.*, 1997; Harle and Vickers, 2001; Williams *et al.*, 2002). For example, there is evidence to suggest that for closed, accuracy-based motor skills, quiet eye duration is positively related to task expertise (for a review, see Vickers, 2007). The quiet eye period is defined as: "*the final fixation from onset to the first observable initiation of the movement*" (Vickers, 1996, p. 348). Consequently, expert performers have been found to fixate significantly longer on a target than non-experts before initiating the movement. This expertise-related perceptual strategy is exemplified by Williams *et al.* (2002) who examined the interactive effect of quiet eye duration, expertise and task complexity on performance of a near and far aiming task (billiards). Specifically, it was found that quiet eye duration significantly increased as a function of both expertise and task complexity. Skilled and less skilled participants fixated for a mean duration of 500 ms and 276 ms respectively. In addition, the quiet eye period was significantly longer for successful (562 ms) when compared to unsuccessful (214 ms) shots. Interestingly, skilled participants not only appeared to demonstrate a longer quiet eye period but also used visual suppression during the execution phase of an action. Vickers (1996) observed that expert participants blink and, in essence, try to suppress on-going visual information as the movement unfolds. This suppression mechanism is suggested to prevent any disruption to the motor program that has been executed. Collectively, the use of a longer quiet eye period in conjunction with visual suppression is referred to as the location-suppression hypothesis. Consequently, the location-suppression hypothesis is suggested to permit more effective motor (pre)programming during the preparation phase, coupled with greater automaticity during the execution phase.

Although, motor schema theory has remained a robust theoretical framework since its inception almost 40 years ago, a number of criticisms have been proposed. These criticisms include those pertaining to; storage, novelty, “degrees of freedom problem” and homunculus (or “man in the brain problem”) (for a review, see Handford *et al.*, 1997), and can collectively be embodied by the concept of organismic asymmetry[2] (see Davids and Araújo, 2010; Araújo and Davids, 2011). In addition, proponents of information-processing theory have been accused of compartmentalising behaviour and focussing, principally, on outcome variables such as performance or reaction time.

[2] Organismic asymmetry relates to the emphasis on internal, “organism-centred” (Davids and Araújo , 2010, pp. 633) mechanisms for the explanation of human motor behaviour, as opposed to seeking explanations based on the interaction between the individual and the environment.

Moreover, much of the early empirical work focused on simple, laboratory based studies that, although permitted high internal validity, did not allow sound transfer to more complex, representative actions. Newell (1989) argued that narrowing the range of tasks under investigation may ultimately lead to a line of thinking that holds little relevance. Supporting the notion of organismic asymmetry, this argument is further captured by Walter (1998, p. 326) who summarised the need to move towards alternative experimental paradigms, and based these insights on the work of Lewin's (1936) (cited in Walter, 1998) monograph entitled "*Principles of Topological Psychology"*:

> *"Particular emphasis was placed on what he (Lewin) described as the need for a transition from the Aristotelian view of "cause" as intrinsic to an isolated object, organism, or component to the Galilean notion of the importance of relationships in determining events."*

Consequently, dynamical systems theory has emerged as a rival theory to address such limitations and offer a more viable theoretical framework for processes of motor control and motor skill learning. In accordance with Lewin's (1936) original recommendation, dynamical systems theory placed stronger emphasis on the interaction between the organism and environment. Consequently, dynamical systems theory has, in some quarters, been referred to as the "natural physical alternative" to traditional cognitive psychology (e.g. Davids *et al.*, 1994).

2.2.2 DYNAMICAL SYSTEMS THEORY

With the often maligned product-oriented nature of information-processing theory driven research (e.g. Handford *et al.*, 1997; Newell, 2003), dynamical systems theory emerged as a viable alternative, although not itself without its critics and challenges (see Lee, 1998; Walter, 1998), that placed greater emphasis towards a process-oriented perspective. The challenges facing the promotion of dynamical systems theory as a viable theoretical framework were surmised by Lewis (2000, p. 36) who, in attempting to debunk the seminal principles of dynamical systems theory, stated that: "*Many developmentalists are intrigued by the DS (dynamical systems) approach but they do not fully understand it, and their confusion is exacerbated by the new and competing terminologies, conceptual ambiguities, and methodological disagreements that pervade DS writings*".

Rather than a hierarchical control structure, as postulated by information-processing theorists, dynamical systems theory advocated a more heterarchical structure, where: "*intelligence can reside at many levels of the neuromotor apparatus and where no level is privileged*" (Jensen *et al.*, 1989, p. 399). Specifically, dynamical systems theory aligned itself to the aforementioned "degrees of freedom problem" pioneered by Bernstein (1967), and rejected the notion of the "computer metaphor". Bernstein (1967) was particularly concerned with how effective coordination emerged at different levels of analysis (e.g. inter-limb, intra-limb etc.), when so many different (and complex) interactions could occur between the respective muscles and joints. Bernstein (1967) classically defined coordination as:

"...the process of mastering redundant degrees of freedom of the moving organ, in other words its conversion to a controllable system."

(Bernstein, 1967, p.127)

Furthermore, Turvey (1990) argued that coordination could be defined either macroscopically, in terms of patterning of limb and body movements, or microscopically, for instance, configurations and patterning of sub-systems at a cellular level. Dynamical systems theorists actively pursued what Latash and Anson (1996) referred to as the quest for coordinative rules as opposed to unique solutions of motor control problems. Explaining how order and regularity emerged from a complex, degenerate human movement system was central to the inception and development of dynamical systems theory.

Dynamical systems theory is a multi-disciplinary approach to motor control and motor skill learning that integrates ideas from numerous scientific disciplines, such as physics, mathematics, biology and psychology (Davids *et al.*, 2003a). It has been applied to a number of scientific fields, including; motor development (e.g. Thelen, 1985; Thelen *et al.*, 1987; Thelen, 1995; Newell *et al.*, 2003), sports medicine (e.g. Davids *et al.*, 2003a), physical therapy (Harbourne and Stergiou, 2009), motor skill learning (e.g. Schoner *et al.*, 1992; Zanone and Kelso, 1997; Newell *et al.*, 2003; Hong and Newell, 2006), as well as multi-agent (social) systems such as inter-personal coordination (Schmidt *et al.*, 1990; Turvey *et al.*, 2011) and player-player, or, attacker-defender interactions during sports competition (e.g. Grehaigne *et al.*, 1997; McGarry *et al.*, 2002; Walter *et al.*, 2007; Correia *et al.*, 2011; Passos *et al.*, 2011).

Broadly speaking, a dynamical system is considered to be any system that evolves over time (Kay, 1988). Classically, three major time scales have been proposed that are suggested to influence the emergence of coordinated behaviour; the very slow time scales of evolution (phylogeny), the more rapid time scales of ontogenetic (socially driven) development, and the much more rapid time scales of biological processes (see

Newell *et al.*, 2003). In contrast to structural models of motor coordination, dynamical systems theory is considered to belong to the subclass of phenomenological models, whose goal is to describe functional properties without addressing the structural basis of these properties (Beek *et al.*, 1995). Stated more simply, the central tenets of dynamical systems theory can be used to explain the emergence of coordinated behaviour, regardless of system structure. This phenomenological approach is a particular strength because it provides a credible theoretical framework for how a wide variety of systems exhibit the same type of behaviour, irrespective of how different their internal structures may be (Beek and Beek, 1989).

The characteristic features of a non-linear dynamical system include: (1) attractors, (2) multi-stability (3) bifurcations, (4) critical fluctuations, and (5) hysteresis. Before outlining the pertinent research supporting these characteristic features, it is important to operationally define each term. An attractor is a: "*preferred state or sequence of states that is "attracted to" from arbitrary initial conditions or following perturbation*" (Kay, 1988, p. 347). Hence, attractor states equate to functionally preferred patterns of coordination, and represent the stable and reproducible spatial and/or temporal relationships that exist between elements, or micro- or macro-components, of a biological system (see Schoner *et al.*, 1992; Clark, 1995). Multi-stability relates to: "*the existence of multiple, qualitatively distinct patterns in a state space, each of which is stable over some range of values of a control parameter*" (Bardy *et al.*, 2002, p. 511). The terms bifurcations and critical fluctuations can be considered complementary. Bifurcations relate to the abrupt qualitative changes in a system's organisation when a control parameter reaches a critical value, whereas critical fluctuations are increases in movement variability that are deemed to facilitate the emergence of a new coordination mode. Finally, hysteresis broadly relates to the differential influence of scaling direction i.e. increasing or decreasing a control parameter, on system transitions (for a review of these terms, see Bardy *et al.*, 2002).

Empirical support for these unique dynamical features is founded on bimanual rhythmic coordination tasks (e.g. Kelso *et al.*, 1981; Scholz and Kelso, 1989; Scholz and Kelso, 1990; Schmidt *et al.*, 1992; Court *et al.*, 2002), and postural dynamics (e.g. Bardy *et al.*, 2002). Bimanual rhythmic coordination tasks involve the synchronous oscillation of body segments, typically the index fingers, at varying movement frequencies. During bimanual rhythmic coordination there are two stable patterns of coordination, or attractors; an in-phase pattern and an anti-phase pattern. The in-phase pattern involves the simultaneous flexion/extension of right and left limb/fingers, whereas an anti-phase pattern means one limb/finger is flexing whilst the other limb/finger is extending. Coordination between oscillating limbs/fingers is captured using a collective variable, or order parameter. The order parameter is a variable that adequately captures the coordination dynamics of a system. In the case of bimanual rhythmic coordination, the order parameter is typically relative phase, with a relative phase value of 0° and 180° equating to an in-phase and anti-phase pattern respectively. Inter-limb coordination is then monitored as a specific control parameter is manipulated. A control parameter is something that moves the system through its potential states, constraining the behaviour of a system e.g. movement frequency (for a review, see Kelso, 1994).

One of the seminal studies concerning bimanual rhythmic coordination was conducted by Scholz and Kelso (1989). Participants were required to rhythmically oscillate their index fingers in either an in-phase or anti-phase mode of coordination. A metronome was used to regulate movement frequency, and after a period of 10 s, the metronome pulse increased incrementally by 0.2 Hz. Participants were requested not to intentionally switch between coordination modes because intentionality is considered a powerful organismic constraint for stabilising desired coordination dynamics (Scholz and Kelso, 1990). It was found that the in-phase pattern of coordination was inherently more stable than the anti-phase pattern of coordination, indicating differential stability within this particular task. This finding was evidenced by the transition from anti-phase to in-phase mode of coordination as oscillatory speed increased. However, there was no such change from in-phase to anti-phase with increased movement speed. The in-phase pattern persisted regardless of any change in the control parameter. Interestingly, increases in movement variability, termed critical fluctuations, subserved the transition from anti-phase to in-phase pattern of coordination. Hence, movement variability appeared to possess a functional role in permitting a new pattern of coordination to emerge.

Corroborating data have been found for human stance. Bardy *et al.* (2002) examined postural coordination during a task that involved tracking a moving target with the head. The oscillation frequency of the target (control parameter) was incrementally changed, and the corresponding effect on lower limb coordination (order parameter), calculated as the relative phase between hip and ankle, recorded. Commensurate with bimanual rhythmic coordination, two modes of coordination were observed; an in-phase mode and an anti-phase mode. Multi-stability therefore appears to be a distinctive feature of (non-linear) dynamical systems. The in-phase mode was, again, inherently more stable than the anti-phase mode, and changes in coordination pattern were preceded by critical fluctuations, increases in the standard deviation of relative phase. Following the phase change, however, there was a significant reduction in relative phase variability.

The findings of Bardy *et al.* (2002) and those relating to bimanual rhythmic coordination (e.g. Scholz and Kelso, 1989; 1990) can be explained using the central principles of dynamical system theory: (1) synergies (coordinative structures), (2) self-organisation, and, (3) constraints. According to dynamical systems theory, system complexity is harnessed through the development of synergies, functional couplings between interacting macro- or micro-components (for a review on synergies, see Lee, 1984; Turvey, 2007). Kelso and Schoner (1988, p. 28) classically defined a synergy as: "*an ensemble of neuromuscular components temporarily assembled as a task-specific unit*." In dynamical systems parlance, synergies are also referred to as coordinative structures (e.g. see Vereijken *et al.*, 1997). The formation of coordinative structures governs the emergence of functional, task-specific attractors, or, patterns of behaviour. Motor system degeneracy is also afforded by the flexible nature of coordinative structures because Kay (1988) highlights that a single component i.e. a biomechanical degree of freedom, such as a joint or segment, can contribute to different coordinative structures at different times. Conversely, a single coordinative structure may incorporate different components on different occasions. A characteristic feature of coordinative structures is the interdependency and compensatory adjustments between components (see Latash *et al.*, 2002). For instance, if a single component introduces an error into the output, other components contributing to the coordinative structure can attenuate this error by adjusting their relative contributions. The development of coordinative structures and the notion of attractors provide an appealing theoretical explanation for the stability and flexibility exhibited by the human motor system.

The assembly of coordinative structures and the concomitant emergence of attractor states is suggested to be guided and influenced by the process of self-organisation. Self-organisation is one of the central principles of dynamical systems theory and emphasises coordination modes as emergent rather than prescribed properties (Newell *et al.*, 2003). Beek *et al.* (1995, p. 577) acknowledged that the concept of self-organisation is sometimes: "*interpreted by some movement scientists as a kind of mystical ability, according to which movements come out of the blue*." Misinterpretation of self-organisation could be due, in part, to readers' misinterpretation and over-emphasis on the word "spontaneously" that sometimes pervades the literature. For example, Kelso and Schoner (1988, p. 30) refer to self-organisation as: "*the structure or change in structure that occurs spontaneously in open systems*," whereas Kelso (1991, p. 94) states that: "…*in open nonlinear dynamical systems, spatial, temporal, and functional patterns arise spontaneously in a self-organised fashion*." However, processes of self-organisation possess greater scientific rigour than that, unintentionally conveyed by the term "spontaneously", and a more principled account is provided by Kugler and Turvey (1988). Specifically, Kugler and Turvey (1988) reveal compelling evidence of self-organisation in the context of nest building behaviour in social insects. Beek *et al.* (1995, p. 577) offer a more detailed definition of self-organisation:

> *"The notion of self-organisation implies that coordinated movements are the orderly products of complex organisations that are composed of a very large number of interacting elements and that may adapt in a flexible manner to changing internal and external conditions by adopting a different coordination pattern without any explicit prescription of this pattern."*

Moreover, processes of self-organisation do not operate in isolation, and are themselves, governed by the confluence of constraints on action. Dynamical systems are open systems, open to the flow of matter and energy from the environment. Kugler and

Turvey (1988) argue that the flow of energy and matter transactions between the individual and environment generate constraints that can constrain the system's abundant degrees of freedom. The notion of constraints is therefore fundamental to regulating and harnessing inherent processes of self-organisation, and shaping the intrinsic pattern dynamics. Thelen (1995) defined intrinsic dynamics as the preferred patterns of behaviour that emerge as a function of its current status, its history, and the social and physical context by which the individual resides.

2.2.3 CONSTRAINTS-LED APPROACH

The constraints-led approach can be considered to be an adjunct to dynamical systems theory, and primarily came to prominence with Newell's (1986) model of constraints, which was latterly revised by Newell and Jordan (2007). Since its inception, the constraints-led approach has become a powerful theoretical framework for the coordination and control of human movement, and has been popularised by the work of Davids and colleagues (e.g. Davids *et al.*, 2003b; Chow *et al.*, 2006; Davids *et al.*, 2008; Glazier and Davids, 2009a; Renshaw *et al.*, 2010; Hristovski *et al.*, 2011; Renshaw *et al.*, 2011). The constraints-led approach has also garnered much interest from the wider human movement science community and been applied to numerous scientific domains, such as physical therapy (e.g. Newell and Valvano, 1998), motor development (e.g. Rosengren *et al.*, 2003), strength and conditioning (e.g. Jeffreys, 2011), skill acquisition (e.g. Davids *et al.*, 2008) and performance analysis (e.g. Glazier and Robins, 2013).

Constraints are an inherent feature at all levels of neurobiological systems, including the biochemical, neurological, behavioural and morphological (Newell and Jordan, 2007). The constraints-led approach allied itself to the aforementioned coordinative structure theory, supporting the notion that the constraint-driven assembly of task-specific coordinative structures is an emergent rather than a prescribed property (see Newell *et al.*, 1989). Within Newell's (1986) original constraints framework, constraints were broadly categorised as those pertaining to the individual, referred to as organismic constraints, the task, and, the environment. Furthermore, Newell (1986) classically defined a constraint as a characteristic of the task, environment or organism that either facilitates or restricts movement. For instance, constraints either allow individuals to explore the available phase-space (e.g. Robins *et al.*, 2006), or alternatively, constrain the human movement system to a narrow range of kinematic solutions (e.g. Higuchi *et al.*, 2003). In other words, constraints set boundaries or limits within a dynamical system (Clark, 1995). Importantly, these three constraints do not operate in isolation, they *interact* and channel the search towards the emergence of functional, coordinated, goal-directed behaviour (see Figure 1). As such, it is not individual constraints but the confluence of constraints that guide action.

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Figure 1. Confluence of constraints shaping the emergence of functional, goal-directed behaviour (Davids *et al.*, 2008, p. 40).

Organismic constraints refer to those properties of the individual. Broadly speaking, organismic constraints are those constraints imposed physiologically, morphologically or psychologically (McGinnis and Newell, 1982). To account for the diverse nature of organismic constraints, two sub-classes of organismic constraints have been proposed; structural and functional constraints. Organismic constraints have been partitioned into either structural or functional constraints to reflect the time dependent nature by which this specific type of constraint manifests (Newell and Valvano, 1998). Structural constraints are those properties of the individual that change very slowly with time, whereas functional constraints concern those properties that change over a more rapid timescale. Examples of structural constraints include, amongst others, height, mass, body composition, anthropometrics, strength, flexibility, muscle architecture and fibre composition, genetic make-up, task expertise, and visual acuity. Some of these structural constraints, specifically those relating to muscle architecture e.g. the location of muscle origins and insertions, and fibre composition, are also commonly classified as neuromuscular-skeletal constraints, or, neuro-anatomical constraints within the literature (e.g. Carson *et al.*, 1999; Carson and Riek, 2000; Carson *et al.*, 2000). Furthermore, these neuro-anatomical constraints have been shown to significantly affect the stability of inter-limb rhythmic coordination (for a review, see Carson and Kelso, 2004). Conversely, functional organismic constraints include those psychological and physiological factors that change over much shorter timeframes, such as, anxiety, self-confidence, motivation, (focus of) attention, intention, and neuro-muscular fatigue.

Environmental constraints are considered to be any physical properties that are external to the organism (Newell and Jordan, 2007). Consequently, environmental constraints tend to be global and non-performer specific. Examples of environmental constraints include ambient light, wind, altitude, ambient temperature, gravitational forces, together with properties of walls, floors and ceilings etc. Socialisation also constitutes an important environmental constraint, encompassing factors such as peer groups and societal expectations (McGinnis and Newell, 1982; Chow *et al.*, 2006). Even the location of a competitive sporting event, such as playing at home or away, can be considered an environmental constraint, and has been shown to affect collective team behaviour in soccer (Tucker *et al.*, 2005). Historically, within the original constraints framework proposed by Newell (1986), implements, such as a bat, racket or ball were classified as task constraints. However, Newell and Jordan (2007) argued that it would be more logical and coherent to incorporate ((non-)sporting) implements as environmental constraints as opposed to task constraints.

The final category of constraint relates to that of the task. Task constraints can be sub-divided into two sub-classes: (1) the goal of the task, and, (2) the rules specifying a particular movement pattern to satisfy a goal (Newell and Jordan, 2007). McGinnis and Newell (1982, p. 299) clarify the nature of task constraints by arguing that:

> *"Task criteria define a different type of constraint. Task constraints, are not physical, rather they are implied constraints or requirements which must be met within some tolerance range in order for the movement to produce a successful action. The nature of the constraints imposed upon movement by the task criteria will determine which space the movement is most efficiently described in."*

Examples of task constraints could include shooting distance during a basketball match (e.g. Robins *et al.*, 2006), or imposing a one-touch rule within a simulated football match during a training session. The manipulation of task constraints is considered to be hugely important for motor skill learning because augmented feedback, in the form of verbal instruction e.g. attentional focus instruction, or visual demonstration, is also viewed as a type of task constraint. Within this coaching-related context, task constraints have also been referred to as informational constraints (e.g. Al-Abood *et al.*, 2001) or instructional constraints (e.g. Al-Abood *et al.*, 2002; Lopes *et al.*, 2012). However, it should be acknowledged that the term "informational constraint" is also synonymous with the field of ecological psychology and the use of visual information to constrain behavioural output (e.g. Travassos *et al.*, 2012). Examples within the literature include the experimental manipulation of visual information, such as that performed during visual occlusion studies (e.g. Bennett *et al.*, 1999a; 1999b), or the use of video simulation versus in situ performance conditions (e.g. Pinder *et al.*, 2011).

2.3 MOVEMENT VARIABILITY

In light of the inherent complexity and degeneracy of the human movement system, variability is a ubiquitous feature both within and between all biological systems (Newell and Corcos, 1993). Under the same experimental conditions, no two movements will be performed the same, and indeed, no movement pattern by two individuals is likely to be identical. This is captured nicely by Bernstein's (1967) expression "repetition without repetition". Hence, intra-individual and inter-individual variability have been the subject of great interest within the human movement sciences (e.g. James, 2004; Davids *et al.*, 2006; Bartlett *et al.*, 2007), and interpretations relating to this pervasive movement phenomenon have strongly influenced coaching and pedagogical practices (see Brisson and Alain, 1996; Glazier and Davids, 2005). Each of the aforementioned motor control theories conceptualise the role of movement variability differently during goal-directed behaviour. The historical background to movement variability will now be explored, and the dominant lines of scientific enquiry outlined.

From an information-processing perspective, movement variability was synonymous with noise and considered to be error that must be removed or eliminated (for a review, see Newell *et al.*, 2006). Error could be in the form of measurement error during data collection procedures or neuro-motor noise manifesting at different levels of the movement system. Hence, use of appropriate filtering and smoothing techniques during data analyses were emphasised, and task expertise was characterised by the pursuit for motor invariance. This variability-task expertise relation is exemplified by Hatze (1986, p. 5) who stated that: *"…an iterated, stereotyped motion is considered an indicator of the respective athlete's training status."* Furthermore, inter-individual variability was viewed negatively, leading to "common optimal movement patterns" being espoused within the coaching fraternity. This negative connotation resulted in movement variability being considered often in statistical terms, and defined as the dispersion of data around the mean (see Newell and Slifkin, 1998). Typically, coefficients of variation, variance or standard deviations were deemed adequate to capture movement variability, and consequently, reflected the amount of noise present. As such, movement variability was historically an under-valued and under-researched phenomenon, and was often a by-product of experimental design i.e. data presented as means ± standard deviations, and not considered worthy of scientific investigation in its own right. Moreover, the relative lack of movement variability research is highlighted by Rosengren (2002, p. 337) who states the challenges for experimentation. Although, these comments relate to the motor development domain they are still applicable to the broader human movement sciences:

"This paucity of adequate data stems from a central problem related to studying variability. The problem is that in order to effectively study variability it is often the case that researchers must collect data over a different time course, in different

configurations, and in greater quantity than is typical of most (developmental) research."

Traditionally, the experimental designs advocated by Rosengren (2002) were the exception rather than the "norm" (e.g. McDonald *et al.*, 1989). Following the inception of Schmidt's (1975) Schema Theory, much of the empirical work relating to movement variability focused on motor output variability theory and the associated impulse-variability models (e.g. Sherwood and Schmidt, 1980; Newell *et al.*, 1982; Newell and Carlton, 1985; Sherwood, 1986; Sherwood *et al.*, 1988). Impulse-variability theory states that end-point variability in faster movements, or those requiring greater force output, increases because of the larger variability of impulses producing the movement (Darling and Cooke, 1987). The experimental tasks tended to be single degree of freedom movements or isometric force production tasks, thereby limiting external validity and generalisation to complex multi-articular actions. This line of empirical research is epitomised by the study of Sherwood *et al.* (1988), where participants were required to complete a rapid reversal movement using a horizontal lever. Participants performed 50 trials during each of 6 experimental conditions. The conditions were counterbalanced and the load on the lever was adjusted with weights of 0.26, 0.52, 0.78, 1.04 and 1.50 kg. A positive curvilinear relationship was found between force and force variability, with force variability increasing with force output until a plateau was reached at a weight of 0.78 kg. The increase in force variability was explained by increased noise in the neuromuscular system with increasing force output (see Newell *et al.*, 1982). The same theoretical interpretation has been offered to explain the increase in movement variability with shooting distance in basketball (Miller, 2002), which, in turn, could expound Fitts' (1954) speed-accuracy trade-off.

Another dominant line of scientific enquiry concerning movement variability involves elucidating the variability-task expertise relationship (e.g. Darling and Cooke, 1987; McDonald *et al.*, 1989; Gabriel, 2002; Button *et al.*, 2003; Schorer *et al.*, 2007; Wilson *et al.*, 2007; Wagner *et al.*, 2012). The term task-expertise is used here to define the proficiency by which individuals can complete a particular goal-directed action, and is used instead of the more general term "expertise" to differentiate it from other kinds of expertise typically identified within the research e.g. perceptual expertise (see Williams and Ward, 2003). The theoretical contention proposed by information processing theorists that performers should aspire towards complete motor invariance was, in part, a consequence of, first, the reduction seen in outcome error during linear positioning tasks (see Adams, 1971), and second, the reduction in movement (kinematic) variability with practice reported in later research (e.g. Darling and Cooke, 1987). For instance, in the study by Darling and Cooke (1987) participants were required to perform 60 flexion and 60 extension movements of a vertical rod attached to a manipulandum. Two specific amplitudes of movement were investigated; 10° and 30°. In addition, 4 of the participants completed 300-1000 trials to examine the effects of longer term practice on trajectory variability. It was found that trajectory variability decreased with practice, and that variability diminished throughout the whole of the action. The findings were interpreted in accordance with information-processing theory, whereby the ability to reproduce the desired movement was suggested to be the result of more effective programming and generation of neural commands. Comparable findings have also been reported by Gabriel (2002) who found a decrease in trajectory variability following 400 trials of a rapid elbow flexion task.

Although reductions in movement variability with practice are now commonly reported within the literature (e.g. Chow *et al.*, 2008; Chapman *et al.*, 2009), interestingly, there have also been studies that have found either no difference (e.g. Chow *et al.*, 2007) or a u-shaped relationship (e.g. Wilson *et al.*, 2008). A review of these findings and a critical appraisal of this research can be found within Section 3.1, providing the relevant experimental underpinning for Study 1 of this programme of work. The findings of Chow *et al.* (2007) and Wilson *et al.* (2008) oppose the traditional cognitive perception of variability and provide putative evidence that expert performers can display as much variability as their lesser skilled counterparts, but can exploit the variability in a functional manner to satisfy the specific constraints on action. This alternative interpretation of movement variability aligns itself to the central tenets of dynamical systems theory, that of attributing a functional role to movement variability. Moreover, what dynamical systems theory considered, which traditional cognitive theorists failed to do, was to differentiate between the variability owing to experimental noise, such as measurement error, and variability due to the dynamics of the human movement system (van Emmerik and van Wegen, 2002). This attempt to better understand movement variability has prompted the migration away from quantifying the variability of isolated joints at discrete points of interest, and instead, moved towards metrics such as coordination variability. Coordination variability is deemed crucial to capture the consistency of complex coordinated actions (Bartlett *et al.*, 2007), and in turn, provides a fuller understanding as to the control of human movement. Yet, until recently coordination variability has rarely been used as a dependent variable of interest within biomechanics or motor control research (e.g. Hamill *et al.*, 1999; Heiderscheit *et al.*, 2002; Button *et al.*, 2003; Robins *et al.*, 2006; Mullineaux and Uhl, 2010; Rein *et al.*, 2010).

From a dynamical systems perspective, variability is not now defined in statistical terms but as: *"the differences between responses that are observed when the same experiment* *is repeated in the same specimen"* (Faisal *et al.*, 2008, p. 292). Li *et al.* (2005) offer a different definition, viewing variability to be information concerning fluctuations in coordination (Li *et al.*, 2005). It is important to note that, although a loss of stability during, for instance, bimanual rhythmic coordination tasks was implicated by increased variability (critical fluctuations), variability is not synonymous with stability. Subsequently, these two variables should not be viewed on opposing ends of a single continuum. In other words, a system that displays greater variability does not necessarily mean it is less stable, and vice versa (see van Emmerik and van Wegen, 2000; Li, 2000). Where variability is considered to be the magnitude of trial-to-trial differences in some kinematic or kinetic variable, stability relates to the ability of a system to resist or offset a perturbation. The distinction between variability and stability was examined by the empirical work of Li *et al.* (2005), who quantified gait kinematics when walking at different speeds on a treadmill. Participants walked at 6 different velocities and during each walking trial a visual perturbation was introduced. The visual perturbation consisted of moving a 90 cm * 60 cm poster, suspended from the ceiling, approximately 50 cm toward the participant. Measures of variability and stability were calculated respectively using the standard deviation of knee joint angle across the gait cycle and recovery time of the knee joint angle trajectory following the visual perturbation. No significant correlation was found between variability and stability, highlighting the independent nature of these two variables.

With the reconceptualisation of movement variability by dynamical systems theorists as a functional characteristic of motor behaviour, it has consequently been the subject of much interest across the scientific sub-disciplines of motor control (e.g. McDonald *et al.*, 1989; Schorer *et al.*, 2007; Wagner *et al.*, 2012), biomechanics (e.g. Bartlett *et al.*, 2007; Wilson *et al.*, 2008; Seay *et al.*, 2011), and performance analysis (e.g. McGarry and Franks, 1996). Moreover, there are numerous converging lines of scientific evidence that attribute a functional role to movement variability, each of which will now be explored in turn. These will also be revisited within each experimental chapter and the most salient points expanded. Briefly, movement variability reputedly affords motor system flexibility, permits adaptive behaviour to changing environmental conditions, and facilitates the broader distribution of impact forces to attenuate possible overuse injury (for a review, see Bartlett *et al.*, 2007). Furthermore, the functional role of movement variability is also exemplified by the strong compensatory behaviour and covariance between interacting joints that develops with practice, and is used to satisfy specific task goals (e.g. Arutyunyan *et al.*, 1969, Winter, 1984; Kudo *et al.*, 2000; Ko *et al.*, 2003b; Chiang and Yeou, 2007).

2.4 THE FUNCTIONAL ROLE OF MOVEMENT VARIABILITY

2.4.1 THE STRUCTURE OF MOVEMENT VARIABILITY

The first line of research relates to the structure of movement variability. Traditionally, variability was considered to be synonymous with noise, and in particular, white noise with a Gaussian distribution that was superimposed onto a deterministic signal (Newell and Corcos, 1993). This interpretation was adopted from information theory (Shannon and Weaver, 1949, cited in Newell *et al.*, 2006), which, with the advances in computer technology at the time coinciding with the theorising about human movement from an information-processing perspective, provided a compelling explanation for this movement phenomenon, or movement artefact as traditional cognitive theorists may have supposed. Hence, variability was likened to randomness (Riley and Turvey, 2002). Newell *et al.* (2006, p. 11) argue that randomness is a "*slippery term, ...where the sequential properties of the time series are independent*." However, to dispel this association research within the human movement sciences began to formally examine the structure of movement variability through the use of nonlinear tools (e.g. Riley *et al.*, 1999; Balasubramaniam *et al.*, 2000) rather than simply computing the standard deviation as a measure of variance around the mean. Consequently, it was revealed that this proposition, likening variability to randomness, appeared no longer tenable (for a review, see Newell and Slifkin, 1998). For instance, Riley *et al.* (1999) examined the centre of pressure during quiet stance during each of four conditions; head facing forwards and sideways, each performed with eyes both open and closed. Recurrence quantification analysis (RQA) was used to examine the structure of variability. RQA is a sophisticated non-linear, multi-dimensional technique that captures both the recurrent patterns and nonstationarities within time series data (Balasubramaniam *et al.*, 2000). Continuous actions such as upright posture and walking gait are typically used as task vehicles because of the quantity of data required to perform such tests. Riley *et al.* (1999) reported that the centre of pressure signals contained deterministic structure, indicating that postural sway was not simply a random process, yet may be regulated by both deterministic and stochastic[3] elements. Support for the deterministic nature of postural control was found by Balasubramaniam and colleagues (2000) during a precision aiming task whereby the focus of a laser pointer towards a target was regulated by deterministic postural motion.

Consequently, the dynamics of human movement, in this case, centre of pressure, was suggested to comprise both deterministic and random processes, a concept referred to as piecewise determinism (Riley and Turvey, 2002). Moreover, the structure of movement variability is now routinely captured using techniques such as recurrence quantification analysis (Schmitt *et al.*, 2006; Negahban *et al.*, 2010; Kiefer *et al.*, 2011; 2013; Labini *et al.*, 2012), approximate entropy (Challis, 2006; Mackenzie *et al.*, 2008; Ofori *et al.*,

[3] "Stochastic processes can be used to refer to a behaviour that is random, or, to a behaviour that is influenced by both deterministic and random processes" (Riley and Turvey, 2002, p. 100).

2010; Sethi *et al.*, 2013) and Lyapunov exponents (Buzzi *et al.*, 2003; Dingwell and Marin, 2006; Bruijn *et al.*, 2009; Federolf *et al.*, 2012), with typical areas of study comprising age-related changes in force output variability, or alterations in movement variability, such as walking gait, with differing pathologies e.g. developmental coordination disorder, or following stroke. Although the intricacies of these tests are beyond the scope of this programme of work, Lyapunov exponents capture the rate of divergence of close trajectories in state space, or, "predictability" of the time series data (Federolf *et al.*, 2012), whereas approximate entropy assesses the regularity of a data set, with values ranging from 0 (regular) to 2 (random) (Challis, 2006). To exemplify the utility of these tests, Buzzi *et al.* (2003) used Lyapunov exponents to investigate age-related changes in gait variability. 10 younger and 10 older participants with age ranges of 20-37 years and 71-79 years respectively performed 30 strides on a motorised treadmill. Two key findings were reported: (1) the Lyapunov exponents revealed walking to be a deterministic process within both sample groups, and, (2) the elderly participants had greater noise and local instability within their time series data when compared to their younger counterparts. Consequently, and interestingly, the authors postulated that optimal functioning may reside somewhere between "*complete regularity and complete randomness*" (p. 442), a proposition that is supported by Fetters (2010) (see Section 3.1), and the proposed optimal variability model (Harbourne and Stergiou, 2009). In support of this region of optimal variability, Sethi *et al.* (2013) used approximate entropy to quantify the structure of variability during prehension in healthy individuals and those with chronic stroke. The participants with chronic stroke exhibited significantly lower approximate entropy values in comparison to the controls, indicating that their ability to adapt to changing environmental demands was compromised. Clearly, examining the structure and organisation of movement variability has become a fruitful line of research to not only further our understanding of variability as a phenomenon, but in light of the overarching focus of this programme of work, it yields additional insights into the benefits movement variability can serve during goal-directed behaviour.

2.4.2 COMPENSATORY VARIABILITY

The second line of research relates to examining the functional interaction between joints along the kinematic chain during goal-directed behaviour. As mentioned previously, according to dynamical systems theory, a characteristic feature of coordinative structures is the interdependency and compensatory adjustments between component parts of the human movement system. This movement phenomenon is commonly referred to as compensatory variability (Bootsma and van Wieringen, 1990) or covariance (Muller and Sternad, 2004). The first, seminal study relating to compensatory variability was undertaken by Arutyunyan and co-workers (1969) who examined the organisation of arm movements in experienced and inexperienced pistol shooters. It was observed that experienced shooters formed a functional synergy between the wrist and shoulder whereby the joints operated in a complementary fashion to facilitate successful task performance. This compensatory relationship was evidenced by the stronger correlation coefficient between the wrist and shoulder joints in the horizontal plane.

Comparable to the work of Arutyunyan and colleagues (1969), Bootsma and van Wieringen (1990) found corroborating evidence when executing a table tennis shot, and subsequently formerly coined the term compensatory variability to capture this functional coupling. Specifically, joints in a kinematic chain were considered to interact in a functional manner to preserve invariance in the performance outcome. Thus, it was suggested that consistency in the outcome did not necessitate consistency of joint movements, nor joint positioning at ball impact. Empirical support for compensatory variability has also been reported for postural control mechanisms (Ko *et al.*, 2003a; 2003b) and targeted throwing tasks (Muller and Loosch, 1999; Kudo *et al.*, 2000; Button *et al.*, 2003; Muller and Sternad, 2004; Woo *et al.*, 2007). For instance, Muller and Sternad (2004) decomposed the variability in the execution of a virtual skittles task into three components; noise reduction, task tolerance and task-specific covariance. Muller and Sternad (2004) reported that covariation between execution variables is crucial for task accomplishment during accuracy-based throwing tasks. In addition, it was purported that this factor becomes more important with practice. Additional support for the role of covariance during movement execution was reported by Kudo *et al.* (2000). Through the development of an index of coordination for release parameters (ICRP), a measure of the *relationships* between parameters rather than their *consistency*, it was found that covariance between height, speed and angle of release contributed towards minimising the variability in performance outcome. In agreement with Muller and Sternad (2004), coordination between release parameters improved with practice. Consequently, compensatory behaviour appears crucial for targeted aiming / throwing tasks, and will be revisited with specific relations made to basketball shooting research in Section 3.1.

2.4.3 THE VARIABILITY-PATHOLOGY DEBATE

The final line of research pertains to the "variability-pathology debate". The association between variability and pathology has long been a subject of much scientific interest (for a review, see Stergiou and Decker, 2011). Moreover, it has garnered interest from the fields of physiology (Korpelainen *et al.*, 1996; Bjelakovic *et al.*, 2010), biomechanics (Heiderscheit, 2000; Heiderscheit *et al.*, 2002; Prosser *et al.*, 2010; Yakhdani *et al.*, 2010; Myers *et al.*, 2011) and motor control (Latash and Anson, 1996;

van Wegen *et al.*, 2001). From a physiological perspective, there is clear evidence to suggest that heart rate variability is, in fact, a sign of normal, healthy function. For example, Korpelainen *et al.* (1996) analysed both the temporal and frequency domain characteristics of heart rate variability within 31 patients with hemispheric brain infarction, and compared these to sex-matched healthy controls. All measured components of heart rate variability were found to be significantly lower in the patients with hemispheric brain infarction. Moreover, it was suggested that hemispheric brain infarction appeared to cause substantial and prolonged damage to the autonomic regulatory system. These findings support those of Bjelakovic *et al.* (2010) who observed decreased heart rate variability in infants with central coordination disturbance.

Commensurate with the physiology literature, from the biomechanical domain, movement variability has been suggested to be an important variable to differentiate "healthy" (non-impaired) individuals from those with clinical pathologies (Heiderscheit, 2000). Moreover, Hausdorff (2005, p. 3) views gait variability to be a: "*sensitive and clinically relevant parameter in the evaluation of mobility, fall risk and the response to therapeutic interventions*". To date, the research has examined a number of clinical pathologies, including, bilateral cerebral palsy (Prosser *et al.*, 2010), Parkinson's disease (van Emmerik *et al.*, 1999), Huntingdon's disease (Hausdorff *et al.*, 1998), and intermittent claudication (Myers *et al.*, 2011), orthopaedic injuries such as unilateral patellofemoral pain (Heiderscheit *et al.*, 2002) and knee osteoarthritis (Fallah Yakhdani *et al.*, 2010), as well as those individuals who are recovering from surgical procedure, such as anterior cruciate ligament (ACL) reconstruction (Moraiti *et al.*, 2010), or those who are ACL deficient (Zampeli *et al.*, 2010). Despite stereotypic motor behaviour being an apparent indicator of developmental disorders (Touwen, 1993), the affect that clinical pathologies have on movement variability differ both in terms of the research findings and their associated interpretation. However, the differences in findings may be due to the different kinematic variables quantified. For instance, stride-to-stride variability measures such as; walking velocity, cadence, step length, single support time, double support time and stride time are common variables of interest (Hausdorff *et al.*, 1998; Prosser *et al.*, 2010). Within these studies, patients with cerebral palsy (Prosser *et al.*, 2010) and Huntington's disease (Hausdorff *et al.*, 1998) have been shown to have increased stride-to-stride variability when compared to healthy controls. This increase in stride-to-stride variability has been associated with an increased risk of falling. Corroborating evidence relating to fall prevention comes from Fallah Yahkdani *et al.* (2010) who quantified movement variability using Lyapunov exponents. Fallah Yakdani and co-workers (2010) reported that patients with knee osteoarthritis had less variability than controls, and exhibited even further reductions in variability post surgery. In addition, the reduction in variability corresponded with a concomitant decrease in the risk of falling. Thus, collectively these findings appear to suggest that a high level of variability is detrimental to human locomotion and increases the risk of falls.

However, there are several arguments to be made against this general assumption. First, as Touwen (1993, p. 1) identifies: "*The question 'How normal is variable or how variable is normal' is a wrong question, as any form of variability must be interpreted according to its extent, type and age adequacy*." This contention is supported by Heiderscheit (2000) who argues that variability should be considered in terms of the movement measure, meaning that its function may not be generalised to all measures of movement variability. Furthermore, although individuals with, for example, knee osteoarthritis have increased stride-to-stride variability, from a dynamical systems perspective this can be interpreted as exploratory behaviour whereby individuals are searching the perceptual-motor workspace for a task-relevant attractor state. Thus, the elevated movement variability is still, arguably, serving a functional role (see Glazier and Davids, 2009b). Therefore, caution should be given to the "less is best" mentality when evaluating the (dys)function of movement variability. Support for these points is exemplified by Zampeli *et al.* (2010) who examined stride-to-stride variability in patients who were ACL deficient. Lyapunov exponents were calculated from the joint angle time series data, and the ACL deficient patients exhibited significantly lower Lyapunov exponents in contrast to their healthy counterparts. Zampeli *et al.* (2010) argued that this more constrained movement pattern, one that was characterised by lower movement variability, would mean that the individuals were less capable of responding to potential perturbations and changing environmental demands. This interpretation, again, attributes a functional role to movement variability, whereby a functional repertoire of movement patterns permits motor system flexibility.

This functional role attributed to gait variability is supported by work that has investigated changes in coordination variability with patellofemoral pain (Heiderscheit *et al.*, 2002) and Parkinson's disease (van Emmerik *et al.*, 1999). Coordination variability was used to overcome the limitations of typical stride-to-stride measures, which were deemed to lack adequate sensitivity (see Barratt *et al.*, 2008), as well as those measures that only examine discrete points of interest. Thus, coordination variability effectively captures the consistency by which joints are sequenced throughout the entire movement cycle. Specifically, van Emmerik *et al.* (1999) reported that although no significant differences were found in stride duration or the variability of stride duration, the Parkinson's disease patients demonstrated significantly lower variability in pelvic-thoracic coordination, determined by the standard deviation of relative phase, when compared to the elderly control group. Partial support for this pathology-related decrease in coordination variability was observed by Heiderscheit *et al.* (2002) who found that, in contrast to the non-impaired group, there was reduced coordination variability for the thigh rotation-leg rotation joint coupling at heel strike for the patellofemoral pain group's injured leg. Interestingly, in contrast to van Emmerik *et al.* (1999), no significant difference was observed between the groups for continuous coordination variability, coordination variability quantified using data from the entire movement trial. However, this may be due to the different methods by which to quantify coordination. Heiderscheit *et al.* (2002) used the vector coding technique whereas van Emmerik *et al.* (1999) used relative phase, the latter arguably being more sensitive because it contains zero and 1st order derivatives. Hence, the standard deviation of relative phase between two joints may be more adept at detecting pathology-related differences in coordination variability. For a critical appraisal of analytical techniques for measuring coordination variability readers are directed to the work of Wheat and Glazier (2006).

As previously mentioned, the movement variability evidenced by normal, healthy individuals may not only provide motor system flexibility and the ability to adapt, it may also have important implications for overuse injury. The reduction in movement variability seen in persons with patellofemoral pain, for instance, means that the impact forces are dissipated across a larger area. In contrast, those individuals exhibiting lower movement variability may experience more localised loading of the anatomical structures, which could be the cause of the orthopaedic problem (Hamill *et al.*, 1999; Barratt *et al.*, 2008). However, caution should be expressed when trying to elicit cause and effect because a problem inherent within the movement variability-injury research is that it uses retrospective experimental designs. Therefore, it is currently not clear whether the reduced movement variability caused the orthopaedic problem, such as patellofemoral pain, or, if the patellofemoral pain constrained the motor system prompting a decrease in coordination variability (Bartlett *et al.*, 2007). Nonetheless, there is evidence to suggest from the variability-pathology research that movement variability can serve two purposes: (1) permit flexibility and adaptability, and, (2) prevent localised impact forces, facilitating the broader distribution of mechanical stress to attenuate possible overuse injury.

2.5 MOVEMENT VARIABILITY UNDER CONSTRAINT

From the aforementioned research within Section 2.4 it is clear that there is now a wealth of evidence advocating a functional role to movement variability. However, it is crucial to understand how movement variability is governed by the confluence of constraints on action. Newell and Vaillancourt (2001) suggest that the dimensionality of attractor dynamics is influenced by the confluence of constraints on action. Furthermore, the magnitude of movement variability also appears to be dependent on the specific constraints on action (see Newell and James, 2008). This is evidenced by the changes in movement variability with task constraints such as accuracy demand (Sidaway *et al.*, 1995b) and organismic constraints such as anxiety (Higuchi *et al.*, 2002), both of which are explored within the relevant experimental chapters (i.e. Chapters 3 and 5 respectively). However, there is currently limited empirical evidence pertaining to movement variability under certain constraints, such as those concerning target distance (e.g. Robins *et al.*, 2006), anxiety (e.g. Higuchi *et al.*, 2002), dioptric blur, or, focus of attention (Lohse *et al.*, 2010). The purposes of selecting these constraints were three fold: (1) it offers an opportunity to gain an enhanced theoretical insight into studying movement variability under constraint, (2) from an applied perspective, all of these constraints are pertinent to competitive sport and therefore can be considered to be of high practical importance, and, (3) research within these fields of study typically focus on product-oriented variables, rather than exploring process-related factors such as movement kinematics and movement variability. Thus, measures such as coordination variability are of particular value and are used within the current programme of work to capture the consistency of coordinated behaviour. Moreover, changes in movement variability with expertise can offer revealing insights and is, again, an area where there is a scarcity of research. Emphasis appears to be placed on examining expert performance only, a sentiment echoed by Phillips *et al.* (2012). Finally, there is also a distinct lack of research into whether the change in movement variability under specific constraints is mediated by task expertise. There is tentative evidence to suggest that expertise can play a mediating role in overcoming perturbations such as anxiety (Janelle *et al.*, 2000), however, the role that expertise plays in using movement variability to satisfy and adapt to changing constraints, and whether increases or decreases in movement variability with changing constraints are mediated by expertise thus far remain elusive.

Therefore, there are clear gaps within the movement variability research that need to be addressed, and an acute understanding about how movement variability changes with varying constraints can be achieved by using a unified, inter-disciplinary experimental design, one that uses motor control theory in conjunction with biomechanical data collection techniques. Requests for this approach have been made repeatedly within the human movement sciences (e.g. Davids *et al.*, 2000; Buttfield *et al.*, 2009; Davids and Glazier, 2010; Sarpeshkar and Mann, 2011), yet interdisciplinary research of this nature is rarely undertaken (e.g. Heiderscheit, 2000; Button *et al.*, 2003; Robins *et al.*, 2006), a point also acknowledged by Davids and Glazier (2010). This sentiment is epitomised by Elliott (1999, p. 307) who stated that:

"Seldom is a complex question answered by research based in a single science discipline. Hence, the biomechanist must combine with the exercise physiologist, and biochemist, the sport psychologist and the motor development specialist to structure appropriate research design."

Therefore, the aim of this programme of work was to examine how the manipulation of organismic and task constraints affected movement variability, and more broadly, perceptual-motor organisation during a discrete multi-articular action.

CHAPTER III

DISTANCE AND TASK EXPERTISE AS CONSTRAINTS ON MOVEMENT VARIABILITY DURING BASKETBALL SHOOTING

3.1 INTRODUCTION

Sport competition encompasses a rich tapestry of constraints that allows human movement scientists to examine how individuals adapt and respond to task and situation-specific contexts. It has been suggested that movement models from sport represent valuable task vehicles for the study of coordination and control processes (Davids *et al.*, 2005). Important movement models are provided in the sport of basketball, which necessitates a repertoire of complex multi-articular actions, such as passing, catching, dribbling and shooting. As successful performance outcomes in basketball competition are measured quantitatively through the number of points scored by a team, an important motor skill is shooting. Consequently, a large body of research has been dedicated to exploring the kinematics of basketball shooing performance (for a review, see Bartlett and Robins, 2008). Specifically, research has investigated performance differences in relation to sex (Elliott, 1992), playing position (Miller and Bartlett, 1996), defender interference (Rojas *et al.*, 2000), neuromuscular fatigue (St. Michel *et al.*, 1995; Uygur *et al.*, 2010), shooting accuracy (Miller, 1998; Mullineaux and Uhl, 2010), distance (Elliott and White, 1989; Miller and Bartlett, 1993; Liu and Burton, 1999; Miller, 2002; Robins *et al.*, 2006; Rein *et al.*, 2010; Okazaki and Rodacki, 2012) and task expertise (Penrose and Blanksby, 1976; Hudson, 1985; Miller and Jackson, 1996; Button *et al.*, 2003).

One of the key findings to emerge from the existing literature is that the ball release parameters during shooting i.e. height, speed and angle of release, and subsequent movement kinematics are tailored to satisfy specific constraints on action. For instance, in a study by Rojas and co-workers (2000), professional basketball players were required to perform jump shots with and without an opponent present. It was reported that both angle and height of release were significantly greater when facing an opponent, and were used to minimise potential defender interference. This alteration in release parameters was achieved by an increased knee and shoulder joint angular displacement at the instant of ball release. Height of release has also been shown to increase as a function of task-expertise (Hudson, 1985; Button *et al.*, 2003). When expressed relative to participant height, the height of release ratio was reported to be 1.23 ± 0.06, 1.25 ± 0.05 and 1.30 ± 0.04 for poor, good and elite basketball players respectively (Hudson, 1985). This finding corroborates data reported by Button *et al.* (2003) who observed a moderate correlation between height of release and task expertise (r = 0.36). From a coaching perspective, the importance of an increased height of release is that a smaller speed of release is required because the ball has a smaller distance to travel. This relationship between height and speed of release is known as the minimum speed principle. An increased height of release also positively impacts on angle of release, whereby a steeper angle of entry into the basket is favourable because it increases the margin for error because the basketball ring presents a larger elliptical surface area (see Figure 2).

Figure removed for copyright reasons.

Figure 2. Angle of entry as a function of release trajectory (Miller and Bartlett, 1993).

An increased distance has also been shown to instigate a reorganisation of motor system dynamics. For instance, Liu and Burton (1999) revealed a significant decrease in shooting accuracy as shooting distance increased as well as abrupt changes in movement form at critical distances. This is supported by Okazacki and Roacki (2012) who found shooting accuracies of 59%, 62% and 37% at distances of 2.8 m, 4.6 m and 6.4 m respectively. Furthermore, not only is an increased speed of release required at farther distances but there is also a corresponding reduction in angle of release (Miller and Bartlett, 1996). The increased speed of release was due to the increased angular velocities of both the shoulder and elbow, coupled with the increased speed of the centre of mass in the direction of the basket. The use of a smaller angle of release with increasing distance was interpreted by Miller and Bartlett (1996) using the minimum speed principle, and proposes that successful shooting is predicated on a compromise between margin for error and energy expenditure. As such, at greater distances individuals sacrifice margin for error, determined by the size of the elliptical area presented by the basket (see Figure 2), in favour of a lower release speed, permitting greater control of the generated impulse.

Despite the quantity of literature dedicated towards the kinematics of basketball shooting performance, there is little reported research pertaining to movement variability (Miller, 2002; Button *et al.*, 2003; Robins *et al.*, 2006; Woo *et al.*, 2007; Mullineaux and Uhl, 2010; Rein *et al.*, 2010). As a result, further empirical evidence is required to identify how variability changes as a function of changing organsimic constraints, such as expertise, and task constraints, such as accuracy demands. Currently, there is a distinct lack of clarity on this issue. For example, Miller (2002) examined the change in absolute (standard deviation) and relative (coefficient of variation) variability of segment end-point linear speeds when shooting from three distances: short-range (2.74 m), free-throw line (4.25 m), and long-range (6.40 m). A positive relationship was reported between segment end-point speed and variability, with increased variability also evident for the long-range shots. These findings were explained in accordance with impulse-variability theory. Furthermore, absolute variability increased distally along the kinematic chain whereas relative variability exhibited the opposite trend. These data were attributed to the synergistic and compensatory behaviour of interacting joints.

Comparable to Miller (2002), a similar proximal to distal increase in variability along the kinematic chain was identified by Robins *et al.* (2006) who quantified variability of both discrete and continuous variables within skilled basketball players when shooting from distances of 4.25, 5.25 and 6.25 m. Participants were required to complete five standardised, successful shots at each of the three distances. A successful shot was defined as one that passed cleanly through the ring without touching the backboard or basketball ring itself. Robins and co-workers (2006) observed that joint angle variability at the instant of ball release increased distally along the kinematic chain, and this trend was evident irrespective of changing accuracy demands. However, there was no increase in joint angle variability with distance, which counters previous work by Miller (2002). A reduction in coordination variability was also reported by Robins *et al.* (2006), as evidenced by the decrease in standard deviation of continuous relative phase at larger distances. Consequently, it was argued that changes in task constraints can influence the magnitude of movement variability observed during task performance, a contention acknowledged by Newell and Vaillancourt (2001). This sentiment was further corroborated by Sidaway *et al.* (1995a) who quantified both joint amplitude and movement variability during a serial aiming task, and observed a decrease in inter-trial movement variability with a corresponding reduction in target size.

The current data pertaining to movement variability and changing accuracy demands provide support of sensorimotor equivalence at closer distances, affording skilled individuals motor system flexibility, as well as supplementary evidence into compensatory behaviour. However, it is currently unknown whether this alteration in coordination variability with changing accuracy demands is a universal strategy adopted irrespective of task expertise. Furthermore, similar to the study by Miller (2002), no formal assessment of the magnitude of covariance and, therefore, extent of compensatory behaviour between interacting joints was conducted by Robins and colleagues (2006), thereby warranting further investigation. This is particularly important as it is the structure, and not the magnitude, of movement variability that identifies its functionality during goal-directed behaviour (see Glazier and Davids, 2009b).

There is also limited empirical evidence examining the change in movement variability with task expertise (e.g. see Chow *et al.*, 2007; Schorer *et al.*, 2007; Chow *et al.*, 2008; Wagner *et al.*, 2012). Moreover, findings from the existing literature appear equivocal. For example, previous work by Darling and Cooke (1987) and Gabriel (2002) both found a reduction in variability of movement phase plane trajectories with practice during a rapid elbow flexion and extension task. More recently, research has progressed from single degree of freedom tasks to complex multi-articular actions, with movement models including soccer chipping (Chow *et al.*, 2008) and cycling (Chapman *et al.*, 2009). For instance, Chow *et al.* (2008) reported a general decreasing trend in coordination variability, evidenced by the normalised root mean squared difference (NoRMS), with practice. However, a multiple single-participant design was implemented so no formal group inferential statistics were reported. This decrease in movement variability with practice can be attributed to the development of a functionally stable attractor state within the perceptual-motor workspace. The attainment of stable attractor states is suggested to occur when individuals progress through stages of coordination, control and skill (Newell, 1985). For instance, during the early stage of learning, commonly referred to as the ‘coordination stage’, processes of exploration are undertaken where individuals search for appropriate kinematic solutions. This typically manifests in large trial-to-trial variability as individuals begin to understand the requirements of the task. However, with practice, individuals progress through stages of ‘control’ and ‘skill’ where attractor states are honed, resulting in reduced inter-trial variability (for a review, see Handford *et al.*, 1997). In support of this theoretical interpretation, Chapman *et al.* (2009) observed greater consistency in inter-joint coordination in elite cyclists than in novice cyclists. In a commentary on the work by Chapman and co-workers, Glazier and Davids (2009b) argued that despite novices demonstrating greater variability in comparison to expert cyclists, variability can be considered to be functional within both population samples. It was postulated that the high variability demonstrated by novice cyclists could be indicative of exploratory behaviour, whereas the experts exhibit a narrower bandwidth of variability that can be used to permit adaptation to continuously fluctuating constraints on action.

Consequently, when expressed relative to performance outcome, it could be argued that skilled motor performance is facilitated by a functional bandwidth of movement variability, or, stated differently, a region of optimal functioning. Excursion beyond this bandwidth could, potentially, lead to decrements in performance. This theoretical interpretation is commensurate with the ideas of Fetters (2010) who postulated that a lack of movement variability is a hindrance to the development of skilled human action, possibly because the movement system is constrained thereby inhibiting exploratory behaviour or adaptive and corrective processes. Conversely, excessive movement variability is deemed to be counterproductive and could interfere with the production of dependable and typical functional action. These ideas also align themselves with the "optimal state of movement variability" theoretical model proposed by Stergiou *et al.* (2006). Support for this contention can be found from the work of Mullineaux and Uhl (2010). Within this study, coordination variability of swishes and misses were analysed from a sample of fifteen collegiate level basketball players, with coordination variability calculated using the vector coding technique. Increased coordination variability was found at the instant of ball release for the misses when compared to the swishes, thus providing empirical support for the idea that successful task performance dictates that movement variability is confined to a tolerable, functional range.

However, these data and theoretical interpretations counter evidence by Button *et al.* (2003) who reported no clear reduction in variability of phase plane trajectories with increasing skill level during a basketball free-throw task. Furthermore, Chow *et al.* (2007) found no significant difference in coordination variability between skilled, intermediate and novice participants during a soccer kicking task. In fact, from visual inspection of the descriptive statistics the skilled participants demonstrated the greatest coordination variability when compared to their intermediate and novice counterparts. This lack of statistical difference within the study of Chow and colleagues (2007) is exemplified by mean (± SD) NoRMS values for the hip-knee joint-coupling of 16.76° (± 10.69°), 14.26° (± 8.81°) and 13.53° (± 5.04°) for the skilled, intermediate and novice participants respectively. There are, however, several limitations within the study by Chow *et al.* (2007) that warrant consideration. First of all, only five participants were assigned to each of the expertise groups. Therefore, this limited sample size may impact upon the statistical power of the study. Second of all, and arguably of more importance, no performance pre-test was undertaken to objectify participant recruitment and allocation to specific experimental groups. This may explain why there was no significant difference in performance outcome between skilled and intermediate performers, irrespective of target distance, and, could be a contributory factor for the large within group variance evidenced by the skilled group.

In contrast to the work of Button *et al.* (2003) and Chow *et al.* (2007), more recent work by Wilson and co-workers (2008) has presented a U-shaped relationship between coordination variability and expertise in triple jump performance. Wilson *et al.* (2008) argued that skill acquisition can be characterised by a three-stage process: (1) exploratory variability, (2) motor system refinement, (3) functional variability, and is congruent with the central tenets of dynamical systems theory. Although aligned with dynamical systems theory, an alternative theoretical explanation can be offered using the ideas developed from Neuronal Group Selection Theory (see Sporns and Edelman, 1993; Barclay, 1995; Hadders-Algra, 2000; 2002). Although predominantly used as a theory of motor development, i.e. progression from fetal life to infancy, adolescence and ultimately adulthood, the insights from Neuronal Group Selection Theory (NGST) can also be used as a viable theoretical framework to explain changes in movement variability as a function of task expertise. For instance, NGST proposes a three-stage developmental process: (1) primary variability, (2) selection, (3) secondary (adaptive) variability. Consequently, incorporating this conceptual framework it could be argued that skilled performers could exhibit the same magnitude of variability as their novice counterparts but use the variability functionally to satisfy specific constraints on action and adapt to performance perturbations. Novices, on the other hand, use the variability in an exploratory fashion to search for functional task-specific kinematic solutions. However, there is currently limited evidence to support this proposition. Furthermore, the application of this interpretation to the Wilson *et al.* (2008) study is contentious, if not erroneous, because the participant sample comprised individuals with personal bests ranging from 70-86% of the current world record, all of whom were deemed to be experts. As a consequence, further investigation is required that examines movement variability across a more heterogeneous sample; one that comprises participants differing more substantially in expertise, i.e. novices, intermediates and experts.

Therefore, this study had two aims. The first was to understand the interacting effects of expertise and target distance on movement variability during a discrete multi-articular action such as a basketball shooting task. The second was to build upon existing research pertaining to accuracy-based throwing tasks by formally addressing how compensatory variability might change as a function of both task expertise and shooting distance.

3.2 METHODS

3.2.1 PARTICIPANTS

Twenty-seven male participants with a mean (± SD) age, height and mass of 24.4 (± 4.4) years, 1.82 (± 0.07) m and 80.8 (± 12.8) kg respectively provided written voluntary informed consent to participate in the study (see Appendix 1). Two participants were left-handed while the remaining twenty-five participants were right handed. Each participant completed a health screening questionnaire (see Appendix 2), and were issued with a Participant Information Sheet (see Appendix 3). All procedures were risk assessed (see Appendix 4) and approved by the local institutional research ethics committee (see Appendix 5). Participants were categorised as expert, intermediate or novice using stringent inclusion criteria. Specifically, a performance pre-test and a questionnaire indicating previous basketball experience were completed before data collection (see Appendix 6).

The performance pre-test required participants to complete thirty shots of a Spalding Tacksoft Size 7 basketball towards a portable basketball ring (Spalding Powerforce) elevated to a regulation height of 3.05 m and located at a distance of 4.25 m. A distance of 4.25 m equated to the location of the free-throw line within a regulation basketball court. The outcome of each shot was awarded a score based upon an eight-point nominal rating scale (see Table 1), and entered in a participant scoring table (see Appendix 7). Thus, a maximum score of 240 points was possible.

Table 1. Assessment scale for basketball shooting performance.

Score	Outcome Characteristics
1	Ball misses rim and backboard completely, no score
2	Ball makes light contact with the outside of the rim only, no score
3	Ball makes strong contact with the outside of the rim, no score
4	Ball hits the top of the rim or backboard, no score
5	Ball hits the top of the rim or backboard, score
6	Ball makes strong contact with the inside of the rim, score
7	Ball makes light contact with the inside of the rim, score
8	Ball passes cleanly through the basket without contacting the rim, score

Moreover, this scale permitted greater sensitivity and overcomes the limitations inherent within previous 5-point (Landin *et al.*, 1993) and 7-point (Rein *et al.*, 2010) basketball performance scoring systems. For instance, within the scoring system devised by Landin *et al.* (1993), 3 points were awarded when the basketball: "Hits the top of the rim; would fall *in or out* of basket." Consequently, the gross nature of the measurement scale meant that a score of 3 points could account for both successful and unsuccessful outcomes. Similar ambiguity is also evident from examination of the scoring system used by Rein *et al.* (2010). For instance, scores of 5 and 6 points were awarded when the ball hit the outside or inside of the rim respectively and resulted in either a score or no score.

Participants were classified as experts, intermediates or novices according to the criteria outlined in Table 2 (adapted from Vickers, 1996). To be deemed an expert, participants required a performance pre-test score in excess of 168 points (> 70%). Intermediate and novice performers were classified as those who obtained pre-test scores of 144-167 points (60-69%) and less than 143 points (< 59%) respectively. In accordance with the inclusion criteria, nine participants were subsequently assigned into each of the three expertise groups.

Table 2. Participant inclusion criteria.

Participant Classification	Performance Pre-test Score (%)
Expert	> 70%
Intermediate	60 – 69%
Novice	< 59%

3.2.2 PROCEDURES

After a thorough warm-up of the involved musculature, participants were required to complete thirty trials from each of three distances: 4.25, 5.25 and 6.25 m. Performance outcome was assessed using the eight-point nominal scale presented in Table 1. Adequate rest was permitted between trials to negate any intervening effects of fatigue. The distances of 4.25 and 6.25 m equated to the free-throw line and three-point line respectively, and are routinely used within the existing literature to examine the kinematics of basketball shooting (e.g. Elliott and White, 1989; Elliott, 1992; Button *et al.*, 2003; Robins *et al.*, 2006). An intermediary distance of 5.25 m was also used to permit additional comparative analyses. Before data collection, participants completed five habituation trials at each of the three shooting distances. Furthermore, the sequence of distances presented during data collection was counterbalanced across participants to minimise any confounding order effects.

Kinematic data were collected using an eight-camera motion analysis system sampling at 200 Hz (Motion Analysis Corporation, Santa Rosa, CA). The dimensions of the performance capture volume were 4 m (x) * 1.5 m (y) * 3 m (z). The measurement accuracy of this motion analysis system (Motion Analysis Corporation) has previously been empirically tested and verified (Richards, 1999). Specifically, Richards (1999) reported that when utilising a volume length of 4 m and placing two fully visible markers at a distance of 50 cm, the average measured distance across all six trials recorded by the motion analysis system was 49.795 cm. This is comparable to the dynamic wand (50 cm) calibration scores found within the current study (50.04 ± 0.14 cm).

Twenty five 12.7 mm retro-reflective markers were attached to appropriate anatomical landmarks and used to define 4 body segments: the trunk, upper arm, lower arm and hand. Markers were only attached to the dominant shooting arm because the influence of the supporting (non-dominant) arm for ball propulsion is considered negligible and is used predominantly for ball alignment purposes (Wissel, 2004). The retro-reflective markers were attached to the following anatomical landmarks: dominant (d) and non-dominant (n) acromion process, 7th cervical vertebrae, 8th thoracic vertebrae, jugular (suprasternal) notch, xiphoid process, anterior superior iliac spine (d & n), posterior superior iliac spine (d & n), medial and lateral epicondyle (d), radial and ulnar styloid processes (d), 2nd and 5th metacarpal-phalangeal joints (d), and base of the 3rd metacarpal (d). The markers located at the medial and lateral epicondyles, and radial and ulnar styloid processes were used solely for static calibration purposes. The selection of these anatomical landmarks was based on recommendations by Rab *et al.* (2002) who suggested that surface marker sites should be in regions of thin subcutaneous tissue to reduce any confounding influence of this variable. Two marker clusters, shaped to the curvature of the arm, and each consisting of four markers were also situated over both the upper and lower arm (see Figure 3). The marker set used was comparable to that published within the literature (Schmidt *et al.*, 1999) and reported by the International Society of Biomechanics (ISB) guidelines for standardisation of joint coordinate systems (Wu *et al.*, 2005). Information relating to the laboratory and joint coordinate systems is presented in Appendix 8.

(a) (b) (c)

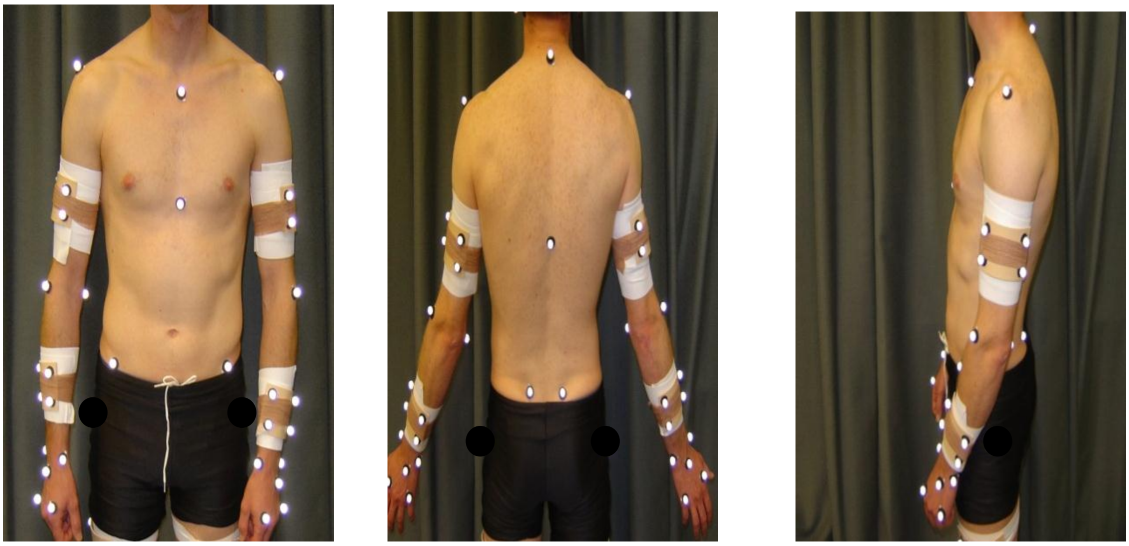

Figure 3. Exemplar retro-reflective marker placement (a) anterior; (b) posterior; (c) lateral view. This dual limb marker set is for illustrative purposes. Markers were only attached unilaterally to the shooting arm.

Leardini *et al.* (2005) state that there are two sources of error at the interface between the motion analysis system used and the bony prominence(s) under investigation. These include anatomical landmark misplacement and soft tissue artefact. Consequently, to assist with precision and accuracy of marker placement, participants were asked to flex and extend the joints of interest whilst the landmarks were palpated by the researcher. In support of Leardini *et al.* (2006), the palpation process was deemed particularly important because mislocation of marker placement has been shown to have large implications on calculation and subsequent validity of joint angular kinematics (see Stagni *et al.*, 2000). However, it should be acknowledged that soft tissue artefact was a key source of measurement error within the current programme of work because external (skin surface) markers were used as opposed to skeletal (bone) markers. There is greater measurement error when using skin surface markers, with the suggested causes including deformation of the subcutaneous tissue, skin displacement and inertial effects (Peters *et al.*, 2010). Conversely, skeletal markers permit greater accuracy because the markers are mounted onto bone pins that are, in turn, screwed directly into the bone itself (see Fuller *et al.*, 1997).

Thus, soft tissue artefact has been a topic of much discussion within biomechanics (for a review, see Peters *et al.*, 2010), with the emphasis being on investigation of its effects on lower limb kinematics (Fuller *et al.*, 1997; Reinschmidt *et al.*, 1997a; Reinschmidt *et al.*, 1997b ; Sangeux *et al.*, 2006; Akbarshahi *et al.*, 2010; Andersen *et al.*, 2010; Schulz *et al.*, 2011), although some attention has been given to upper body kinematics (Schmidt *et al.*, 1999; Roux *et al.*, 2002; Cutti *et al.*, 2006). There have been several, seminal studies that have used skeletal markers, via bone pins, to examine the magnitude of soft tissue artefact (e.g. Fuller *et al.*, 1997; Reinschmidt *et al.*, 1997a; 1997b). In one such study, Fuller *et al.* (1997) quantified soft tissue artefact skin, contrasting surface markers placed on the thigh and shank against skeletal markers attached via surgical screws into the bones of the lower limb. Specifically, two rigid marker arrays were attached directly to the tibia and femur, with an additional twenty skin markers attached along the thigh and shank. Interestingly, there was twenty millimetres of displacement relative to the underlying bone for the skin markers, and, the magnitude of soft tissue artefact varied across the four different tasks e.g. stationary cycling, squatting, normal gait and a voluntary swing movement.

In a series of bone marker studies by Reinschmidt and co-workers , soft tissue artefact was examined in either walking (Reinschmidt *et al.*, 1997a) or running (Reinschmidt *et al.*, 1997b; 1997c). Within the study by Reinschmidt *et al.* (1997a) five participants were required to complete three walking trials with skeletal markers attached via bone pins into the calcaneus, tibia and femur. To make direct comparison to surface markers, additional markers were placed onto the skin along the thigh and shank, and onto the shoe of each participant. The mean root mean squared difference for abduction/aduction, internal/external rotation and flexion/extension of knee joint rotations were 2.4°, 3.9° and 2.1° respectively. For the same respective rotations for the ankle joint complex, root mean squared differences were 2.5°, 3.4° and 3.1° respectively. These values observed by Reinschmidt *et al.* (1997a) are slightly lower than those reported for knee (Reinschmidt *et al.*, 1997b) tibiocalcaneal (Reinschmidt *et al.*, 1997c) rotations when running. Specifically, the root mean squared error for abduction/adduction, inversion/eversion and (plantar) flexion/(dorsi) flexion for the knee were 4.1°, 4.4° and 5.3° respectively (Reinschmidt *et al.*, 1997b), and 3.6°, 4.6° and 4.7° respectively for tibiocalcaneal rotations (Reinschmidt *et al.*, 1997c).

Consequently, in light of the aforementioned research pertaining to soft tissue artefact, the use of skin surface markers constitutes a source of measurement error that could confound and impact upon the validity of movement variability findings from this programme of work. However, to the author's knowledge there have been no studies to date that have examined movement variability of a multi-articular throwing task, such as basketball shooting, using skeletal markers. Furthermore, the current programme of work examined sagittal plane kinematics only, a plane which, as reported by Reinschmidt *et al.* (1997a), appears to have the smallest discrepancy between skin surface and skeletal markers when compared to transverse and frontal plane movements.

A Sony TRV950E digital camera, sampling at 25 Hz, was synchronised to the motion analysis system to permit visual identification of the beginning and end of each performance trial as well as the instant of ball release. The shutter speeds of both the motion analysis system and Sony TRV950E digital camera were set to 1/1000 s. Moreover, the guidelines pertaining to two-dimensional video analysis were adhered to throughout (Dainty and Norman, 1987; Bartlett, 1997). A representation of the experimental set-up is depicted in Figure 4.

Figure 4. Experimental set-up.

3.2.3 DATA ANALYSIS

First, the position of the twenty five retro-reflective markers at each frame of the participants' static calibration trials was identified using EvaRT version 4.6 (Motion Analysis Corporation, Santa Rosa, CA). During the static calibration, participants adopted the anatomical position. The anatomical position refers to a person standing erect with the face directed forward, the upper limbs hanging to the sides, and the palms of the hands facing forward (Seeley *et al.*, 2007). Second, the same process was repeated for the twenty one retro-reflective markers during each of the 90 dynamic performance trials per participant (see Figure 5).

(a) (b) (c)

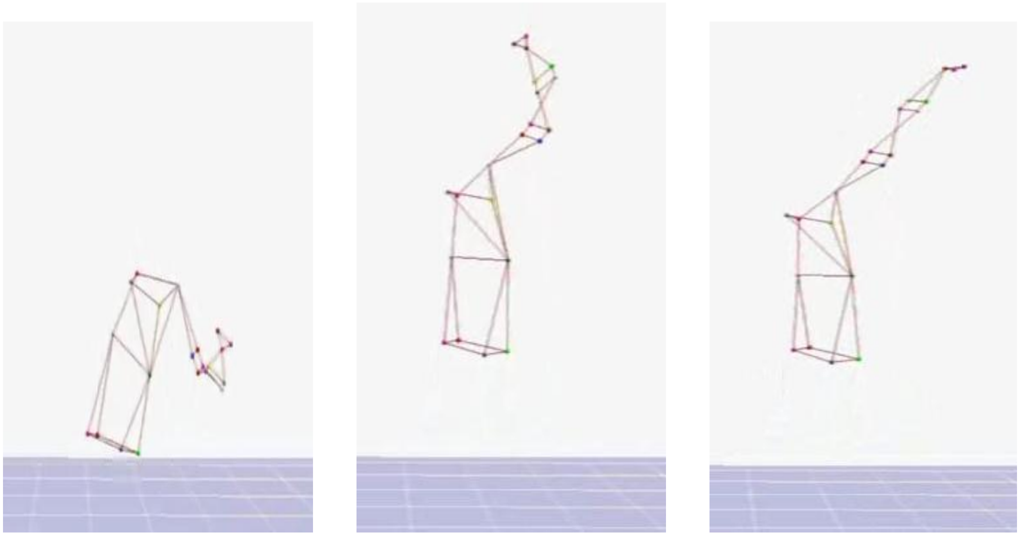

Figure 5. Representation of retro-reflective marker reconstruction during; (a) preparation; (b) execution; (c) transition phases.

The raw three-dimensional coordinate data were filtered using a zero lag 4th order Butterworth filter with the cut-off frequency selected at 6 Hz. The cut-off frequency was chosen based on visual inspection of the fit of the residuals. The three-dimensional joint coordinate system angles for the wrist, elbow and shoulder joints were then generated using Visual 3D version 3.79 (C-Motion Inc., MD, USA). Because the basketball shot is essentially planar, only movements within the sagittal plane were considered for further analysis. Furthermore, the joint angles for the shoulder, elbow and wrist were defined in relation to the anatomical position. As such, an angle of 0° and 180° denoted full elbow extension and shoulder extension respectively. Moreover, wrist flexion and hyperextension were signified by positive and negative angles respectively. Each trial was then cropped using the beginning and end points identified from the SONY digital camera and subsequently interpolated to 101 data points using a cubic spline technique. Data interpolation was again carried out using Visual 3D version 3.79 (C-Motion Inc., MD, USA). The beginning of each performance trial was defined as the first upward movement of the ball and the end was determined by peak flexion of the wrist. The purpose of data interpolation was to eliminate inequalities in trial length both within and between participants and, therefore, each trial was normalised to percentage time.

In addition to the joint angular kinematics derived from the motion analysis system, the release parameters, height, speed and angle of release, of the basketball were also computed. To achieve this, the centre of the basketball was manually digitised from the sagittal plane video recording using SIMI Motion (Simi Reality Motion Systems GmbH). Specifically, the basketball was digitised at the instant of release (n) as well as one frame before (n^{-1}) and one frame after (n^{+1}). Ball release was defined as the first frame in which the ball had left the participant's dominant shooting hand. Two intersecting metre rules were used for calibration purposes, and once digitisation was complete, the two-dimensional ball coordinates were exported into Microsoft Excel (Microsoft Corporation, USA) for further analysis. Height of release was calculated using the absolute height (m) from the floor, signified by the y-coordinate data, at the instant of ball release. Speed and angle of release were quantified using the finite central difference method (equation 1) and trigonometry respectively.

$$\text{Speed of Release} = \frac{\sqrt{(x_{n+1} - x_{n-1})^2 + (\mathrm{y}_{n+1} - \mathrm{y}_{n-1})^2}}{2t} \qquad (1)$$

where t denotes time, x_{n+1} is the x *coordinate* one frame after release, x_{n-1} is the x coordinate one frame before release, y_{n+1} is the y coordinate one frame after release and y_{n-1} is the y coordinate one frame before release.

The reliability and objectivity of coordinate digitising is of particular importance if movement variability is the subject of interest (see Bartlett *et al.*, 2006). Reliability is a measure of the consistency of data whereas objectivity relates to data that are collected without bias (Vincent, 1999). Furthermore, the inconsistency of measurement can have a profound effect upon the meaningfulness of the data presented (Cooper *et al.*, 2007), particularly if measurement inconsistency introduces extraneous experimental error into the data which is subsequently interpreted as kinematic variability. The reliability of coordinate digitising was assessed by the researcher digitising the same block of 30 trials for a single participant over four separate occasions. Each occasion was separated by at least one week to minimise any confounding learning effects. Objectivity, on the other hand, was examined by contrasting the release parameter data obtained by the researcher from a single block of 30 trials to that obtained by three other experienced, qualified sport and exercise scientists. All three sport scientists had previously received formal training from the software manufacturer on the operation of SIMI Motion, an important consideration when undertaking inter-operator reliability analyses (see Bradley *et al.*, 2007).

Reliability and objectivity of height, speed and angle of release was determined using two techniques. First, mean absolute and relative error were calculated (see Table 3). Second, the reliability and objectivity of each release parameter was assessed using 95% limits of agreement (Bland and Altman, 1986). Assessment of the reliability and objectivity of data is considered to be univariate. As such, 95% limits of agreement is deemed to be more appropriate than traditionally used bivariate inferential statistics, i.e. correlation and *t*-test (see Atkinson and Nevill, 1998). Reliability was assessed by contrasting the researcher's first sample of scores (Time 1), used as the criterion measure, against the ensemble average scores generated from the three subsequent re-tests. Objectivity was assessed using a similar approach and compared the researcher's scores from the first sample of scores (Time 1) to that of the ensemble average of operator scores.

Table 3. Reliability and objectivity of coordinate digitising.

		Release Parameter		
		Height (m)	Speed (m/s)	Angle (º)
Reliability	Mean Absolute Error	0.01	0.09	0.58
	Mean Relative Error (%)	1.35	1.32	1.10
Objectivity	Mean Absolute Error	0.02	0.21	0.62
	Mean Relative Error (%)	0.02	2.85	1.19

Through examination of test-retest differences, the reliability for height, speed and angle of release was 0.01 ± 0.01 m, 0.09 ± 0.12 m/s and 0.58 ± 1.03º respectively. Furthermore, the objectivity for height, speed and angle of release was -0.023 ± 0.049 m, 0.205 ± 0.119 m/s and 0.624 ± 1.215º respectively. In light of these reported values, the magnitude of test-retest differences were deemed acceptable. Exemplar limits of agreement plots are also presented in Figures 6 and 7, depicting graphically; systematic bias, random variance and the 95% confidence limits.

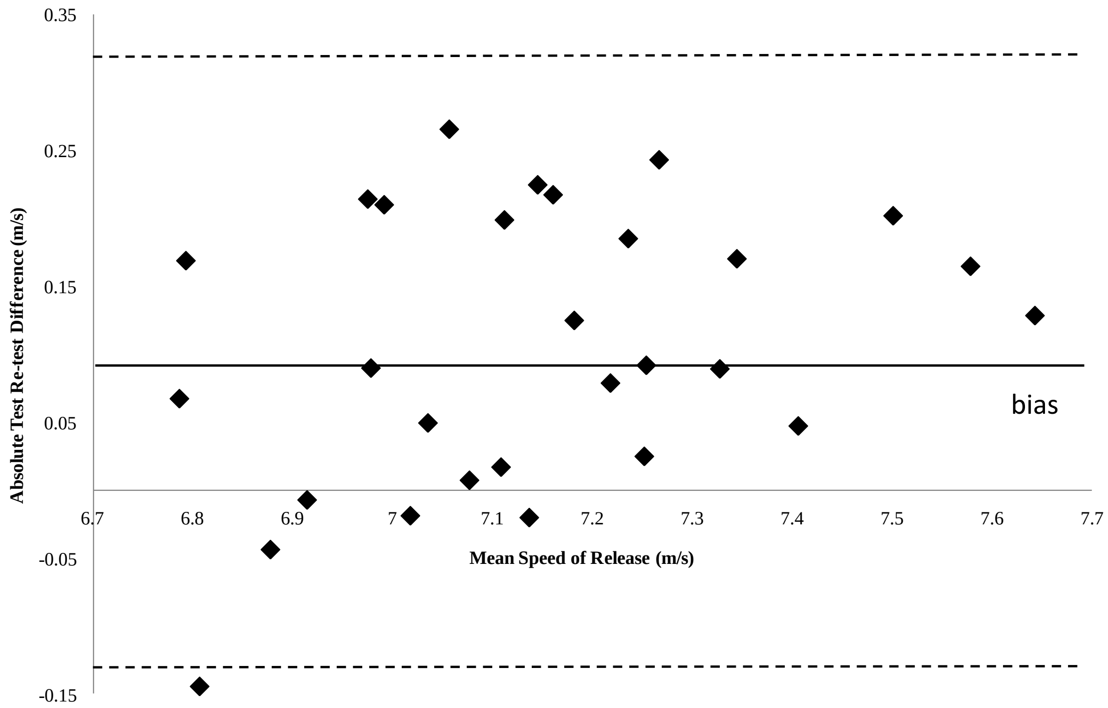

Figure 6. Intra-operator reliability for Speed of Release.

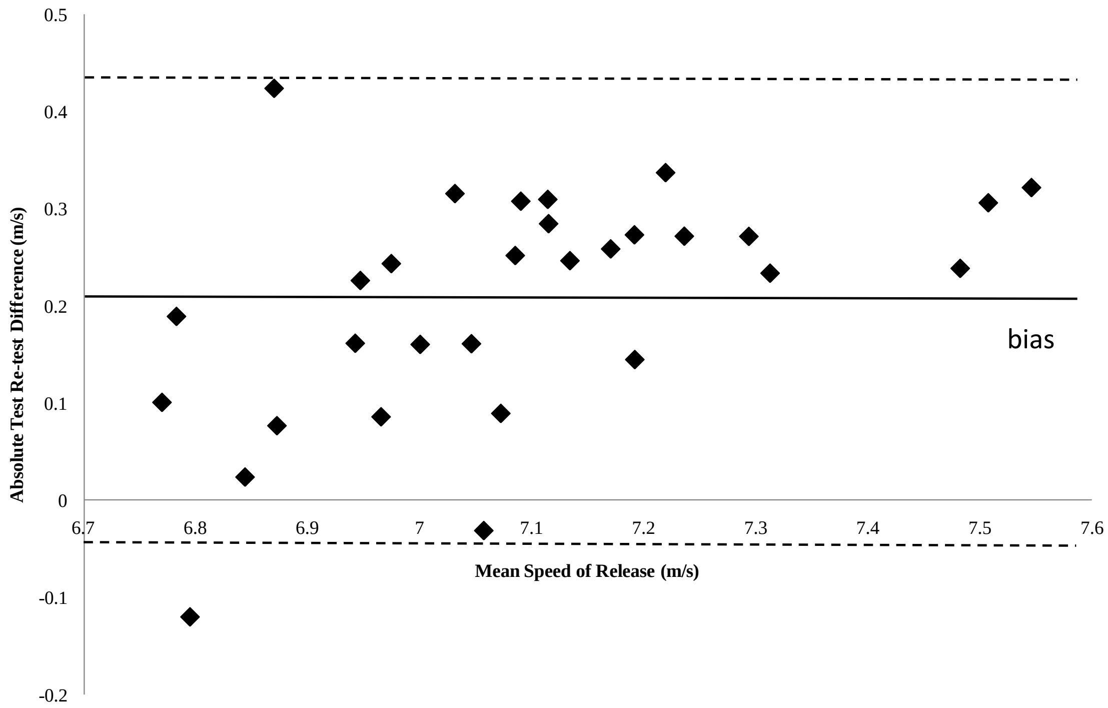

Figure 7. Inter-operator reliability for Speed of Release.

The dependent variables of interest included shooting performance score, variability of ball release parameters (height, angle and speed of release), variability of shoulder, elbow and wrist joint angular displacement at ball release and coordination variability. Ball release parameters and segmental configuration at ball release have regularly been acknowledged as fundamental to success in basketball shooting (Miller and Bartlett, 1993; 1996; Miller, 1998; Robins *et al.*, 2006), and have been incorporated within devised deterministic models of performance (see Figure 8).

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Figure 8. Deterministic model for Basketball Shooting (Miller and Bartlett, 1993).

The variability of such measures was expressed in absolute terms and computed simply by the standard deviation. This method was preferred over alternative techniques such as the coefficient of variation, which has previously been used to provide a relative index of movement variability (Miller, 1998; 2002). Coefficient of variation was not utilised within the current study because it can provide a misleading representation of movement variability because the value is contingent upon the magnitude of the mean. For instance, ball release typically occurs when the wrist joint is close to its anatomical, neutral position. Hence, the mean angular displacement for the wrist is low which consequently creates an erroneously high relative variability score.

Examination of coordination variability was deemed essential as basketball shooting is a discrete multi-articular action and analysis of single joint time-series data was considered too reductionist. Furthermore, for successful task accomplishment, coordination (and exploration) between interacting biomechanical degrees of freedom is required. Consequently, coordination variability was calculated for three joint couplings: wrist-elbow, elbow-shoulder and wrist-shoulder. First, relative motion (angle-angle) plots were created for all three joint-couplings. The variability of angle-angle plots was then quantified using the normalised root mean squared difference (NoRMS) technique proposed by Sidaway *et al.* (1995a). The normalised root mean squared difference was calculated using equation 2.

$$100\sum_{j=1}^{k}\sqrt{\sum_{i=1}^{n}(\bar{x}_A - x_{Ai})^2 + (\bar{x}_B - x_{Bi})^2/n_j}/kR \qquad (2)$$

where *A* and *B* denote the two variables of interest, *k* is the number of cycles, *n* is the number of data points, *R* is the resultant excursion of the mean angle-angle curve over the entire cycle, $\bar{x}$ is the mean position of a given variable at the *i*th data point and *x* is the position of a given variable at the *i*th data point on the *j*th cycle.

Although there are many techniques available to quantify coordination, e.g. continuous relative phase (Kurz and Stergiou, 2002; Peters *et al.*, 2003; Wheat *et al.*, 2003), and cross-correlation (Amblard *et al.*, 1994), as well as the magnitude of coordination variability, e.g. standard deviation of continuous relative phase (Hamill *et al.*, 2000; Miller *et al.*, 2010), normalised root mean squared difference (NoRMS, Sidaway *et al.*, 1995), Fourier analysis of phase-plane portraits (Polk *et al.*, 2008; DiBerardino *et al.*, 2010), principal components analysis (Daffertshofer *et al.*, 2004), spanning set (Kurz and Stergiou, 2003; Kurz *et al.*, 2003), and vector coding (Whiting and Zernicke, 1982; Sparrow *et al.*, 1987; Tepavac and Field-Fote, 2001) (for a review, see Wheat and Glazier, 2006), analysis of coordination variability using normalised root mean squared difference was the preferred technique implemented. The rationale for choosing the normalised root mean squared difference technique was three-fold. The first reason relates to using relative motion plots for the examination of intra-limb coordination. Specifically, when examining coordination, the use of relative motion plots does not rely on the assumption of either a sinusoidal time history, as does continuous relative phase, or linearity in the data, as does cross-correlation (Wheat and Glazier, 2006). Consequently, although continuous relative phase has previously been used to quantify coordination in basketball shooting (Robins *et al.*, 2006), and is considered to be a more sensitive measure of coordination when compared to relative motion plots (see Wheat *et al.*, 2002), it was not considered appropriate within the current programme of work. Continuous activities such as bimanual rhythmic coordination (Kelso *et al.*, 1981; Kelso and Schoner, 1988; Kelso, 1991) and gait (Hamill *et al.*, 2000) have been shown to conform to a sinusoidal time history, providing suitable justification for measuring coordination using continuous relative phase for these movement types. Conversely, discrete actions such as basketball shooting may violate this assumption, and when using the standard deviation of continuous relative phase to compute coordination variability, artefacts may be introduced into the data that can be misinterpreted as kinematic variability.

The second reason relates to using NoRMS as a measure of coordination variability. It is suggested that NoRMS offers a good measure of coordination variability because it encapsulates changes in both the magnitude and shape of relative motion plots (Wheat and Glazier, 2006). Furthermore, the normalised root mean squared difference method also has an advantage over the recently introduced spanning set technique proposed by Kurz and co-workers (Kurz and Stergiou, 2003; Kurz *et al.*, 2003) because it permits the quantification of *coordination variability* for specific joint couplings, such as wrist-elbow or elbow-shoulder, by inputting the kinematic data from two joints. The spanning set technique, however, examines the variability of isolated joints which permits only a partial understanding of the movement. The same limitation is also evident within phase plane portraits because the angular displacement of one joint is plotted against the angular velocity of the same joint.

The third and final reason is that the resultant value derived from NoRMS is in the unit of degrees, allowing ease of interpretation. Consequently, despite the proposed limitations of using NoRMS i.e. only providing a single value of movement variability, rather than at discrete points of interest, and, the normalisation of the data, which is comparable to the calculations used when quantifying coefficient of variation (Wheat and Glazier, 2006), this was one of the contributing reasons why NoRMS was used instead of, for instance, the vector coding technique. As a result, despite vector coding being used previously to examine the movement variability of basketball shooting (e.g. Mullineaux and Uhl, 2010), vector coding produces a value ranging from 0 (no movement variability) to 1 (maximum movement variability). This can, subsequently, be argued to be rather abstract and difficult to interpret.

3.2.4 STATISTICAL ANALYSIS

The assumptions underpinning the use of parametric statistics, i.e. normality and homogeneity of variance etc., were tested for and verified (Minitab version 15, Minitab

Inc., State College, PA, USA) (see Appendix 9). Specificially, normality, homogeneity of variance and sphericity were tested using an Anderson-Darling test, Levene's test and Mauchly's test of sphericity respectively. Subsequently, each dependent variable of interest was assessed for statistical significance using a 3 (expertise) * 3 (distance) ANOVA with expertise as the between-individuals factor and distance as the within-individuals factor ($P < 0.05$). The ANOVA was performed using the Statistical Package for the Social Sciences (SPSS) version 17 (IBM Corporation, New York, USA). An example SPSS output is presented in Appendix 10. An overall alpha level of 0.05 was selected to compromise between committing a type I or type II error (see Franks and Huck, 1986; 1987). Furthermore, based on the recommendations of O'Brien and Israel (1987), exact *P*-values were stated throughout. Following a statistically significant difference, *post-hoc* pairwise comparisons were conducted using a Bonferroni correction. Although use of the Bonferroni correction has received scrutiny (see Perneger, 1998), an adjustment was used to prevent inflation of the type I error rate caused by conducting multiple pairwise comparisons. Inferential statistics were supplemented with measures of effect size (η^2) to quantify the meaningfulness of the differences. Eta squared (η^2) is a measure of the proportion of the total variance that is explained by the treatment effects. Accordingly to Cohen (1988), eta squaredvalues in the order of 0.02, 0.13 and 0.26 represent small, medium and large effects respectively.

Quadratic regression analyses were also conducted to identify: (1) relationships between shooting performance score and wrist-elbow, elbow-shoulder and wrist-shoulder joint coupling variability; (2) covariance in shoulder, elbow and wrist joint angular displacement at the instant of ball release. Based on the theoretical insights from Neuronal Group Selection Theory that argue that expert performers may demonstrate as much coordination variability as their novice counterparts, quadratic regression was deemed to most appropriately reflect this hypothesised non-linear relationship between shooting performance and joint coupling variability. Moreover, quadratic regression has previously been used to capture the relationship between coordination variability and task expertise in elite triple jumpers (Wilson *et al.*, 2008). Quadratic regression was also used to determine the magnitude of covariance between interacting joints because it was hypothesised that the wrist, elbow and shoulder joints would not contribute uniformly to the execution of the skill, and hence would not exhibit a linear relationship. Instead, in light of the summation of speed along the kinematic chain (see Bunn, 1972), it was postulated that the contribution from each joint towards the skill would be different. Therefore, a change of 1º for one joint may not be equivalent to a 1º change in another joint.

3.2.5 NULL HYPOTHESES

H_{01} There will be no significant effect of task expertise on basketball shooting performance score.

H_{02} There will be no significant effect of task expertise on the magnitude of movement variability.

H_{03} There will be no significant effect of shooting distance on basketball shooting performance score.

H_{04} There will be no significant effect of shooting distance on the magnitude of movement variability.

H_{05} There will be no significant relationship between basketball shooting performance score and joint coupling variability.

H_{06} There will be no significant relationship between shoulder, elbow and wrist joint angular displacement at the instant of ball release, irrespective of task expertise.

3.3 RESULTS

3.3.1 SHOOTING PERFORMANCE

The changes in shooting performance with respect to expertise and distance are presented in Figure 9. The two-way ANOVA with distance as the within-individuals factor and expertise as the between- individuals factor revealed no significant expertise * distance interaction (P = 0.984; η^2 = 0.001). There were, however, significant main effects for both distance (P = 0.0001; η^2 =0.499) and expertise (P = 0.0001; η^2 = 0.825). *Post-hoc* tests revealed a significant decrease in shooting performance from 5.25 m to 6.25 m, regardless of expertise (P < 0.05). Skilled participants also performed significantly better at all three distances than their intermediate and novice counterparts (P < 0.005). Finally, the intermediate participants performed better than the novice participants at each of the three distances (P < 0.005).

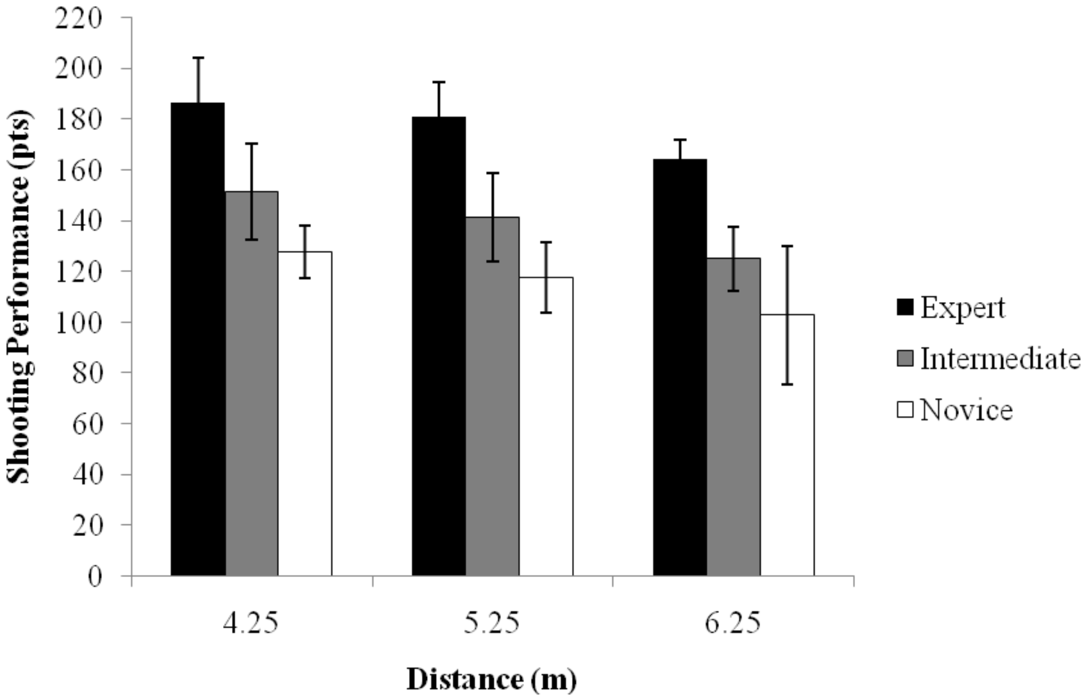

Figure 9. Change in shooting performance with respect to expertise and distance.

3.3.2 VARIABILITY OF BALL RELEASE PARAMETERS

3.3.2.1 HEIGHT OF RELEASE

The changes in mean (± SD) variability of height of release with respect to expertise and distance are presented in Figure 10. There was no significant expertise * distance interaction ($P = 0.285$; $\eta^2 = 0.097$). There was, however, a significant main effect for expertise ($P = 0.008$; $\eta^2 = 0.333$). The *post-hoc* tests revealed that the expert participants exhibited significantly less variability than their novice counterparts ($P = 0.006$). Moreover, the variability of height of release for the novice participants was, on average across the three shooting distances, 28.8% (± 15.7) greater than the expert equivalents. No other expertise differences were observed ($P > 0.286$). However, it is important to acknowledge that, although not reaching statistical significance, variability of height of release was, again on average, 14.4% (± 2.3) greater for the intermediate performers when compared to the experts. A significant main effect was also observed for distance ($P = 0.021$; $\eta^2 = 0.148$). Specifically, less variability was evident at 4.25 m than at 5.25 m ($P = 0.028$). The pairwise comparison between 4.25 m and 6.25 m marginally missed statistical significance ($P = 0.07$).

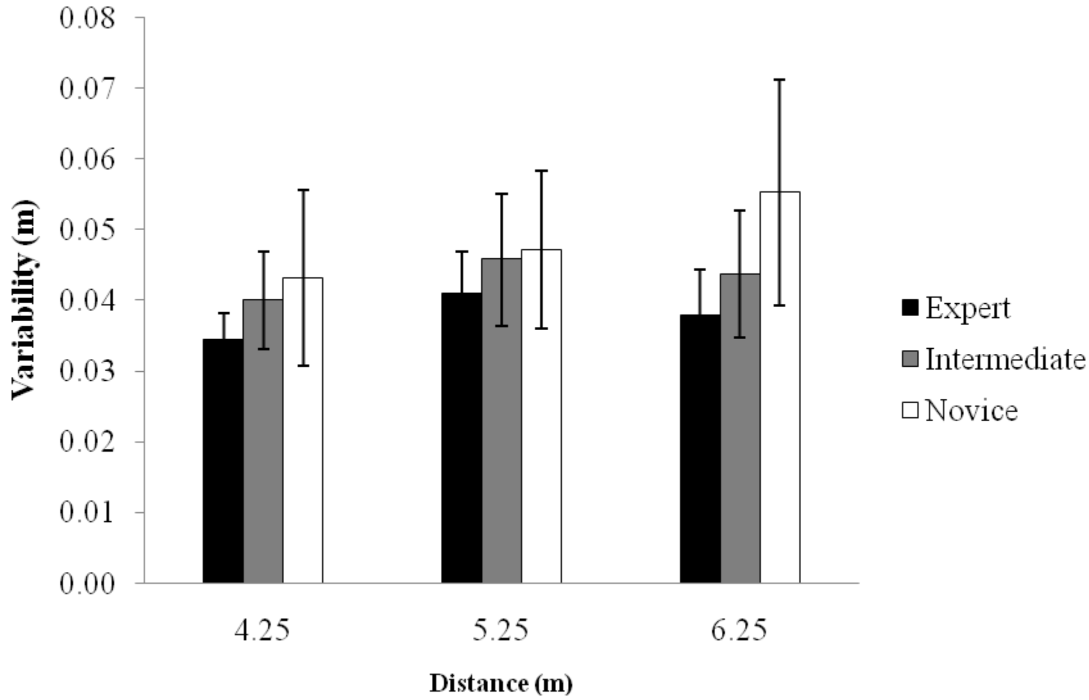

Figure 10. Mean (± SD) variability of height of release as a function of expertise and shooting distance.

3.3.2.2 SPEED OF RELEASE

The mean (± SD) variability of speed of release as a function of expertise and distance is presented in Figure 11. The 3 (expertise) * 3 (distance) ANOVA revealed a significant expertise * distance interaction (P = 0.026; η^2 = 0.202) as well as main effects for both distance (P = 0.046; η^2 = 0.121) and expertise (P = 0.031; η^2 = 0.252). Two findings are worthy of note from the *post-hoc* pairwise comparisons. First, the intermediate participants demonstrated less variability in speed of release than the novices (P = 0.035). Second, the experts exhibited a significant increase in variability with a corresponding increasing in shooting distance, specifically between 4.25 m and 5.25 m (P = 0.042)

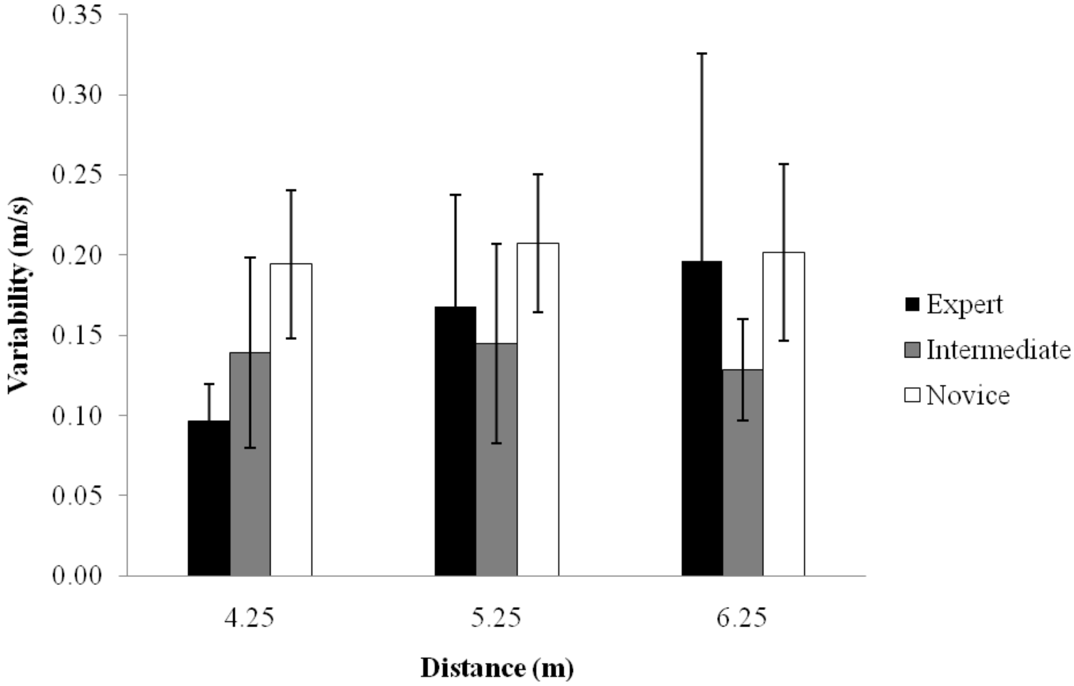

Figure 11. Mean (± SD) variability of speed of release as a function of expertise and shooting distance.

3.3.2.3 ANGLE OF RELEASE

The mean (± SD) variability of angle of release is depicted in Figure 12. No significant expertise * distance interaction was found for this variable of interest (P = 0.359; η^2 = 0.009). There was also no significant distance main effect (P = 0.119; η^2 = 0.009). There was, however, a significance main effect for expertise (P = 0.0001; η^2 = 0.539). Specifically, both the experts and intermediates demonstrated less variability than their novice counterparts at all three shooting distances (P < 0.001). There was no significant difference between the expert and intermediate participants (P = 1.000).

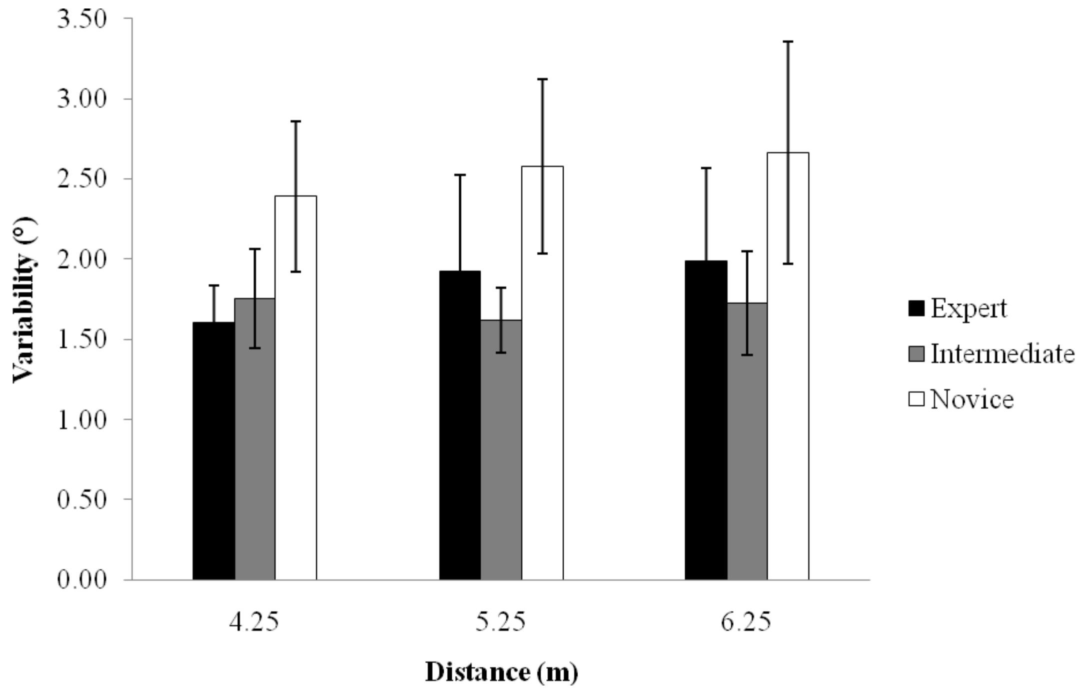

Figure 12. Mean (± SD) variability of angle of release as a function of expertise and shooting distance.

3.3.3 JOINT ANGLE VARIABILITY AT RELEASE

The mean (± SD) values for joint angle variability as a function of both expertise and shooting distance are presented in Table 4. There were no significant expertise * distance interactions for elbow or shoulder variability at release ($P > 0.05$, $\eta^2 < 0.09$). A significant expertise * distance interaction was found, however, for wrist variability at release ($P = 0.05$, $\eta^2 = 0.26$). *Post-hoc* comparisons revealed that the intermediate participants possessed significantly greater variability for the wrist joint at release for shots at 5.25 m compared to the other two shooting distances ($P = 0.05$, $\eta^2 = 0.33$).

A significant main effect for expertise was also found for shoulder variability at release ($P = 0.03$, $\eta^2 = 0.25$). Specifically, the novice participants exhibited greater variability at the shoulder joint at release than the intermediate group ($P = 0.05$). Interestingly, no differences were observed for shoulder joint variability at release between expert and novice participants (P > 0.05). No other significant main effects were observed for either expertise or distance for any of the other dependent variables (P > 0.05, η^2 < 0.09).

Table 4. Mean (± SD) values for joint angle variability at release as a function of both expertise and shooting distance.

Expertise	Shooting Distance (m)	Joint Angle Variability at Release (°) Wrist	Elbow	Shoulder
Skilled	4.25	12.3 ± 4.1	8.2 ± 2.4	3.4 ± 1.2
	5.25	9.5 ± 2.4	8.2 ± 1.9	3.4 ± 0.8
	6.25	10.1 ± 1.0	8.1 ± 1.5	3.6 ± 1.1
Intermediate	4.25	8.8 ± 3.4	6.3 ± 1.3	2.8 ± 1.2
	5.25	11.9 ± 4.4	7.4 ± 1.2	3.5 ± 1.7
	6.25	9.1 ± 2.1	7.5 ± 1.7	3.2 ± 1.5
Novice	4.25	8.4 ± 2.3	7.2 ± 2.0	4.8 ± 2.4
	5.25	8.9 ± 3.5	8.7 ± 3.8	5.3 ± 2.8
	6.25	9.2 ± 3.3	7.1 ± 2.2	5.7 ± 2.4

Further quadratic regression analyses revealed significant relationships between the wrist, elbow and shoulder joint angles at release for skilled, intermediate and novice participants (P < 0.05). However, the magnitude of the relationship changed markedly with respect to expertise. For instance, the mean regression values at a distance of 4.25 m for experts ranged from 0.7 – 0.9, whereas the mean regression values for intermediates and novices ranged from 0.5 – 0.7 and 0.4 – 0.6 respectively. Exemplar regression lines for participants within each expertise group are depicted in Figures 13-15. Furthermore, it is important to note that these range values were similar to those observed at 5.25 and 6.25 m, indicating that the strength of the relationship between interacting joints along the kinematic chain persisted irrespective of shooting distance.

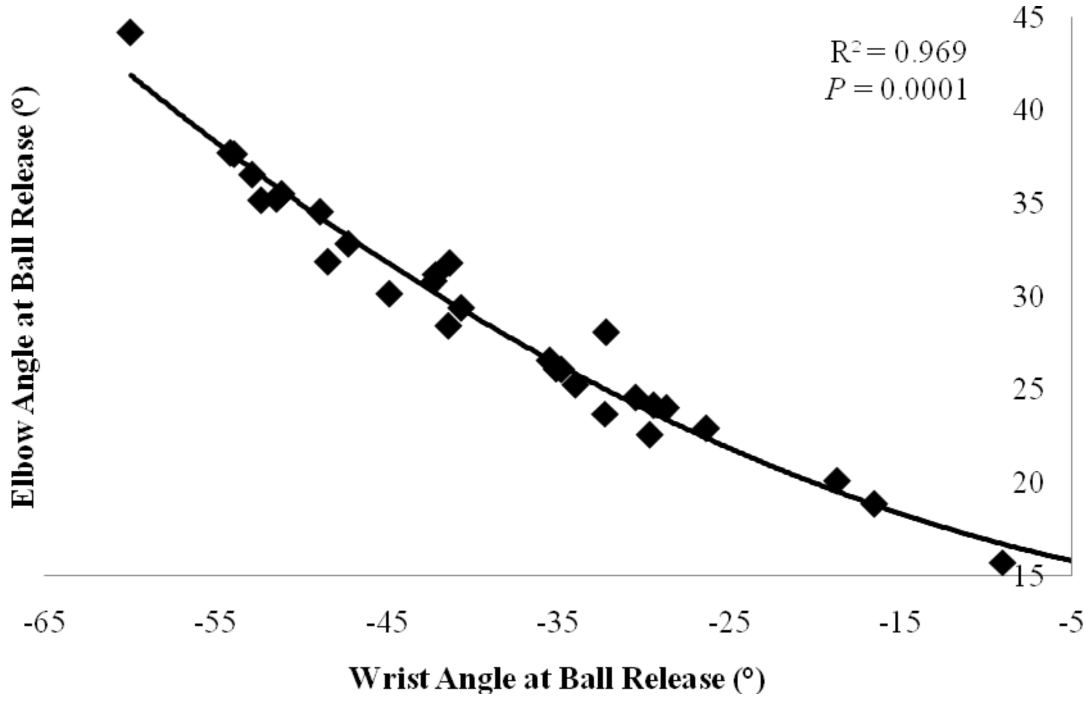

Figure 13. Relationship between wrist and elbow angle at ball release for an exemplar expert participant at a distance of 4.25 m.

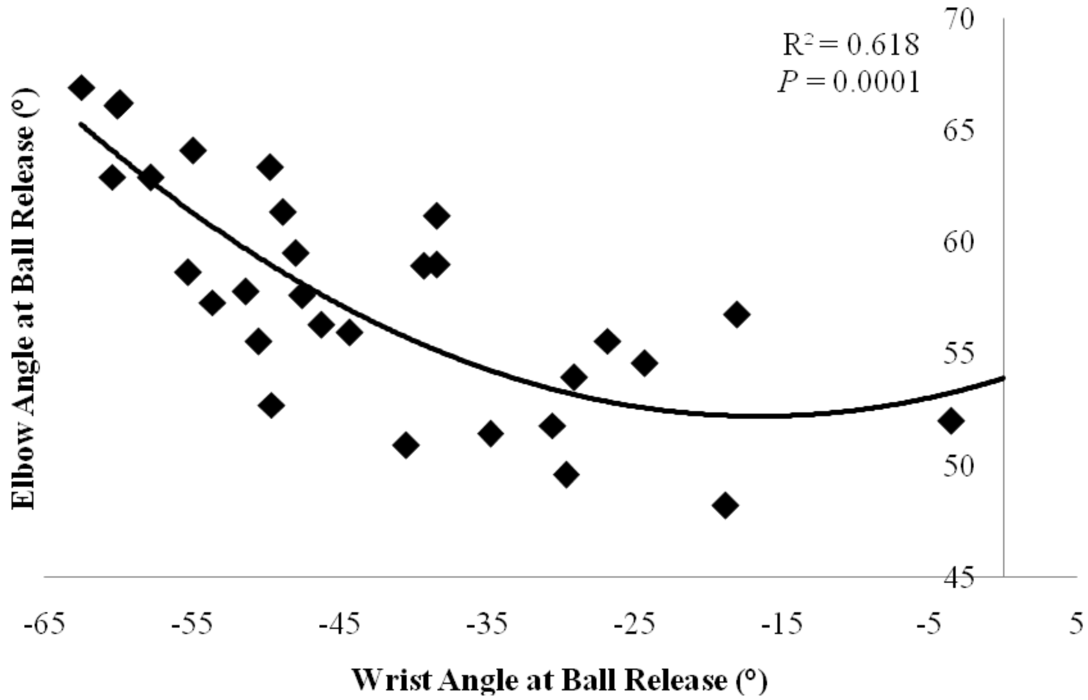

Figure 14. Relationship between wrist and elbow angle at ball release for an exemplar intermediate participant at a distance of 4.25 m.

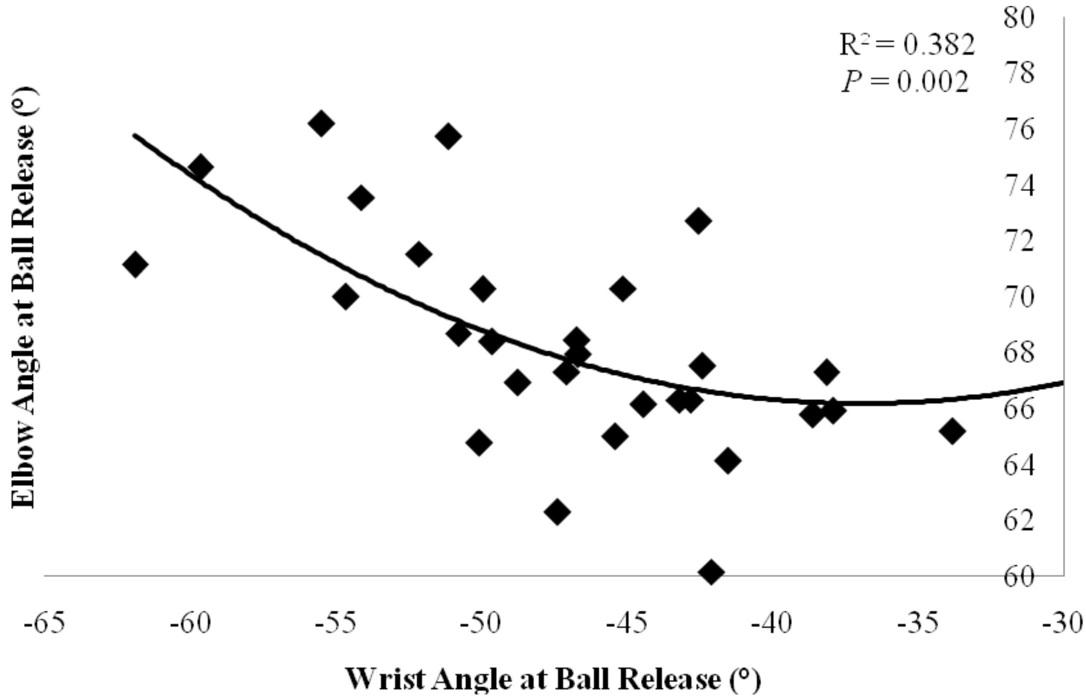

Figure 15. Relationship between wrist and elbow angle at ball release for an exemplar novice participant at a distance of 4.25 m.

3.3.4 COORDINATION VARIABILITY

The mean (± SD) normalised root mean squared differences (NoRMS) as a function of both expertise and shooting distance are presented in Table 5. Furthermore, the angle-angle plots of exemplar participants within each expertise category, and at a distance of 4.25 m, are displayed in Figures 16-18. The two-way ANOVA revealed no significant expertise * distance interactions for any of the three joint couplings ($P > 0.622$; $\eta^2 < 0.052$). No significant main effect was found with respect to distance ($P > 0.260$; $\eta^2 < 0.055$), but a significant main effect was observed for expertise for the variability of all three joint couplings ($P < 0.0001$; $\eta^2 > 0.593$). *Post-hoc* tests revealed that both the skilled and intermediate participants exhibited smaller variability at the wrist-elbow, elbow-shoulder and wrist-shoulder joint couplings than the novice participants at all three distances ($P < 0.01$). The skilled participants also demonstrated reduced variability at all three joint couplings at both 4.25 and 5.25 m when compared to their intermediate counterparts (P < 0.05). These findings are clearly evident from visual inspection of Figures 16-18, which highlight a constrained pattern for the expert participant, one that is characterised by lower inter-trial variability. Conversely, the traces for both intermediate and novice performers appear more diffuse. Greater variability is apparent at the beginning of the trials, irrespective of expertise. Variability then decreases as the trials progress with the relative motion plots converging during elbow extension.

Table 5. Mean (± SD) normalised root mean squared differences (NoRMS) as a function of both expertise and shooting distance.

Expertise	Shooting Distance (m)	Coordination Variability (°) Wrist-Elbow Coupling	Elbow-Shoulder Coupling	Wrist-Shoulder Coupling
Skilled	4.25	5.1 ± 1.0	4.5 ± 1.2	4.8 ± 0.7
	5.25	5.0 ± 1.0	4.6 ± 0.9	4.8 ± 0.9
	6.25	5.0 ± 1.0	5.1 ± 1.4	5.2 ± 1.3
Intermediate	4.25	7.0 ± 3.1	6.5 ± 2.4	6.8 ± 2.8
	5.25	6.6 ± 1.9	6.3 ± 1.6	6.3 ± 2.0
	6.25	6.1 ± 1.6	5.9 ± 1.3	6.1 ± 1.8
Novice	4.25	12.4 ± 4.7	10.6 ± 3.7	13.0 ± 4.8
	5.25	12.0 ± 3.9	10.7 ± 3.2	13.6 ± 5.7
	6.25	11.3 ± 3.1	9.9 ± 3.0	13.6 ± 6.0

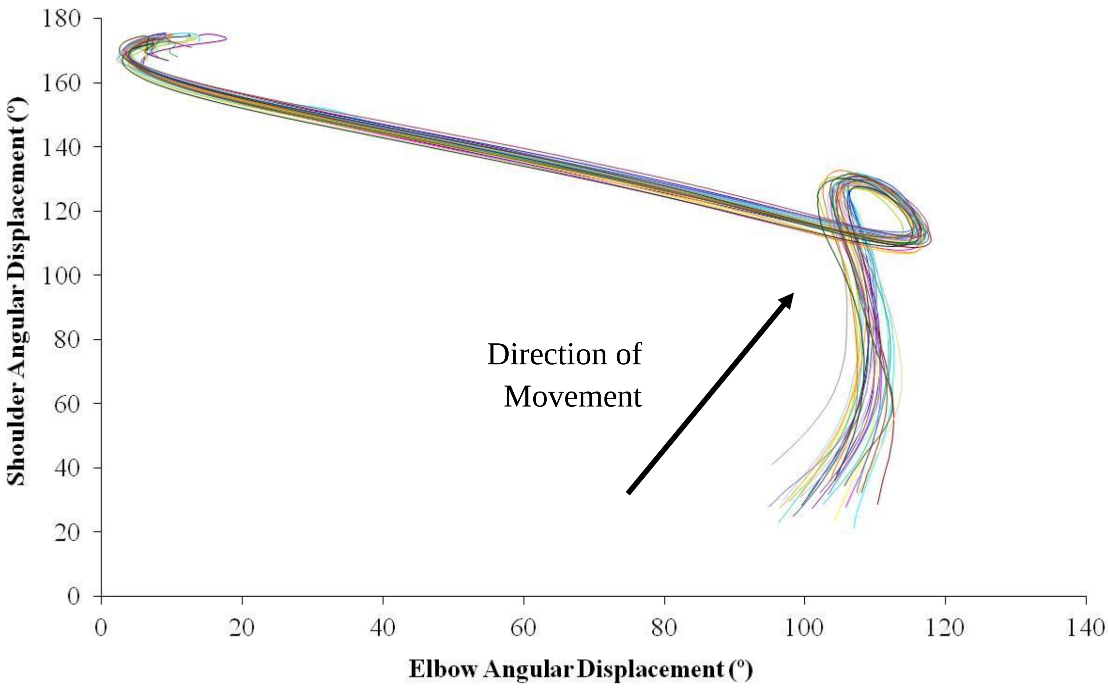

Figure 16. Angle-angle plot for an exemplar skilled participant at a distance of 4.25 m.

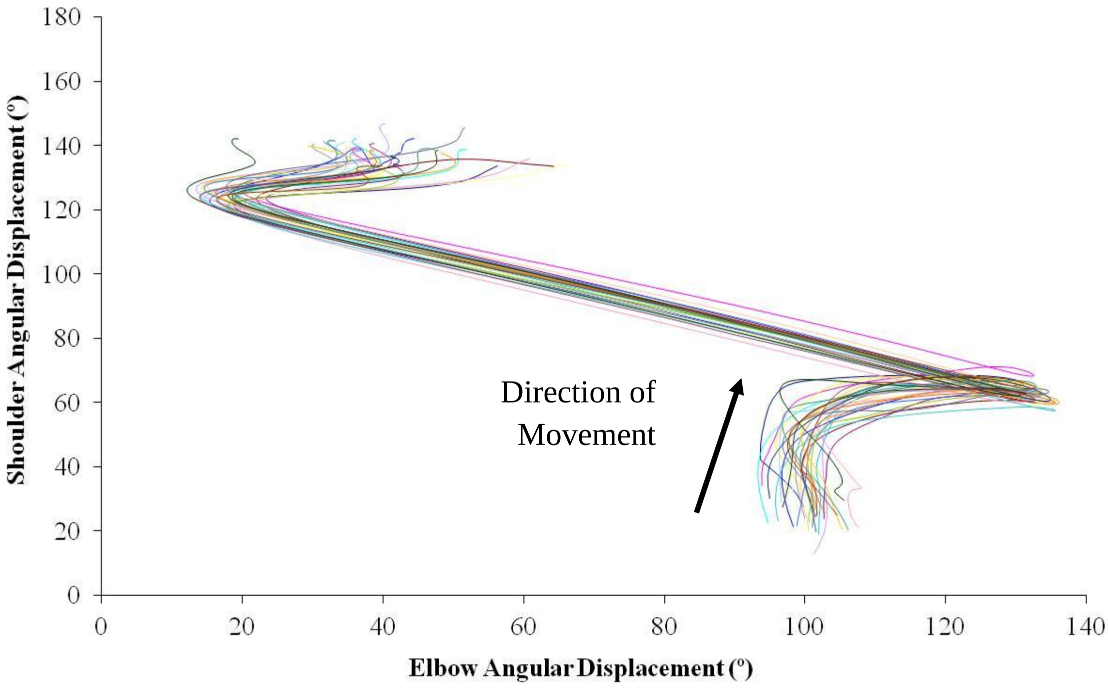

Figure 17. Angle-angle plot for an exemplar intermediate participant at a distance of 4.25 m.

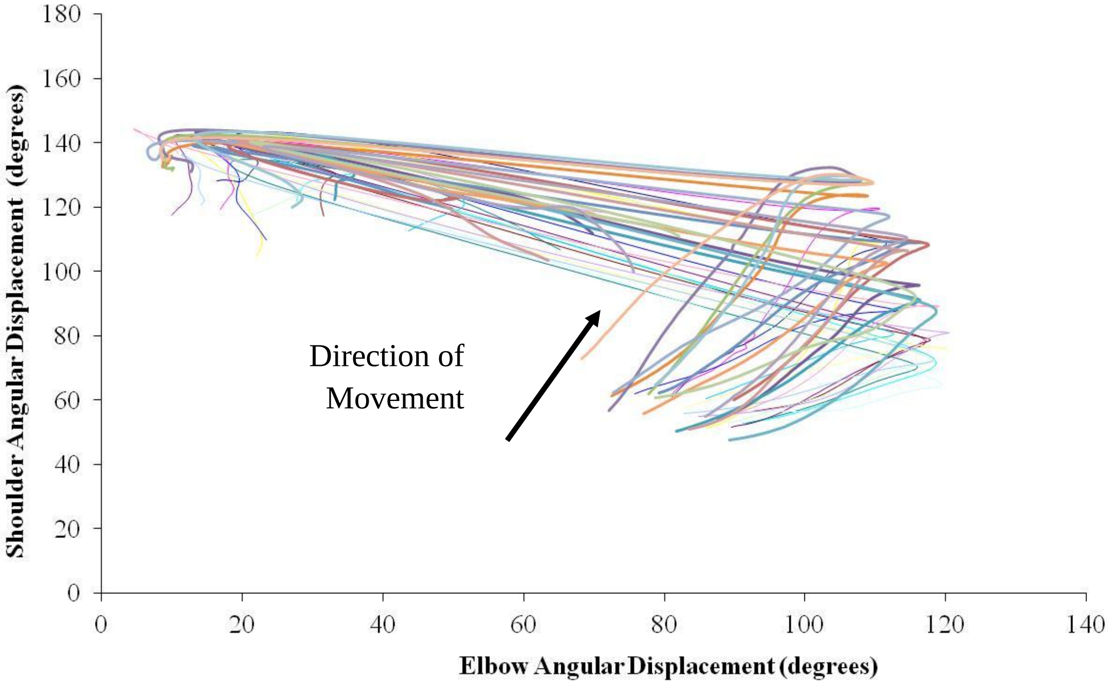

Figure 18. Angle-angle plot for an exemplar novice participant at a distance of 4.25 m.

When plotting shooting performance against coordination variability, the quadratic regression analyses revealed a significant, negative relationship between shooting performance and coordination variability for all three joint couplings irrespective of shooting distance ($P < 0.003$). For instance, regression values of 0.622, 0.586 and 0.539 were found at 4.25 m for the wrist-elbow, elbow-shoulder and wrist-shoulder joint couplings respectively (see Figures 19-21). Furthermore, regression values of 0.673, 0.661 and 0.516 (5.25 m) and 0.36, 0.37 and 0.30 (6.25 m) were found for the same respective joint couplings at the remaining two distances.

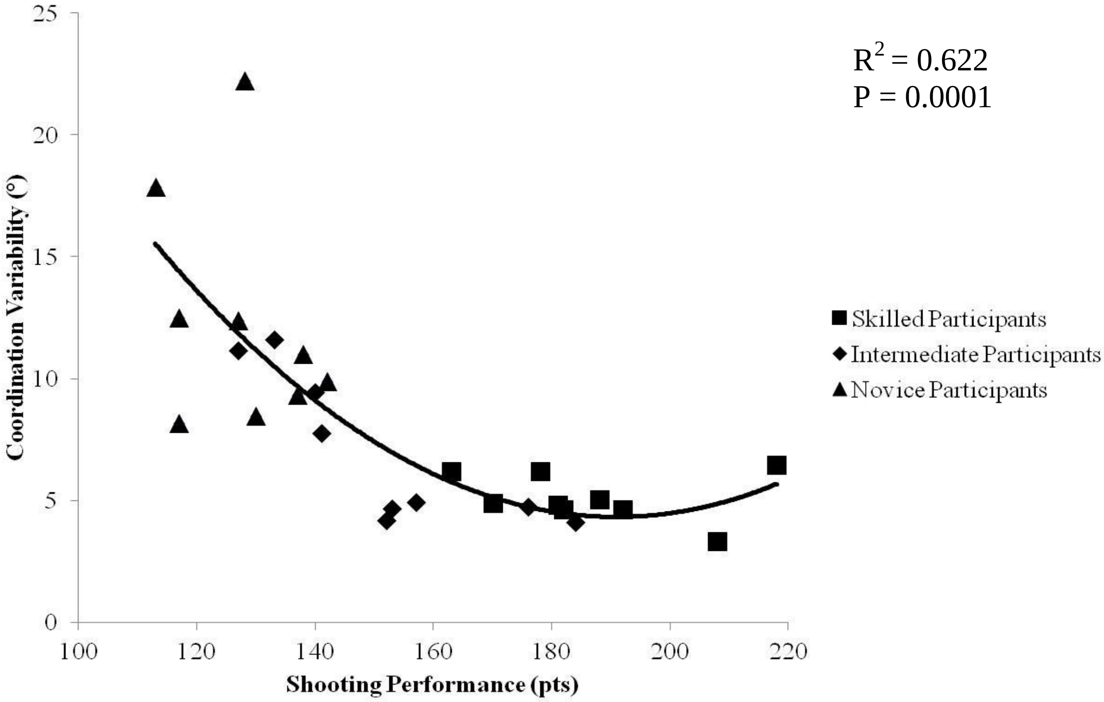

Figure 19. Exemplar regression line identifying the relationship between wrist-elbow joint-coupling variability and shooting performance at a distance of 4.25 m.

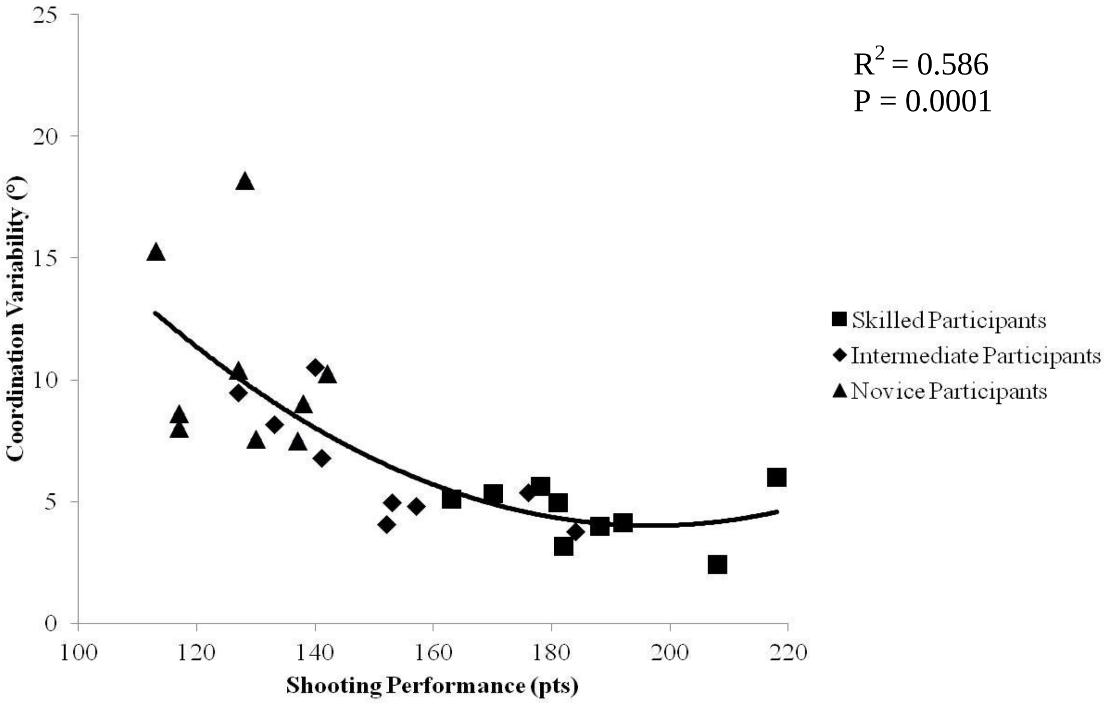

Figure 20. Exemplar regression line identifying the relationship between elbow-shoulder joint-coupling variability and shooting performance at a distance of 4.25 m.

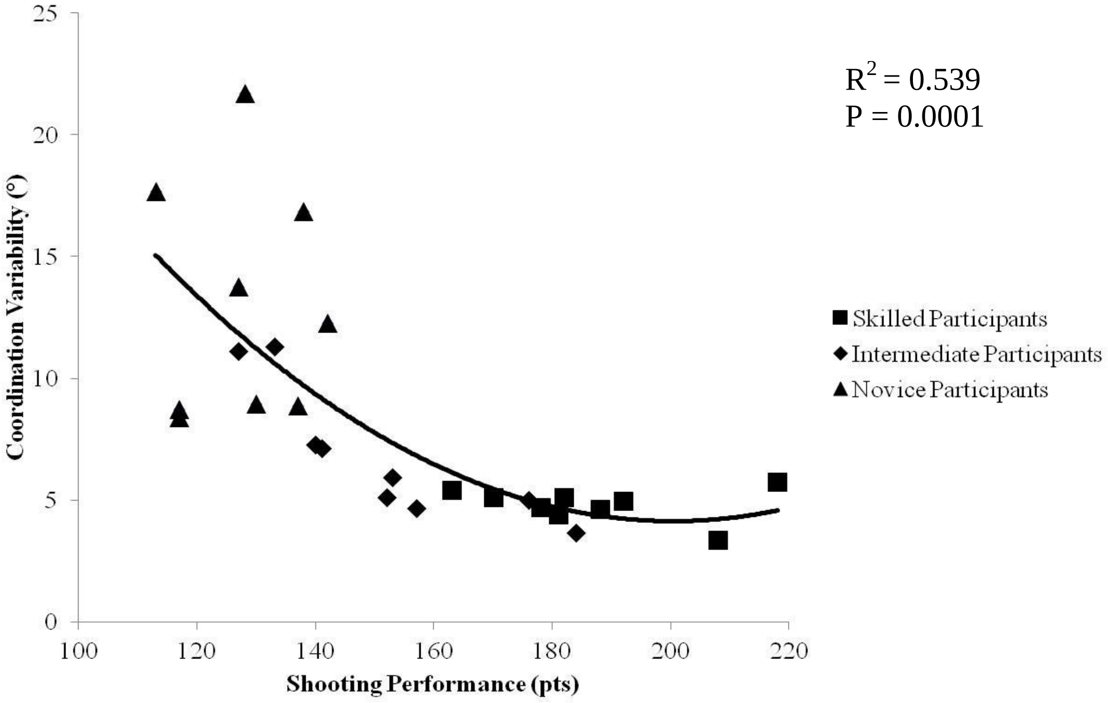

Figure 21. Exemplar regression line identifying the relationship between wrist-shoulder joint-coupling variability and shooting performance at a distance of 4.25 m.

3.4 DISCUSSION

This study had two purposes. The first was to explore the effect of interacting constraints of expertise and distance-to-target on movement variability of basketball shooting. The second was to build upon existing research on targeted throwing tasks by formally addressing how compensatory variability might change as a function of both task expertise and shooting distance. In agreement with existing data from Liu and Burton (1999) and Okazaki and Rodacki (2012), a reduction in shooting performance score was evident with increasing distance, regardless of expertise. The skilled group also demonstrated significantly better shooting performance scores than both their intermediate and novice counterparts, a finding that was consistent across all three shooting distances. This result provides empirical support for the validity of the implemented inclusion criteria.

More importantly, there was a significant decrease in coordination variability as a function of expertise, irrespective of distance or joint coupling. Specifically, the novice participants displayed significantly more coordination variability than their intermediate and skilled counterparts. Interestingly, this finding contradicts those reported during performance of basketball free-throw shooting (Button *et al.*, 2003), soccer chipping (Chow *et al.*, 2007) and triple jump (Wilson *et al.*, 2008). However, discrepancies could be explained because of differences in experimental design between studies. For example, a more heterogeneous sample – of novices, intermediates and experts - was used within the current study. This contrasts with the study of Wilson and colleagues (2008) where the participant sample consisted of individuals with personal bests ranging from 70-86% of the current world record, all of whom were deemed to be experts. Furthermore, within the current study, participants were validated as experts, intermediates or novices based on performance pre-test scores. However, no such performance pre-test was undertaken to objectify participant recruitment within the study by Chow *et al.* (2007). This may explain why Chow and co-workers (2007) found no significant difference in performance outcome between skilled and intermediate performers, irrespective of target distance, and, could be a contributory factor for the large within group variance evidenced by the skilled group, culminating in the failure to find statistically significant between-group differences.

Finally, the current study quantified coordination variability from angle-angle diagrams using the normalised root mean squared difference approach, whereas Button *et al.* (2003) computed the standard deviation of phase-plane trajectories. With the inclusion of zero and first order derivatives, phase-plane trajectories are considered to provide a more sensitive measure of human movement (see Wheat *et al.*, 2002; Wheat and Glazier, 2003). Therefore, it is important to acknowledge that the magnitude of coordination variability, and thus the potential research findings, could be affected by the computational technique used to examine coordination because each approach necessitates the input of differing kinematic variables. In addition, it is also worth noting that phase planes, unless leading on to relative phase through integration of two joint phase planes, refer only to the dynamics of a single joint (or segment), thereby questioning whether phase plane variability is, in fact, a measure of coordination variability. The use of single joint data by Button *et al.* (2003) may have subsequently masked important findings that could have been revealed through more appropriate analyses of intra-limb coordination.

Nonetheless, the observed decrease in coordination variability with task expertise corroborates existing research that reported reductions in the variability of joint kinematics with practice (Darling and Cooke, 1987; Gabriel, 2002; Chapman *et al.*, 2009; Wagner *et al.*, 2012). Gabriel (2002), for instance, found that the variability of phase-plane trajectories decreased during a targeted elbow flexion task after four hundred practice trials. These findings suggest that, under static task constraints, expertise is characterised as the acquisition of stable movement patterns within the perceptual-motor workspace. It is evident from the current study that skilled participants had acquired more consistent motor patterns and could exploit inherent motor system variability functionally to satisfy specific constraints on action. Conversely, novice participants displayed greater variability and seemed to be searching the available phase space for a stable task solution (Glazier and Davids, 2009b). Thus, skilled motor performance appears to be characterised by the exploitation of a narrower, functional bandwidth of coordination variability. This explanation is supported by the quadratic regression analyses, which revealed a decrease in coordination variability with advancing expertise (see Figures 19-21). However, the quadratic regression appears to plateau with advancing expertise. It could, therefore, also be argued that, in comparison to expert participants, intermediate performers displayed variability that was equal in magnitude but less functionally related to performance, due to weak adaptation to the constraints of the task. This theoretical interpretation provides credence to the notion that both the magnitude and functionality of kinematic variability warrant future scientific investigation (see Glazier and Davids, 2009b).

No significant difference in coordination variability was found with distance-to-target, regardless of expertise. Ostensibly, this finding seems to contrast with other data that examined kinematic variability as a function of changing accuracy demand (Sidaway *et al.*, 1995b; Robins *et al.*, 2006). For example, Robins *et al.* (2006) reported significant reductions in coordination variability with increasing shooting distance. Robins and co-workers (2006) argued that this observed decrease was the consequence of a reduced margin for error, caused by the shallower angle of release adopted at greater distances. However, this discrepancy between research findings could be explained in two parts. First, differences could again be attributed to differences in the measurement of coordination, such as the use of relative motion plots in the current study as opposed to continuous relative phase used by Robins *et al.* (2006). Both angular displacement and angular velocity data from the respective joints is needed for the calculation of continuous relative phase, thus yielding, arguably, a more sensitive measurement technique that is better able to detect inter-trial differences. Second, the current study included both successful and unsuccessful shots, and assessed shooting performance using an eight-point nominal rating scale. In contrast, Robins *et al.* (2006) standardised success by only including shots awarded 8 points. Subsequently, the stabilisation of coordination variability values with respect to target distance within the current study may have been a consequence of the inclusion of variable outcomes. In other words, the inclusion of both successful and unsuccessful performances may have masked any potential change in coordination variability prompted by the reduced margin for error available as distance increases. However, the lack of a significant reduction, particularly in relation to the novice participants, could provide additional evidence of exploratory behaviour, whereby individuals are searching for a task-relevant attractor at all three distances. Therefore, because of the diversity in research findings further research is needed to understand the interacting constraints that shape performance of discrete multi-articular actions such as basketball shooting. It is particularly important to examine how the kinematic strategies used for task goal accomplishment differ in relation to task expertise.

With regards to the discrete variables of interest, a proximal to distal increase in variability was exhibited along the kinematic chain at the instant of ball release regardless of expertise. This finding substantiates other research pertaining to targeted throwing tasks (Button *et al.*, 2003; Robins *et al.*, 2006). Interestingly, no significant differences for expertise were found for wrist or elbow joint variability at release. In addition, no significant differences were observed for shoulder joint variability at release between the expert and novice participants. This finding contradicts work by Button and co-workers (2003) who reported standard deviations for wrist and elbow joint angular displacement at ball release of 10.2° and 7.4°, and 1.8° and 5.1° for a 'non-skilled' and skilled basketball player respectively. This discrepancy could be explained by differences in participant inclusion criteria between the two studies. For example, the non-skilled and skilled participant obtained performance pre-test scores of 31% and 81% respectively. Conversely, the inclusion criteria for novice and expert participants within the current study was <59% and >70% respectively, constituting a narrower differentiation in task expertise.

The quadratic regression analyses did, however, reveal stronger covariance between joints along the kinematic chain for expert participants compared to their intermediate and novice counterparts. The mean regression values at a distance of 4.25 m for experts ranged from 0.7 – 0.9, whereas the mean regression values for intermediates and novices ranged from 0.5 – 0.7 and 0.4 – 0.6 respectively. This finding is indicative of heightened compensatory control between interacting joints of the shooting arm, and is supported by the concomitant decrease observed in variability of ball release parameters with expertise. Specifically, the expert participants demonstrated significantly less variability in both height and angle of release than the novice participants. This finding provides additional support for the functional role of movement variability during discrete multi-articular actions. Specifically, expert performers demonstrated evidence of cooperative behaviour between joints of the shooting arm whereby errors in execution of the proximal (shoulder) joint can be offset by compensatory adjustments at a more distal joint (wrist or elbow) joint. Conversely, the variability displayed by novices in particular could be interpreted as neuro-motor noise or random processes (Faisal *et al.*, 2008), or perhaps even the exploration of potential solutions within the perceptual-motor workspace. Other research has also alluded to the role of compensatory variability during both postural control (Ko *et al.*, 2003) and discrete action performance (Kudo *et al.*, 2000; Muller and Sternad, 2004; Woo *et al.*, 2007). For example, Kudo *et al.* (2000) observed that with 150 trials of a ball-throwing task, release parameters were complementarily coordinated and the coordination increased as a function of practice. Muller and Sternad (2004) also highlighted the role of covariance between execution variables for successful task performance. Moreover, Woo *et al.* (2007) recently reported decreases in coefficient of variation for height, speed and angle of release for individuals attaining over 50% of successful trials, when compared to those who obtained less than 50%. As a consequence, there is growing evidence to suggest that covariance between interacting joints is used to preserve invariance in ball release parameters (see Robins *et al.*, 2006).

It is nonetheless important to acknowledge the within-group variation exhibited by the expert performers in terms of both the strength of inter-segmental covariance and variability of ball release parameters, in particular, speed and angle of release. This non-uniformity of perceptual-motor strategy appeared to be particularly evident at the two larger distances (5.25 and 6.25 m). Furthermore, this trend is exemplified through visual inspection of Figures 11 (speed of release) and 12 (angle of release). One explanation for the apparent inconsistency of within-group response could be the inclusion of participants from a range of playing positions. There are three playing positions in the sport of basketball (guard, forward and centre), and each playing position has unique roles and responsibilities. Depending upon playing position, players will ultimately gravitate towards certain regions on the court (see Figure 22). For instance, guards tend to remain on the periphery of the three-point line whereas forwards and centres are often located in close proximity to the basket.

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Figure 22. Playing areas for the three basketball playing positions (Area A = Centres; Area B = Guards; Area C = Forwards) (Miller and Bartlett, 1996).

Unlike the intermediate group of participants that comprised a more homogeneous sample, i.e. 8 guards and 1 forward, the expert participants consisted of guards (n = 5), forwards (n = 3) and a centre (n = 1). Consequently, the heterogeneous response amongst the expert group could be attributed to the unfamiliarity of some participants with shooting from greater distances. As such, the forwards and centre within this sample would demonstrate as much variability as their peer equivalents, but have 'dampened' functionality owing to a weak adaptation to the specific task constraints. This would also presumably impair the cooperative and synergistic behaviour of interacting joints along the kinematic chain resulting in increased variability of ball release parameters at these distances. This hypothesis is supported by Miller and Bartlett (1996) who reported that, in comparison to centres, guards exhibited more consistent changes in kinematic patterns with changes in shooting distance. As such, this capacity to reorganise the perceptual-motor system makes guards adept shooters irrespective of accuracy demand. In light of this limitation, future research should standardise playing position and examine the impact of both personal and task constraints on movement variability during basketball shooting performance. Moreover, as the current study together with the existing programme of research pertaining to basketball shooting examines performance only as task constraints are changed slowly, particular attention should be paid to how expertise supports adaptive movement behaviour in more dynamic performance environments.

In summary, the findings of this study suggest that expert performers are characterised by decreased coordination variability, which is interpreted as the attainment of a (relatively) consistent movement pattern within the perceptual-motor workspace. Conversely, little difference was observed between the expertise groups in the variability of joint angular displacement at ball release. Nonetheless, expert performers appeared to exhibit stronger covariance between wrist, elbow and shoulder joints, with the purpose of reducing variability in ball release parameters, and ultimately, shooting performance. Consequently, judgements about movement variability should not be made when considering magnitude alone, and the type of analysis conducted should be dictated by the variable of interest. A fuller appreciation of movement variability should be sought through the examination of both size and structure. In addition, the movement variability-expertise relationship appears dependent on the level of analysis and the variable of interest i.e. continuous or discrete. Consequently, this variability-expertise relationship should be explored across of range of task constraints.

CHAPTER IV

DIOPTRIC BLUR AS A PERFORMANCE PERTURBATION DURING A DISCRETE MULTI-ARTICULAR ACTION

4.1 INTRODUCTION

According to the tenets of ecological psychology, goal-directed behaviour emerges from the direct and cyclical relationship between processes of perception and action (see Gibson, 1986). Perception was defined by Gibson (1986) as the detection of properties of the environment which can provide information for action, whereas, Bruce *et al.* (1996) suggested that perception is the detection of changes in energy flowing through the environment. With specific reference to visual perception, the ability to pick up and use such changes in energy to support action is essential for processes of decision making and movement execution, and is synonymous with the term ‘visuomotor coordination’. Visuomotor coordination involves the ability to use visual information to generate functional movement patterns (McLeod, 1994). Consequently, vision plays a vital role in successful task accomplishment and acts as an informational constraint governing the emergence of task-relevant, functional motor behaviour (for a review, see Vickers, 2007).

In light of the crucial role that vision has on the control and regulation of human movement, much research has been dedicated to this topic. For instance, research has used occlusion studies to ascertain the role of vision in regulating goal-directed behaviour (Elliott *et al.*, 1999; Khan and Franks, 2003; Khan *et al.*, 2003; Oudejans *et al.*, 2002; Oudejans and Coolen, 2003; De Oliveira *et al.*, 2006; 2007; Muller and Abernethy, 2006), examined perception-action coupling during interceptive actions (Scott *et al.*, 1997; Montagne *et al.*, 2000a; 2000b; Renshaw and Davids, 2004; Chardenon *et al.*, 2005; Renshaw *et al.*, 2007; Pinder *et al.*, 2009; 2011), explicated the ‘duplex account’ of visual information processing (Goodale and Haffenden, 1998; Goodale and Humphrey, 1998; Passingham and Toni, 2001; Mendoza *et al.*, 2005; Milner and Goodale, 2008; van der Kamp *et al.*, 2009; Goodale, 2011), investigated gaze behaviour and visual search strategy through the use of eyetracker technology (Vickers, 1996a; 1996b; Savelsbergh *et al.*, 2002; Williams *et al.*, 2002; Panchuk and Vickers, 2006; Button *et al.*, 2011; Dicks *et al.*, 2010), examined the efficacy of perceptual training programmes (Adolphe *et al.*, 1997; Harle and Vickers, 2001; Farrow and Abernethy, 2002; Williams *et al.*, 2003; 2004; Hagemann *et al.*, 2006; Caserta *et al.*, 2007), and evaluated the role of sports vision (Porisch, 2007; Erickson *et al.*, 2009; Edmunds, 2011).

The importance of visual feedback for successful task accomplishment developed from the pioneering insights of Woodsworth (1899). Specifically, Woodsworth (1899) postulated that a two-component model of limb control existed for targeted aiming tasks. The first component was thought to be an initial pre-programmed movement (impulse) towards the target, whereas the second component involved processes of error detection and correction, governed by sensory information obtained as the movement progressed. Consequently, Woodsworth (1899) argued that aiming tasks were controlled by both offline (pre-programmed) and on-line (error correction) processes (for a review, see Starkes *et al.*, 2002). Corroborating evidence for Woodsworth’s (1899) model of limb control has been found by Khan and co-workers who used a series of rapid perceptual-motor aiming tasks (Khan and Franks 2000; 2003; Khan *et al.*, 2003). In one such study by Khan and Franks (2003), participants were randomly assigned into one of four experimental groups, namely, no vision, vision of only the first 50% of the movement, vision of only the last 75% of the movement, and vision for the whole trial. Participants completed 1,500 trials of a rapid aiming task, involving elbow rotation in the horizontal plane. It was found that there was no practice effect on aiming accuracy when vision was restricted to the first half of the movement. However, the variability of the initial impulse decreased and the accuracy of error correction improved with practice when vision was available during the first 75% of the movement, or, during the entire movement.

Using a similar occlusion approach, other research that has used complex movement models from sport have provided strong empirical support for the use and importance of on-line, prospective movement control (Oudejans *et al.*, 2002; Oudejans and Coolen, 2003; de Oliveira *et al.*, 2007). For example, Oudejans *et al.* (2002) examined basketball shooting performance under four different vision conditions. These conditions included no vision, early vision, late vision and full vision. The early and late vision conditions occluded vision during the final ±350 ms before ball release (early) and until the final ±350 ms before ball release (late) respectively. Oudejans and colleagues (2002) reported shooting percentages to be significantly lower during the early vision condition (30% success), whereas there was no significant difference between the late (60.5% success) and full vision (61.5% success) conditions. The authors interpreted these findings by suggesting that the shooting action was controlled by the continuous use of visual information up to the instant of ball release. Additional support for the role of on-line control during basketball shooting is evident from the work of de Oliveira *et al.* (2007). Seventeen expert basketball players were required to complete jump shots under four vision conditions, namely, full vision, and three conditions where movement initiation was delayed by zero, one and two seconds. In the delayed conditions, the participants were told to shoot zero, one or two seconds post visual occlusion. In agreement with Oudejans *et al.* (2002), shooting performance was found to be significantly better during full vision.

The importance of on-line perceptual control is also clearly evident during interceptive actions. For instance, the theory of perception-action coupling has been used to explain human locomotor pointing (Scott *et al.*, 1997; Montagne *et al.*, 2000a; 2000b; de Rugy *et al.*, 2000; 2002; Renshaw and Davids, 2004), as well as catching (Chardenon *et al.*, 2005; Le Runigo *et al.*, 2005) and cricket batting performance (Renshaw *et al.*, 2007; Pinder *et al.*, 2009; 2011). Consistent with previous data pertaining to long jump (Scott *et al.*, 1997; Montagne *et al.*, 2000a), Renshaw and Davids (2004) investigated step length adjustments during a cricket bowling run-up and observed that participants made continual stride-to-stride adjustments throughout the run-up, facilitating end-point accuracy. In addition, the variability in footfall to bound distance decreased as the participant approached the popping crease. This decreasing trend in step variability, or 'homing-in' phase as it is commonly referred to, appears to be a consistent perceptual-motor strategy regardless of task expertise (see Scott *et al.*, 1997). These findings can be interpreted using one of the main components of ecological psychology: direct perception (see Gibson, 1986). Direction perception is summarised nicely by Chemero (2003, p.181):

"*In direct theories of perception, meaning is in the environment, and perception does not depend on meaning-conferring inferences; instead, the animal simply gathers information from a meaning-laden environment*."

In other words, ecological psychologists place emphasis on the performer-environment synergy, where information constrains the human movement system to particular outputs, or, kinematic responses, and through continuous regulation, allows movement to be corrected on a moment-by-moment, or in the case of cricket bowling or long jump performance, a step-by-step basis (for a review, see Chemero and Turvey, 2007). It is this theoretical framework that has opposed traditional cognitive ideas of 'model-based control', and instead, advocated the notion of 'information-based control' (Fajen, 2007). This distinction between model-based control and information-based control is presented in Figure 23.

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Figure 23. Schematic for model-based and information-based control (Meijer, 1988).

Another avenue of research has been to explore the changes in gaze behaviour under varying constraints, such as expertise (e.g. Savelsbergh *et al.*, 2002) or task complexity (e.g. Williams *et al.*, 2002). By collating the large body of existing research, Williams and Ward (2003) argued that perceptual expertise is characterised by enhanced pattern recall and recognition, improved object detection and recognition, more effective visual search strategies, the capacity of extract pre-event visual cues, attunement to relative motion information, and the maintenance of perceptual processes when perturbed by emotional fluctuations. These differences are exemplified by the work of Vickers (1996a) who conducted a seminal study examining gaze behaviour during a basketball free-throw. Participants were classified as experts or near experts based upon their free-throw shooting percentage, and were required to complete ten successful and ten unsuccessful shots. Experts were found to fixate longer on the target when compared to their near expert equivalents, and also demonstrate an earlier fixation offset during the shooting action. These results were interpreted using the location-suppression hypothesis, and advocated the importance of the quiet eye period. The quiet eye period is defined as the final fixation on the target before the initiation of movement (Vickers, 1996a). This perceptual strategy has received much support from the literature (Vickers, 1996b; Vickers and Adolphe, 1997; Harle and Vickers, 2001; Savelsbergh *et al.*, 2002), thus appearing to be a robust phenomenon for targeted aiming tasks. Moreover, these findings also pervade the clinical domain. When investigating changes in gaze behaviour and lower limb kinematics as a function of participant age and risk of falling, Chapman and Hollands (2006) found that, during adaptive locomotion, high-risk older adults looked away from targets significantly sooner than young adults and low-risk older adults. Furthermore, there was also a moderate yet significant relationship between transfer of gaze and medio-lateral foot placement variability, providing novel insights into the benefits of gaze fixation for fall prevention in older adults.

In addition to exploiting the benefits of the quiet eye period, experts have also been shown to exhibit better anticipation (e.g. Shim *et al.*, 2005), which is suggested to be a consequence of their enhanced ability to extract vital pre-event visual cues. These pre-event visual cues take the form of subtle body movements or kinematic changes that yield important information directing decision making and movement execution. This association between anticipation and expertise is typified by Savelsbergh *et al.* (2002) who observed that expert goalkeepers were more accurate in anticipating the direction of penalty kicks. This enhanced level of anticipation was a direct consequence of experts adopting fewer corrective movements and fixating for longer on task relevant and ‘information rich’ sources, such as the kicking leg and non-kicking leg. In contrast, novices fixated on more irrelevant cues, such as the hips, trunk and arms. These task relevant or irrelevant sources of information are also referred to as constraining and non-constraining variables respectively (see Renshaw *et al.,* 2007). The rationale for these terms is again grounded in ecological psychology and can be explained using the concept of affordances. Information from the environment provides a set of affordances, or opportunities for action. Therefore, constraining variables *constrain* the output of the human movement system, channelling the search towards particular behavioural responses (see Chemero, 2003). With the importance of constraining variables on the emergence of goal-directed behaviour now recognised, research has recently advocated the use of representative task constraints during both experimentation (Dicks *et al.*, 2010) and practice (Renshaw *et al.*, 2007; Pinder *et al.*, 2009).

From the aforementioned literature it is clearly evident that a large body of research has been dedicated to not only elucidate the role of vision during goal-directed behaviour but to also understand the key determinants of perceptual expertise. There is, however, one line of scientific enquiry that has currently received limited attention. This avenue of research relates to examining the effect of changing visual acuity, also referred to as dioptric blur (over-refraction), on goal-directed behaviour (Applegate and Applegate, 1992; Bulson *et al.*, 2008; Hatch *et al.*, 2009; Mann *et al.*, 2007; 2010a; 2010b; 2010c;). In one such study, Applegate and Applegate (1992) investigated the effect of visual acuity on basketball shooting performance. Each participant completed 25 set shots from a distance of 4.57 m at each of five different visual acuities: 6/6, 6/12, 6/24, 6/48, 6/75. Performance outcome was assessed by the total number of successful shots. Interestingly, no significant difference was found in shooting performance as a function of visual acuity. This study was the first to provide preliminary evidence to suggest that the human movement system can tolerate considerable degradation in visual information and offset perturbation caused by induced dioptric blur.

However, contrasting findings have been reported by Mann and colleagues (2007; 2010b; 2010c). Specifically, Mann *et al.* (2007) explored the impact of induced dioptric blur on performance of a complex interceptive action. Eleven Sydney Grade cricketers were required to face sixty deliveries from a bowling machine under five differing visual conditions. These included, no correction, contact lenses of the participant's correct prescription, and + 1.00, + 2.00 and + 3.00 dioptric over-refraction (D). Each condition was presented in a counterbalanced order and performance outcome was assessed subjectively by means of a Level 2 cricket coach. Despite no differences being observed between the baseline (plano) and + 1.00 and + 2.00 D conditions, in opposition to the work of Applegate and Applegate (1992), significant decreases in performance were found during the + 3.00 D condition. Consequently, there is tentative evidence to suggest that grade level participants are able to stabilise batting performance and offset perturbation from impaired visual information. However, only when the performance perturbation was of sufficient strength, as evident during the + 3.00 D condition, which equates to the legal blindness limit, were there any decreases in batting performance. These findings are in agreement with those observed during rifle shooting (Hatch *et al.*, 2009) and golf putting (Bulson *et al.*, 2008). For example, Bulson *et al.* (2008) examined the effect of dioptric blur on golf putting accuracy. Retinal defocus was induced with the use of + 0.50, + 1.00, + 1.50, + 2.00 and + 10.00 D convex spherical lenses, and golf putting performance was found to only decrease with the highest, + 10.00 D, level of visual blur. Similarly, Hatch *et al.* (2009) found that targeted rifle shooting performance significantly decreased with an acuity score of less than 0.7 logMAR when compared to visual acuities of 0.2 logMAR or better. To enable comparison to other research, the 0.2 logMAR and 0.7 logMAR scores equate to Snellen (metric) acuities of 20/32 (6/9) and 20/100 (6/30) respectively. Furthermore, stated in terms of diopters, these visual acuities translate to diopters of + 0.5 D and + 2.00 D respectively.

The apparent disparity in research findings between Applegate and Applegate (1992) and those of both Mann *et al.* (2007) and Bulson *et al.* (2008) could be explained by the specific constraints on action. Basketball shooting is an aiming task that requires a ball to be projected towards a static target of sizeable dimensions. For instance, the basketball hoop is 18″ in diameter, whereas the backboard and inner square of the backboard have dimensions of 42″ (height) * 72″ (width) and 18″ (h) * 24″ (w) respectively. In contrast, cricket batting requires key constraining spatial and temporal information to be obtained from an often rapidly approaching ball approximately 9″ in circumstance. In golf, on the other hand, the ball must be putted into a hole that is only 4.25″ in diameter. As such, each task places differing demands on dorsal and ventral stream processing of visual information. According to the work of Goodale and colleagues (see Milner and Goodale, 2008; Goodale, 2011), ventral stream processing is used for 'vision for perception', whereas dorsal stream processing is concerned with 'vision for action'. In other words, processing in the ventral stream allows identification of objects and events, and the dorsal stream processing of visual information is responsible for the on-line regulation of information about objects in relation to an effector e.g. limb, hand, implement etc. (Goodale, 2011). van der Kamp *et al.* (2008) argue that the target location information (obtained by ventral stream processing), acts as a boundary constraint on vision for action (dorsal stream processing). Taken within the context of the aforementioned research findings, even with moderate levels of visual blur these boundary constraints may still emerge and provide adequate guidance towards an appropriate kinematic solution. In the case of basketball shooting used by Applegate and Applegate (1992), this may also in part be supported by peripheral visual processing of limb movements as the action proceeds. Consequently, the effect that dioptric blur has on the human movement system, and ultimately performance success, may, intuitively, be dictated by the requirements of the task, and more explicitly, the accuracy demands.

This difference in findings between basketball shooting and cricket batting performance could also be explained by making the distinction between static and dynamic visual acuity (see Quevedo-Junyert *et al.*, 2011). Dynamic visual acuity is defined as:

> *"...a very complex visual function that requires the observer to detect a moving target, to visually acquire it by eye movements, and to resolve critical details contained within it, all in a relatively brief time exposure."*
>
> (Quevedo *et al.*, 2012, pp. 132)

With the introduction of dioptric over-refraction, there is a greater challenge to decipher these 'critical details' from an approaching cricket ball (dynamic visual acuity) when compared to a static target of sizeable dimensions e.g. basketball ring and backboard (static visual acuity). As such induced dioptric over-refraction could have a greater impact on those activities requiring dynamic visual acuity. Therefore, as previously suggested, it could be argued that the ability to stabilise performance against such visual perturbation is dictated by the task constraints.

These data of Mann *et al.* (2007) are commensurate with other research presented by Mann and co-workers (2010b; 2010c). For instance, Mann *et al.* (2010b) examined the interactive effect of manipulating both personal and task constraints on performance of a dynamic interceptive action. Ten expert cricket batsmen completed twenty four trials under each of four visual conditions (habitual, + 1.00, + 2.00 and + 3.00 D) and two experimental tasks (bowling machine and cricket bowler). Moreover, two velocities of delivery were also examined, medium pace and fast pace. During the medium pace condition, the data corroborated that of Mann *et al.* (2007), with significant decreases in batting performance only found with + 3.00 dioptric over-refraction. As expected, there was also an interaction between dioptric blur and velocity of ball delivery. This interaction was characterised by a decrease in batting performance apparent at lower levels of blur for the fast-pace bowling condition.

Whereas the previous studies of Mann and co-workers (2007; 2010b) reported no significant difference in performance between baseline and moderate levels of dioptric over-refraction, interestingly, Mann *et al.* (2010c) has provided empirical evidence suggesting that induced visual blur may actually enhance anticipation of ball-flight during cricket batting. Within this study, the visual acuity of expert cricket batsmen was again manipulated as previously undertaken, for instance, baseline, + 1.00, + 2.00 and + 3.00 D. Each participant was required to anticipate the ball flight characteristics during two experimental conditions, where perception and action were either coupled (participants performed the batting action) or decoupled (participants verbally predicted ball flight). In addition, ball velocity was adjusted with participants facing deliveries of both medium and fast pace. Finally, to examine anticipation skill, participants observed the approach of the bowler with either vision occluded at the instant of ball release, or, no occlusion. Within the coupled condition, findings were harmonious with those reported within the programme of work by Mann and colleagues (2007; 2010b). Specifically, decrements in performance were only observed with + 3.00 dioptric over-refraction. However, for the decoupled condition, response accuracy was found to improve in the + 1.00 D condition. Therefore, there is some evidence to suggest that moderate visual blur may actually enhance anticipation within expert batsmen.

From a theoretical perspective, there a number of ways by which these findings could be explained. First of all, the degradation in visual information caused by induced dioptric blur may encourage the allocation of additional attentional resources to the primary performance task. The investment of additional attentional resources has been shown to stabilise performance against emotional fluctuations caused by elevated anxiety (Monno *et al.*, 2000; Murray and Janelle, 2003; 2007; Court *et al.*, 2005). Specifically, Monno and colleagues observed that both in-phase and anti-phase patterns of bimanual rhythmic coordination could be stabilised by the increased allocation of attentional resources. Consequently, a comparable strategy may be employed to offset any perturbation caused by changes in visual acuity. This interpretation is supported by anecdotal evidence from Mann *et al.* (2010a) who reported that during the + 1.00 D condition batters were more 'active' in visually searching for the ball out of the bowler's hand. A second possible interpretation of the research findings explores the benefits of an external focus of attention. Mann *et al.* (2010a) postulated that moderate levels of visual blur may cause the expert cricketers to focus their attention externally, for example, on the effects of their actions (external focus) rather than on the action itself (internal focus). The benefits of an external focus of attention have been documented extensively within the existing literature (for a review, see Wulf, 2007a). Specifically, significant improvements have been reported in basketball shooting (Zachry *et al.*, 2005), golf chipping (Wulf and Su, 2007), vertical jump height (Wulf and Dukek, 2009) and static balance (Wulf *et al.*, 2001b) when adopting an external focus. These focus-dependent benefits in performance can be explained because an external focus of attention is argued to permit inherent processes of self-organisation to regulate task performance (see Araújo *et al.*, 2004). Conversely, an internal focus of attention may constrain intrinsic motor system dynamics, thereby impeding task goal accomplishment.

A third interpretation of the data can be derived from the theory of stochastic resonance (for a review, see Moss *et al.*, 2004). Stochastic resonance draws upon one of the central tenets of non-linear dynamical systems theory, attributing a functional role to variability. Stochastic resonance has been classically defined by Collins and co-workers (1995; 1996; 1999) as a phenomenon in which the introduction of intermediate levels of noise enhances the response of a non-linear system to a weak signal. Moreover, Douglass *et al.* (1993) allude to stochastic resonance as a nonlinear, statistical dynamic, whereby information flow in a multi-state system is enhanced by the presence of optimized, random noise. Although within a linear system noise can be detrimental to the signal to noise ratio (SNR), within a non-linear system moderate levels of noise can reduce the extent of SNR degradation and thus enhance the ability of non-linear systems to detect particular stimuli (Dykman and McClintock, 1998).

Stochastic resonance has been reported within both the physical and biological sciences, providing a viable explanation for the periodic occurrences of the Earth's ice ages (see Wiesenfeld and Moss, 1995), as well as sensory perception in organisms such as sharks (Braun *et al.*, 1994), paddlefish (Russell *et al.*, 1999), and crayfish (Douglass *et al.*, 1993). In one such example, paddlefish are suggested to exploit stochastic resonance for feeding purposes by optimising endogenous sources of noise, permitting the enhanced detection of electrical signals emitted from planktonic prey (Russell *et al.*, 1999). Stochastic resonance has also, more recently, been extended to human motor behaviour, specifically, tactile sensation (Cordo *et al.*, 1996, Collins *et al.*, 1996, Waddington and Adams, 2003) and postural control (Priplata *et al.*, 2002; 2003, 2006; Lafond *et al.*, 2004). In a series of seminal studies by Priplata and co-workers (2002, 2003, 2006), the application of subsensory mechanical noise, created with the use of a vibrating platform or insoles, enhanced postural control in individuals with impaired sensory perception, such as the elderly, patients with diabetes and patients following stroke.

Comparable findings have also been reported by Waddington and Adams (2003), who examined the effect of textured insoles on participants' ability to discriminate between varying ankle inversion angles. Within this study, participants were required to discriminate between five different inversion angles (10.5º, 11.5 º, 12.6 º, 13.3 º and 14.5º) under three experimental conditions, namely, barefoot, athletic shoes and socks, and athletic shoes and socks with textured insole. In comparison to the barefoot condition, movement discrimination scores were significantly worse when wearing athletic shoes and socks. However, when participants wore the textured insoles discrimination scores were analogous to barefoot conditions. Although the authors recognised that the textured insole enhanced sensory feedback and could, therefore, provide important insights about injury prevention, no formal theoretical interpretation or mechanism was alluded to. In a later commentary on Waddington and Adams (2003), Davids and colleagues (2004) argued that stochastic resonance could provide a viable explanation, with the textured insole enhancing deformation of plantar tissue, permitting the exploitation of sensorimotor system noise (see Figure 24).

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Figure 24. Pictorial representation of stochastic resonance. The buoy represents the signal, the dotted line depicts the stimulus threshold, and the waves symbolise the addition of noise (Davids *et al.*, 2004).

As well as impacting upon haptic sensory perception, stochastic resonance has also been shown to affect visual perception (Kitajo *et al.*, 2003; Sasaki *et al.*, 2006, Sasaki *et al.*, 2008a, 2008b, Aihara *et al.*, 2008). Sasaki *et al.* (2006) examined the effect of noise on contrast detection sensitivity, with participants required to detect any changes in the brightness of the signal with and without noise. The authors observed improved contrast sensitivity with the addition of an optimal, intermediate intensity of noise, providing additional evidence that stochastic resonance is a robust phenomenon across multiple sensory systems. Corroborating data has, more recently, been reported by Sasaki *et al.* (2008a) who used a comparable experimental design. Two important findings emerged. First of all, the signal detection rate was, again, found to be significantly enhanced with the addition of moderate levels of noise. Second of all, an inverted U-shaped relationship emerged between signal detection and noise, with signal detection rate decreasing with the addition of more noise past a certain order of magnitude (-10 Db). These findings align nicely with the theoretical insights from stochastic resonance because moderate levels of noise are deemed to be beneficial in enhancing sensory perception. However, excessive noise appears counterproductive, with the apparent randomization at higher noise intensities overriding the co-operative effect seen an intermediate noise levels (Wiesenfeld and Moss, 1995).

It is, however, currently unclear whether the findings and theoretical insights gained from the existing research concerning stochastic resonance can be applied to induced dioptric over-refraction. In addition, there is a lack of consensus about how motor performance changes when visual information is impaired. Moreover, much of the research to date has been product-oriented. Therefore, there is a need for a process-oriented approach to examine how movement kinematics, specifically, movement variability changes with manipulation of visual acuity. Due to these inherent gaps in research and apparent discrepancies in research findings when examining performance change with induced dioptric over-refraction, this study had two aims. The first aim was to examine the effect of induced dioptric blur on shooting performance and movement variability during basketball free-throw shooting. The second aim sought to ascertain whether task expertise plays a mediating role in the capacity to stabilise discrete action performance against perturbation from impaired visual information.

4.2 METHOD

4.2.1 PARTICIPANTS

Fourteen male participants with a mean (± SD) age, height and mass of 24.8 (± 4.1) years, 1.83 (± 0.05) m and 77.9 (± 8.3) kg respectively provided written voluntary informed consent to participate in the study. Each participant completed a health screening questionnaire (see Appendix 2) and all procedures were risk assessed (see Appendix 12) and approved by the local institutional research ethics committee (see Appendix 13). Participants were categorised as either expert or novice using the same procedures and inclusion criteria outlined within Section 3.2.1. Furthermore, the baseline level of dioptric blur for each participant was ascertained by means of routine optometric consultation conducted by a qualified optometrist (also known as an ophthalmic optician) with over twenty years experience (http://www.alexgageoptician.co.uk/). To minimise potential confounding effects caused by variations in between-individual dioptric blur, inclusion criteria for baseline, habitual vision was set at 0 ± 1.00 dioptric over-refraction (D). The mean (± SD) dioptric blur scores for the novice and expert participants are displayed in Table 6. In addition, it is important to note two things. First, only two participants had baseline vision that exceeded + 0.50 D. Second, only three participants had baseline vision of - 0.25 D, indicating only very mild long sightedness. No participants had baseline vision which exceeded - 0.25 D. This is crucial because a baseline score -1.00 D would be corrected to perfect 20/20 vision with the addition of a + 1.00 D lens, thereby eliminating any proposed intervention.

Table 6. Mean (± SD) prescription information for the novice and expert participants.

	Novice		Expert	
Experimental Condition	Left Eye	Right Eye	Left Eye	Right Eye
Baseline (Plano)	0.21 ± 0.42	0.46 ± 0.55	0.04 ± 0.40	0.08 ± 0.34
+ 1.00 D	1.21 ± 0.42	1.46 ± 0.55	1.04 ± 0.40	1.08 ± 0.34
+ 2.00 D	2.21 ± 0.42	2.46 ± 0.55	2.04 ± 0.40	2.08 ± 0.34
+ 3.00 D	3.21 ± 0.42	3.46 ± 0.55	3.04 ± 0.40	3.08 ± 0.34

4.2.2 PROCEDURES

Following a thorough warm-up of the involved musculature, participants were required to complete twenty trials from a distance of 4.25 m under four visual conditions: baseline (habitual vision), + 1.00, + 2.00 and + 3.00 D. The use of four visual conditions permits comparative analyses with existing research (see Mann *et al.*, 2007; 2010b; 2010c), and in accordance with hypotheses derived from the theory of stochastic resonance, examines how both shooting performance and movement variability respond to gradations in dioptric blur. A counterbalanced design was implemented across participants to minimise potential confounding order effects. Dioptric blur was manipulated using a pair of OM268 trial frames which permitted convex, spherical lenses to be inserted in front of the eyes (see Figure 25). The side length, pupillary distance and bridge height were manually adjusted for each participant to ensure a secure fitting.

Figure 25. OM268 trial frames.

The participants wore the trial frames for all experimental conditions, including the baseline condition, thereby enhancing the internal validity of subsequent research findings. Sufficient rest was permitted between trials to minimise intervening fatigue effects. Furthermore, where necessary, participants were also permitted to remove the trial frames in between trials to alleviate any discomfort caused by changes in visual acuity. This occurred principally at the + 3.00 D condition where the level of dioptric blur was particularly severe. For all four experimental conditions, both basketball shooting performance and kinematic data were collected using the procedures previously outlined in Sections 3.2.1 and 3.2.2 respectively.

4.2.3 DATA ANALYSIS

Retro-reflective marker reconstruction and generation of both three-dimensional joint coordinate system angles for the wrist, elbow and shoulder joints and ball release parameters were achieved using the same processes outlined in Section 3.2.3. The dependent variables of interest included the following: shooting performance score, variability of ball release parameters, variability of wrist, elbow and shoulder angle at the instant of ball release, and coordination variability of the shooting arm using the normalised root mean squared difference technique (NoRMS) proposed by Sidaway *et al.* (1995b). Coordination variability was calculated for the following three joint couplings: wrist-elbow, elbow-shoulder and wrist-shoulder.

4.2.4 STATISTICAL ANALYSIS

All assumptions underpinning use of parametric tests were tested for and verified. As per Section 3.2.4, normality, homogeneity of variance and sphericity were again tested using an Anderson-Darling test, Levene's test and Mauchly's test of sphericity respectively. Subsequently, each dependent variable was subjected to a 2 (expertise) * 4 (visual acuity) analysis of variance with expertise as the between-individuals factor and visual acuity as the within-individuals factor. An alpha level of 0.05 was selected to identify statistical significant differences in comparisons. Following a statistically significant difference, *post-hoc* pairwise comparisons were conducted using a Bonferroni correction to prevent inflation of the Type I error rate. Inferential statistics were also supplemented with measures of effect size (η^2) to quantify the meaningfulness of the differences. It should be noted that due to a motion tracking problem during data collection, one expert participant was excluded from the statistical analysis. This resulted in seven novices and six experts being entered for statistical analysis.

4.2.5 NULL HYPOTHESES

H_{01} There will be no significant effect of task expertise on basketball shooting performance score.

H_{02} There will be no significant effect of task expertise on movement kinematics of the basketball free-throw.

H_{03} There will be no significant effect of dioptric blur on basketball shooting performance score.

H_{04} There will be no significant effect of dioptric blur on movement kinematics of the basketball free-throw.

4.3 RESULTS

4.3.1 SHOOTING PERFORMANCE

The changes in mean shooting performance as a function of both expertise and dioptric blur are presented in Figure 26. The two-way ANOVA revealed no significant expertise * dioptric blur interaction for shooting performance ($P = 0.508$, $\eta^2 = 0.067$). However, there were significant main effects for both dioptric blur ($P = 0.05$, $\eta^2 = 0.206$) and expertise ($P = 0.0001$, $\eta^2 = 0.883$), with the *post-hoc* tests indicating that the expert participants outperformed their novice counterparts during all four vision conditions ($P < 0.0001$). Moreover, in comparison to the baseline condition, shooting performance was greater during the + 1.00 ($P = 0.02$) and + 2.00 D conditions ($P = 0.04$). The lack of an interaction indicates that this performance change with moderate levels of induced dioptric blur was consistent across both expertise groups. This assertion is supported when examining the descriptive statistics. Specifically, in contrast to the baseline condition, mean shooting performance increased by 8% and 6% for the + 1.00 and + 2.00 D conditions respectively for the expert participants. The shooting performance of the novice participants increased, similarly, by 7% and 9% respectively for the same two comparisons.

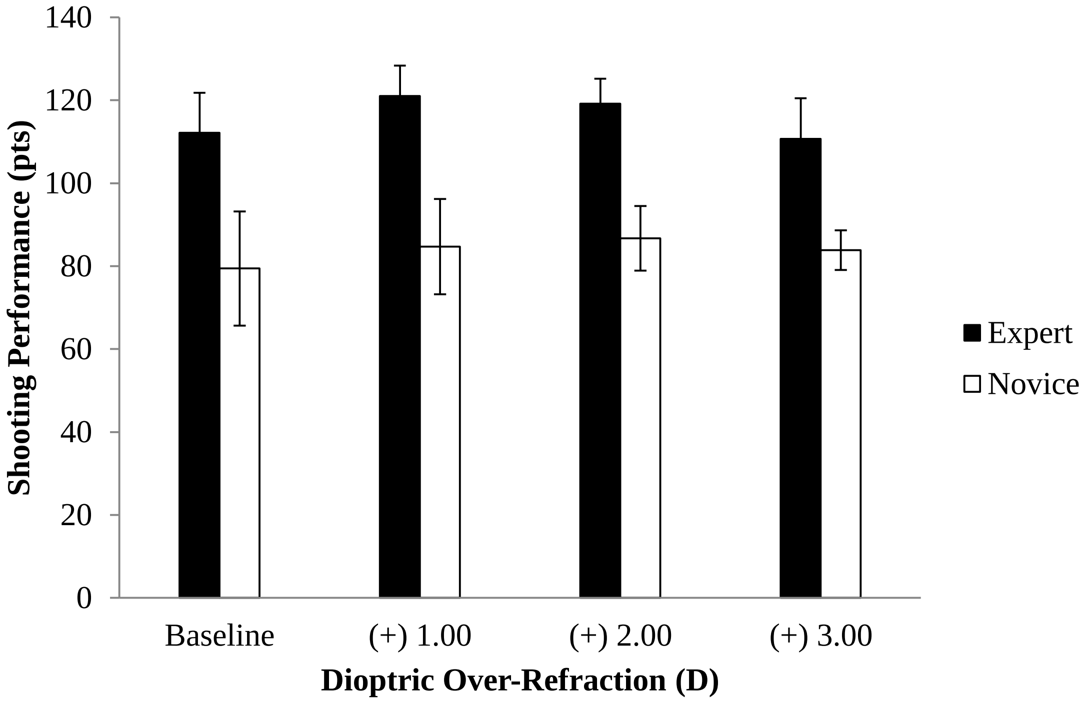

Figure 26. Shooting performance scores as a function of expertise and vision condition.

4.3.2 VARIABILITY OF BALL RELEASE PARAMETERS

4.3.2.1 HEIGHT OF RELEASE

The mean (± SD) variability of height of release is depicted in Figure 27. There was no significant expertise * dioptric blur interaction (P = 0.312, η^2 = 0.101). Neither was there a significant main effect for dioptric blur (P = 0.123, η^2 = 0.158). Moreover, the main effect for expertise did not achieve the required level of statistical significance (P = 0.083, η^2 = 0.248).

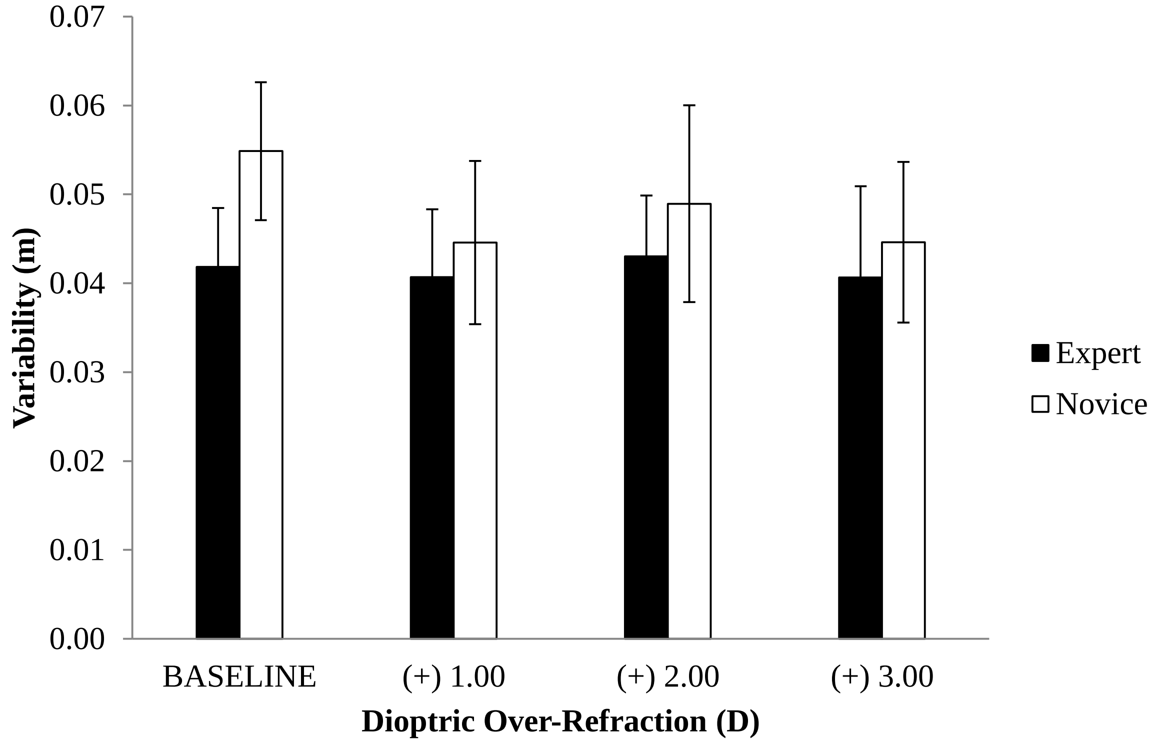

Figure 27. Mean (± SD) variability of height of release as a function of expertise and visual acuity.

4.3.2.2 SPEED OF RELEASE

The mean (± SD) variability of speed of release is presented in Figure 28. No significant expertise * dioptric blur interaction was found (P = 0.558; η^2 = 0.060). Neither was there a main effect for dioptric blur (P = 0.897; η^2 = 0.018). There was, however, a significant main effect for expertise (P = 0.004; η^2 = 0.535). Moreover, novices demonstrated significantly more variability at the baseline, + 2.00 and + 3.00 D conditions ($P < 0.05$).

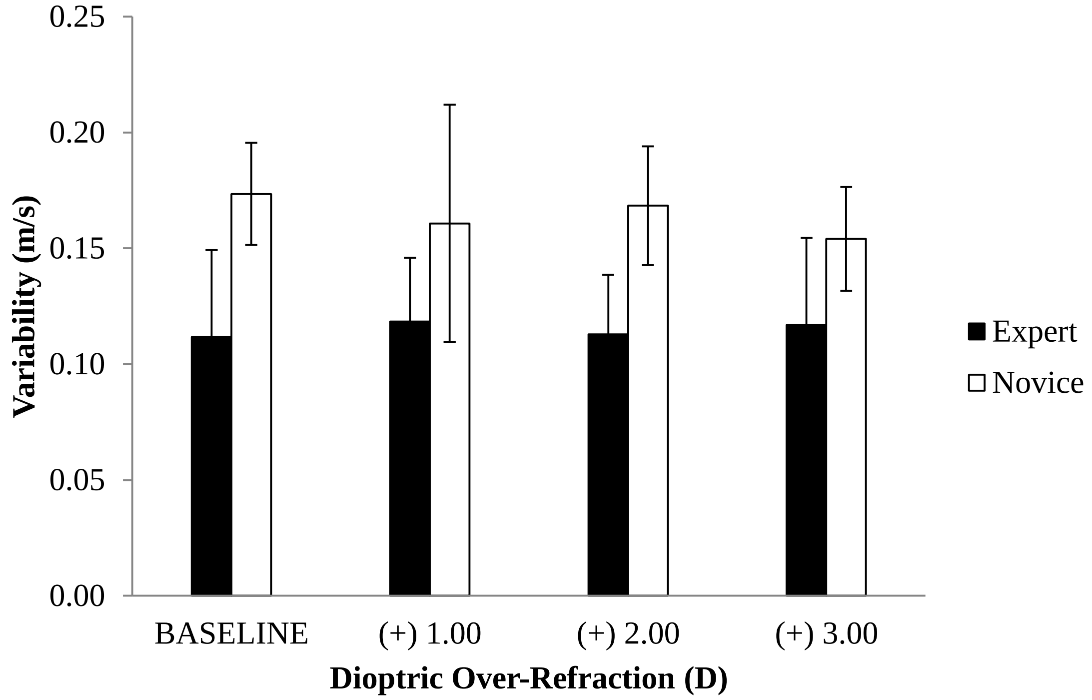

Figure 28. Mean (± SD) variability of speed of release as a function of expertise and visual acuity.

4.3.2.3 ANGLE OF RELEASE

The mean (± SD) variability of angle of release is presented in Figure 29. No significant expertise * dioptric blur interaction was observed (P = 0.234, η^2 = 0.120). There was also no significant main effect for dioptric blur (P = 0.917, η^2 = 0.015). However, a significant main effect was apparent for expertise (P = 0.312, η^2 = 0.101). Specifically, the expert participants demonstrated smaller variability in angle of release than their novice equivalents for all four vision conditions (P < 0.0001). Furthermore, the difference in variability between expert and novice participants appeared to be exacerbated with increasing dioptric blur. For instance, novices exhibited 20.85%, 62.94%, 56.42% and 70.26% more variability in angle of release across the baseline, + 1.00, + 2.00 and + 3.00 D conditions respectively when compared to the experts.

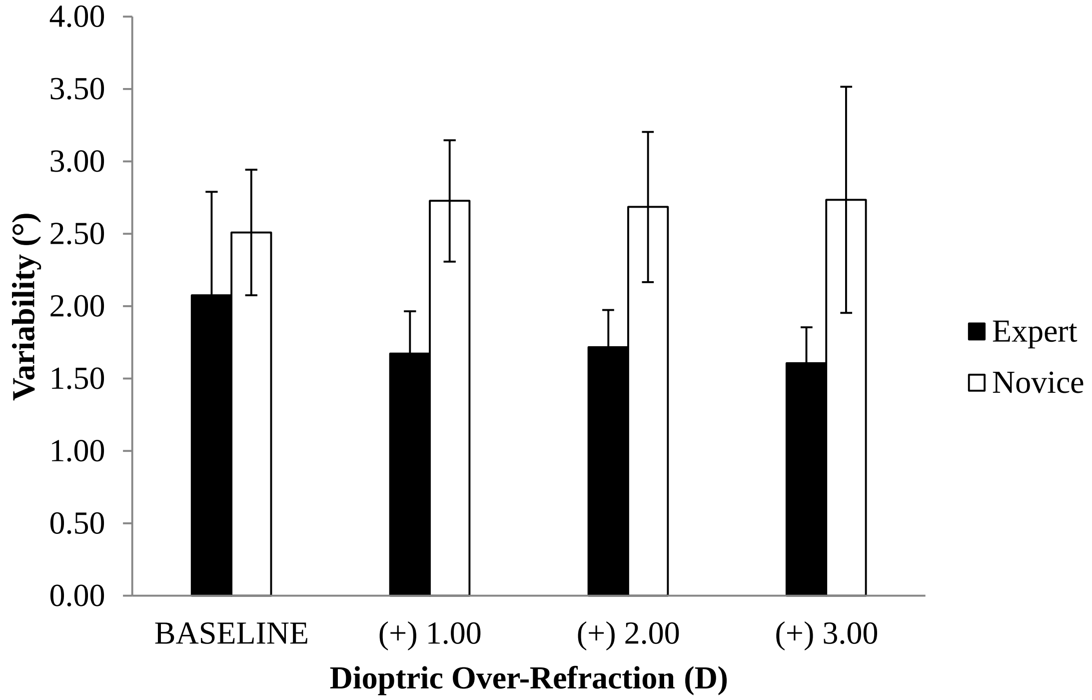

Figure 29. Mean (± SD) variability of angle of release as a function of expertise and visual acuity.

4.3.3 JOINT ANGLE VARIABILITY AT RELEASE

The mean (± SD) values for joint angle variability at release as a function of expertise and dioptric blur are presented in Table 7. No significant expertise * dioptric blur interaction was found for the variability of wrist, elbow or shoulder angle at release ($P > 0.231$, $\eta^2 < 0.120$). There was also no significant main effect for dioptric blur for any of the three joints of interest ($P > 0.231$, $\eta^2 < 0.120$). There was, however, a significant main effect for expertise for wrist angle variability at release ($P = 0.004$, $\eta^2 = 0.553$). Specifically, the expert participants exhibited greater variability at the wrist for the baseline, + 1.00 and + 2.00 D conditions ($P < 0.014$). This notable difference is further supported by the fact that the expert participants demonstrated, on average across the four conditions, 33 ± 2% more variability at the wrist when compared to their novice counterparts (see Table 7).

Table 7. Mean (± SD) values for joint angle variability at release as a function of expertise and visual acuity.

Expertise	Dioptric Over-Refraction (D)	Joint Angle Variability at Release (°) Wrist	Elbow	Shoulder
Novice	Baseline	9.1 ± 1.5	8.2 ± 2.7	4.5 ± 3.3
	+ 1.00	9.3 ± 3.3	7.9 ± 1.1	4.0 ± 1.4
	+ 2.00	10.0 ± 2.0	9.2 ± 3.1	4.1 ± 1.8
	+ 3.00	8.9 ± 1.6	7.3 ± 1.5	3.4 ± 1.0
Expert	Baseline	12.3 ± 2.4	8.9 ± 1.5	3.6 ± 1.0
	+ 1.00	12.1 ± 3.9	9.7 ± 1.6	5.4 ± 3.7
	+ 2.00	13.4 ± 2.0	10.5 ±4.3	3.6 ± 1.5
	+ 3.00	11.9 ± 1.9	9.5 ± 3.8	3.5 ± 1.3

4.3.4 COORDINATION VARIABILITY

Coordination variability (NoRMS) as a function of expertise and dioptric blur is presented in Table 8. No significant expertise * dioptric blur interactions were found for any of the three joint couplings ($P > 0.446$, $\eta^2 < 0.077$). Significant main effects for expertise were apparent for all joint couplings of interest ($P < 0.004$, $\eta^2 > 0.551$), with *post-hoc* tests revealing greater variability for the novice participants when compared to their expert counterparts irrespective of vision condition ($P < 0.019$). Moreover, a significant main effect for dioptric blur was also found for the wrist-elbow coupling ($P = 0.042$, $\eta^2 = 0.217$), with a reduction in coordination variability occurring during the + 3.00 D condition when compared to the + 1.00 and + 2.00 D conditions ($P < 0.05$). Again, the lack of an interaction indicates that this reduction in coordination variability was consistent across both expertise groups.

Table 8. Mean (± SD) normalised root mean squared differences (NoRMS) as a function of expertise and visual acuity.

		Coordination Variability (°)		
Expertise	Dioptric Over-Refraction (D)	Wrist-Elbow Coupling	Elbow-Shoulder Coupling	Wrist-Shoulder Coupling
Novice	Baseline	11.7 ± 4.1	9.0 ± 3.6	10.2 ± 3.7
	+ 1.00	12.3 ± 4.0	8.5 ± 2.4	10.4 ± 2.9
	+ 2.00	12.5 ± 4.0	8.6 ± 2.6	10.1 ± 2.8
	+ 3.00	10.5 ± 2.5	7.3 ± 1.3	9.0 ± 2.3
Expert	Baseline	5.1 ± 1.1	4.5 ± 1.8	5.0 ± 0.9
	+ 1.00	5.4 ± 0.9	4.6 ± 1.5	5.2 ± 0.6
	+ 2.00	5.4 ± 0.6	4.6 ± 1.0	5.1 ± 0.8
	+ 3.00	4.8 ± 0.9	4.3 ± 1.5	4.8 ± 0.7

Angle-angle plots for an exemplar expert and novice participant are presented in Figures 30-37. From examination of the angle-angle plots, it is clear that the expert performer is less variable than the novice performer throughout all phases of the movement. In addition, inter-trial variability appears to reduce for both participants as dioptric blur increases. This is typified by the tighter clustering of lines on the angle-angle plots, particularly evident when comparing the baseline condition against the + 3.00 D.

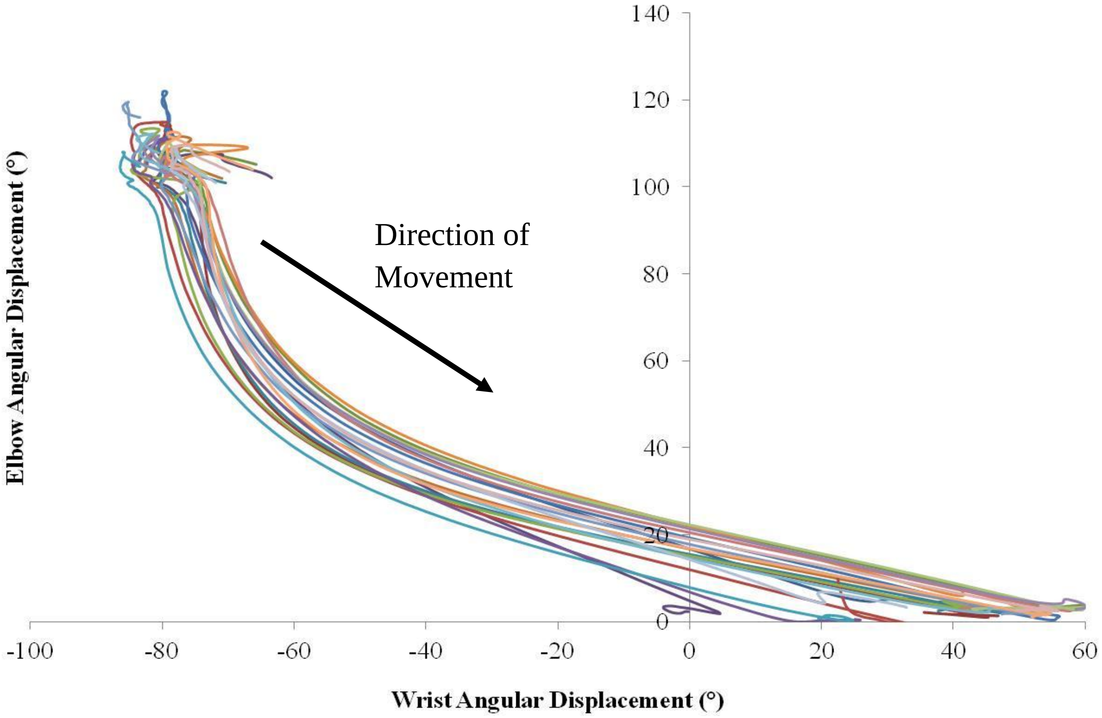

Figure 30. Angle-angle plot for an exemplar expert participant during the baseline condition.

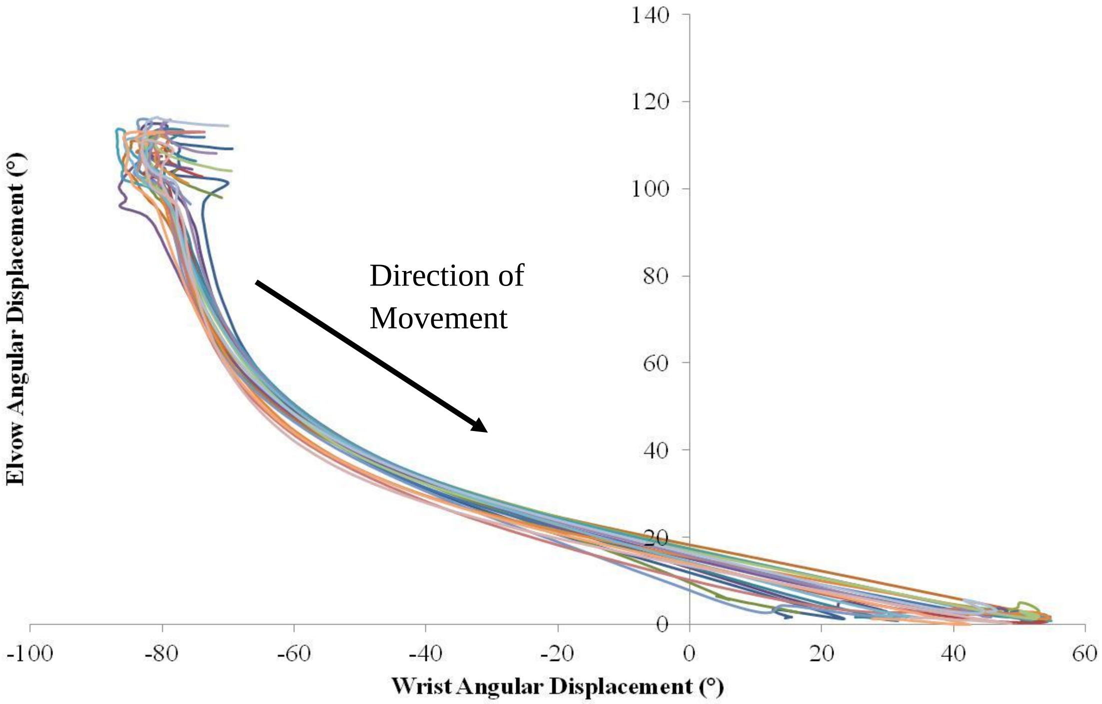

Figure 31. Angle-angle plot for an exemplar expert participant during the + 1.00 D condition.

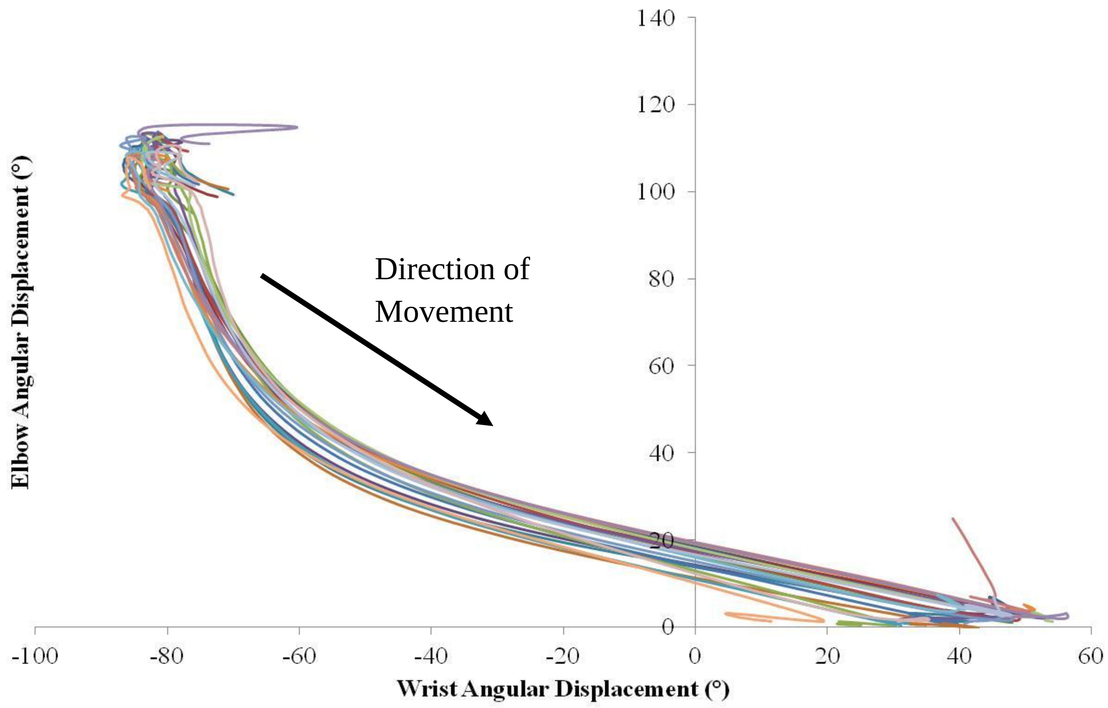

Figure 32. Angle-angle plot for an exemplar expert participant during the + 2.00 D condition.

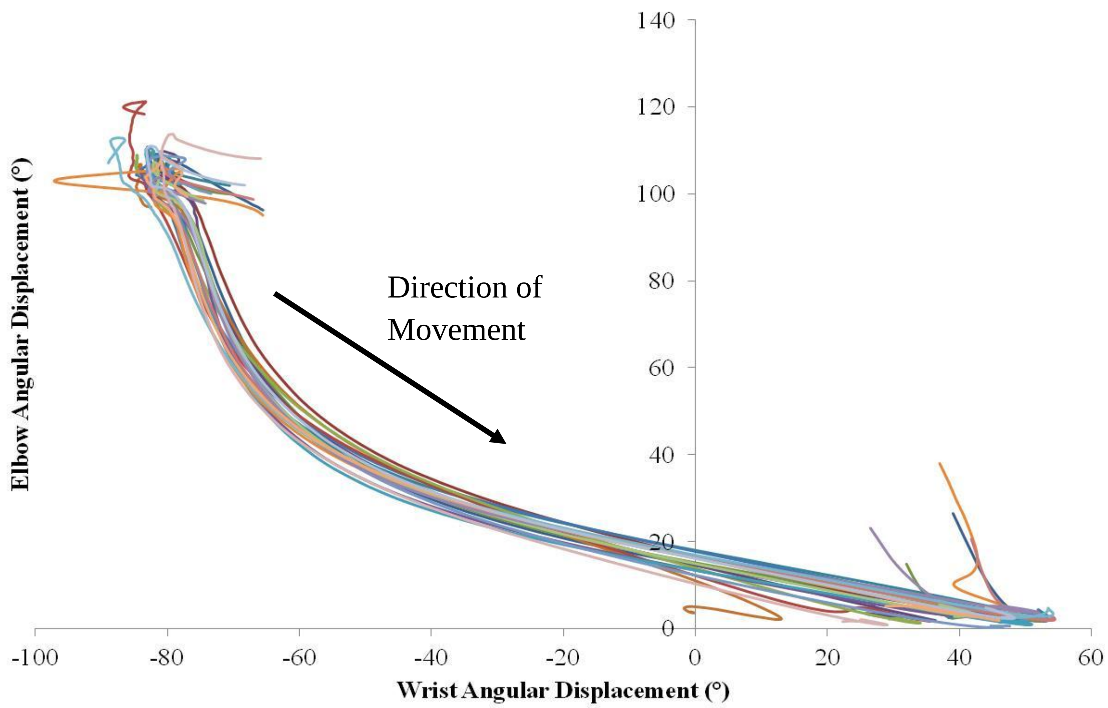

Figure 33. Angle-angle plot for an exemplar expert participant during the + 3.00 D condition.

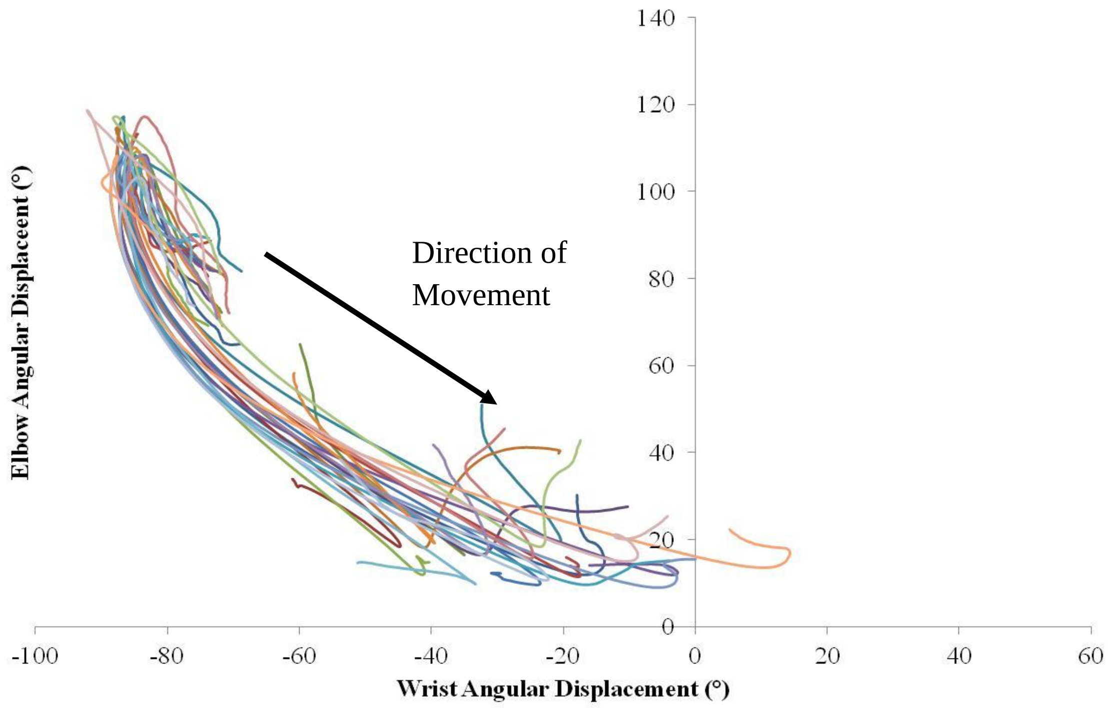

Figure 34. Angle-angle plot for an exemplar novice participant during the baseline condition.

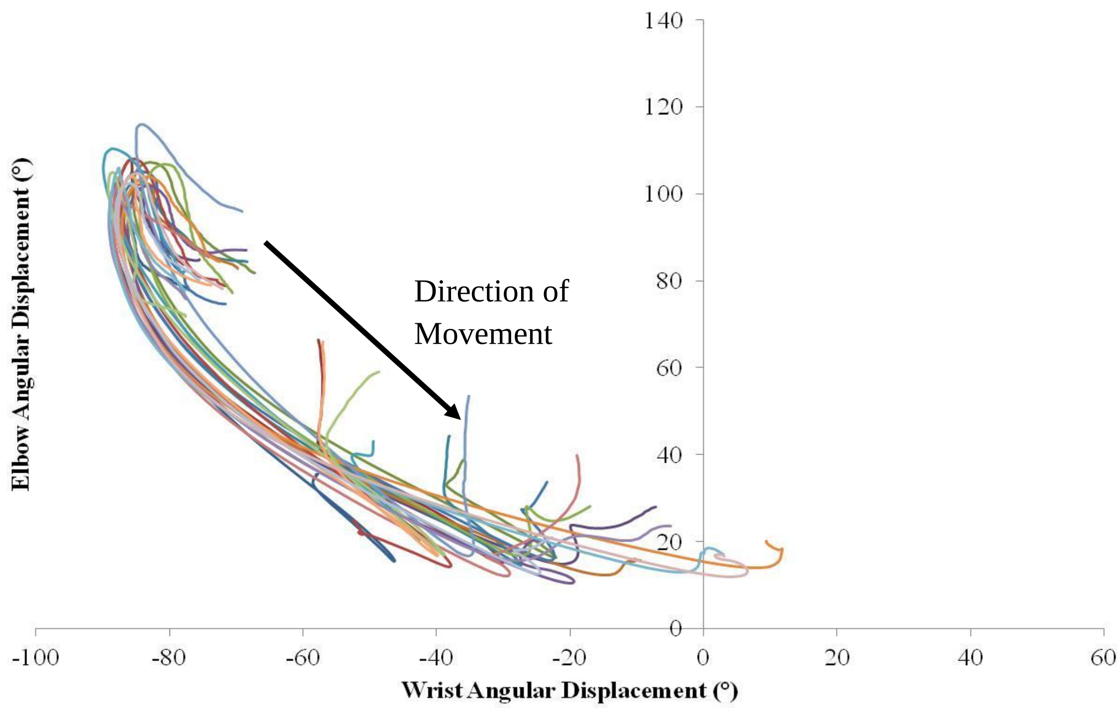

Figure 35. Angle-angle plot for an exemplar novice participant during the + 1.00 D condition.

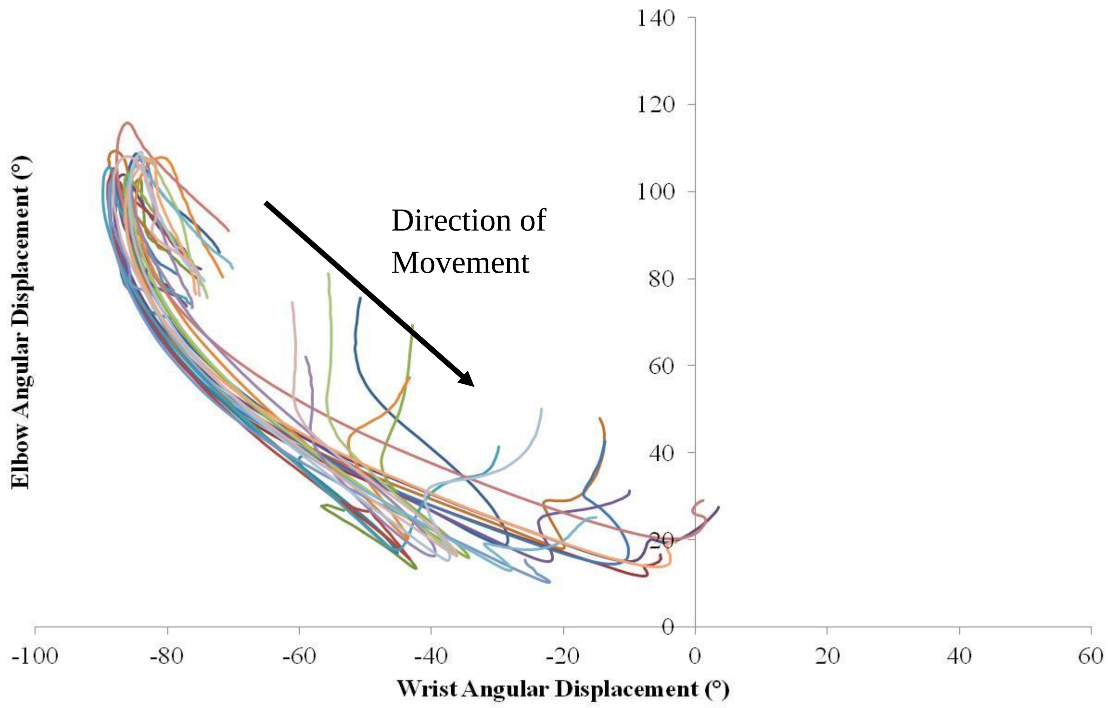

Figure 36. Angle-angle plot for an exemplar novice participant during the + 2.00 D condition.

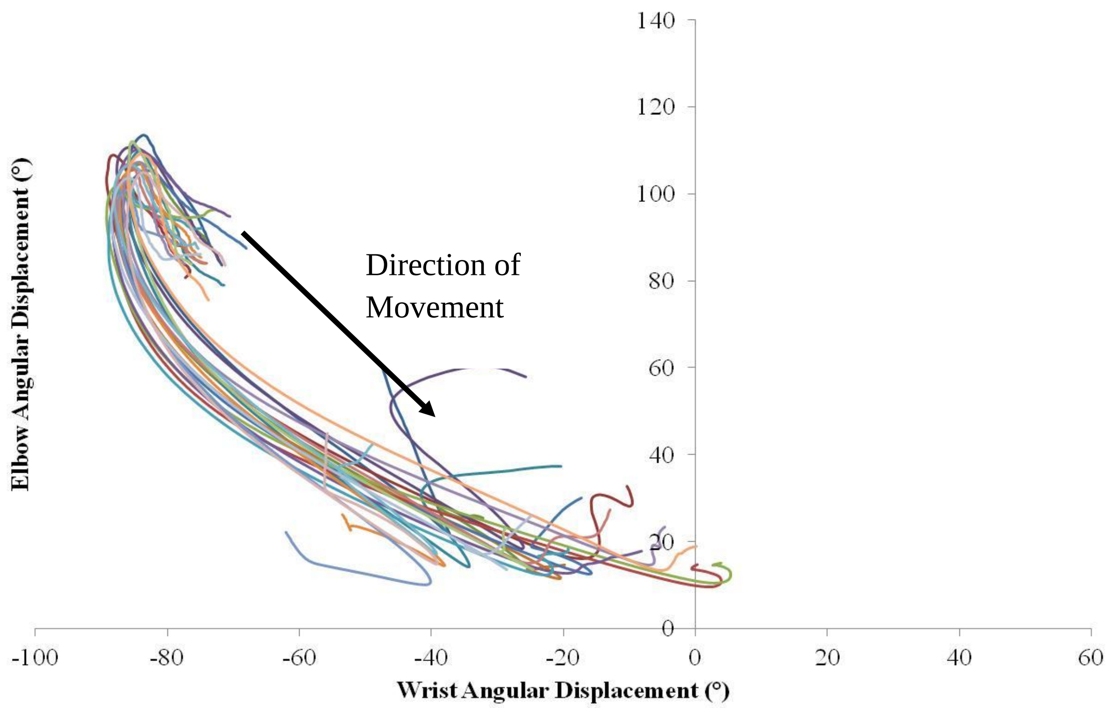

Figure 37. Angle-angle plot for an exemplar novice participant during the + 3.00 D condition.

4.4 DISCUSSION

The study had two aims. The first was to examine the effect of induced dioptric blur on shooting performance and movement variability during basketball free-throw shooting. The second aim sought to ascertain whether task expertise plays a mediating role in the capacity to stabilise discrete action performance against perturbation from impaired visual information. Consistent with the findings from the current programme of work, expert performers, again, demonstrated significantly better shooting performance across all four conditions. Furthermore, the experts also exhibited significantly less variability in both the speed and angle of ball release when compared to their novice counterparts. Taken in conjunction with the significantly greater wrist angle variability at ball release demonstrated by expert participants, these results provide additional compelling evidence that experts can exploit motor system variability in a functional manner to preserve invariance in ball release parameters, and therefore, optimise performance success. These data corroborate those previously reported for other targeted aiming tasks (Kudo *et al.*, 2000; Button *et al.*, 2003; Muller and Sternad, 2004), and support the contentions of Robins *et al.* (2006) who postulated that task expertise is characterised by a high level of covariance, or compensatory variability, between interacting joints along the kinematic chain.

In contrast to the novice participants, experts also had significantly less coordination variability. This is exemplified by the smaller NoRMS values for all three joint couplings – wrist-elbow, elbow-shoulder and wrist-shoulder – across all four experimental conditions. This finding substantiates the current programme of work relating to expertise changes in coordination variability, and can be interpreted as the development of a stable movement pattern within the perceptual-motor workspace. During the early stages of learning, individuals explore a wide range of kinematic solutions in the pursuit of satisfying the requirements of the task. With practice, and guided by the specific constraints on action, inherent processes of self-organisation channel the search towards a particular region of the perceptual-motor workspace, where ultimately, a task-relevant movement pattern is located and refined (for a review, see Handford *et al.*, 1997). This skill acquisition process manifests in the reduction in inter-trial variability. Empirical support for this theoretical insight is provided by Gabriel (2002) who found that the variability of phase-plane trajectories decreased during a targeted elbow flexion task after four hundred practice trials. Comparable expertise-related changes in movement variability can also be found in the work of Darling and Cooke (1987), Chapman *et al.* (2009) and Wagner *et al.* (2012).

The most interesting insights from the current study were those related to the manipulation of dioptric blur. Although no significant changes were found in the variability of ball release parameters, there was a significant improvement in performance during the + 1.00 and + 2.00 D conditions when compared to the baseline or + 3.00 D conditions. The lack of a significant expertise by condition interaction indicates that this was a homogeneous response irrespective of task expertise. In addition, there was a significant decrease in coordination variability for the wrist-elbow joint coupling during the + 3.00 D condition in contrast to the + 1.00 and + 2.00 D conditions. Again, there was no significant interaction suggesting that this decrease was consistent across both expertise groups. This change in coordination variability is a comparable perceptual-motor response to that seen with elevated anxiety (Higuchi *et al.*, 2002) and increased accuracy demand (Sidaway *et al.*, 1995b; Robins *et al.*, 2006). Therefore, visual acuity can be considered to act as an organismic constraint shaping the magnitude of coordination variability. With high levels of dioptric blur, individuals, irrespective of task expertise, constrain motor system dynamics, exhibiting less inter-trial variability.

The increase in shooting performance observed during the + 1.00 and 2.00 D conditions counters results previously reported within the existing literature (e.g. Mann *et al.*, 2007, 2010b, Bulson *et al.*, 2008, Hatch *et al.*, 2009). Within these studies, no significant difference in cricket batting (Mann *et al.*, 2007, 2010b), golf putting accuracy (Bulson *et al.*, 2008) or rifle shooting performance (Hatch *et al.*, 2009) was found between the baseline condition and when experiencing moderate levels of dioptric blur. A deterioration was only apparent with the onset of more severe levels of dioptric blur, such as during the + 3.00 D condition, or in the case of Bulson *et al.* (2008) + 10.00 D. This difference could be explained by the task constraints of the chosen movements. Cricket batting requires the precise timing of movement to intercept and displace a ball that is 9″ in circumstance. Similarly, golf putting necessitates the accurate placement of a ball into a hole that is 4.25″ in diameter. These stringent accuracy demands were also clearly evident within the study by Hatch *et al.* (2009) where participants were required to shoot targets at distances ranging from 50 m – 300 m. On the contrary, free-throw shooting in basketball, although requiring basic levels of accuracy, is a static task. It may impose a greater accuracy tolerance on performers, and due to larger target size e.g. hoop *and* backboard, the key constraining information guiding action may be easier, comparably, to extract with moderate levels of visual blur. This is supported by van der Kamp *et al.* (2008) who argues that the target location information (obtained by ventral stream processing), acts as a boundary constraint on vision for action (dorsal stream processing). Taken within the context of the present study, even with moderate levels of visual blur these boundary constraints still emerge, because of target size, and guide the performer towards the appropriate kinematic solution. This may, in part, also be supported by peripheral visual processing of limb movements as the action proceeds. Furthermore, in comparison to the work of Melmoth and co-workers (2007; 2009) who examined vergence and binocular disparity cues during prehension, this study perturbed vision in both eyes. Hence, the retinal image in both eyes was defocused simulatanaeously. In contrast, the work of Melmoth and colleagues (2007; 2009) has shown that by introducing dioptric blur and defocusing only one eye, thereby altering disparity information, it causes greater decrements in binocular stereoacuity. Therefore, introducing blur monocularly within the current study could have had a greater impact upon basketball shooting performance than blurring vision binocularly because of impaired depth perception. Hence, shooting performance was able to be stabilised to a greater extent.

This stabilisation of task performance within the aforementioned research is consistent with that reported by Applegate and Applegate (1992), who interestingly used the same movement task as the current study – basketball shooting. However, the disparity in research findings between the current study and those of Applegate and Applegate (1992) is somewhat surprising given the similarity in experimental conditions. For instance, Applegate and Applegate (1992) manipulated the visual acuity of participants to 6/6, 6/12, 6/24, 6/48 and 6/75. Conversely, baseline, + 1.00, + 2.00 and + 3.00 dioptric over-refraction was introduced within the current study, which equates to a visual acuity score of approximately 6/6, 6/18, 6/36 and 6/54 respectively (see Thorn and Swartz, 1990). However, differences between the two studies could be attributed to the measurement of performance outcome. Applegate and Applegate (1992) assessed outcome simply on a binary scale – success or failure – whereas the current study assessed performance using an eight-point nominal rating scale. Therefore, the increased sensitivity of the eight-point scale may have permitted better detection of subtle performance changes between the conditions. Consequently, future research into targeted aiming tasks should carefully consider the issue of sensitivity to ensure that important changes in performance are not masked by the gross nature of the outcome measure.

Nonetheless, the increase in shooting performance with moderate levels of visual blur is commensurate with the data presented by Mann *et al.* (2010c). When examining cricket batting performance, Mann and co-workers (2010c) observed a significant increase in response accuracy during the + 1.00 D condition. Collectively, these findings suggest that not only can the human movement system tolerate quite substantial decrements in visual acuity, but that moderate levels of dioptric blur may actually enhance performance. Moreover, it appears that the putative benefits of moderate visual blur can be generalised to both interceptive and discrete action performance. However, further empirical evidence is needed to support this contention.

In addition, one novel contribution from the current study has identified that this performance improvement appears robust regardless of task expertise. Consequently, it could be argued that the observed adjustments to changes in visual acuity might be indicative of a universal adaptation by humans to these alterations in informational constraints on action. However, performance responses to a wider range of vision conditions first need investigation to fully elucidate any expertise-related differences. Furthermore, the main challenge for experimentation remains the identification of the mechanism responsible for this performance change. It is still unclear what strategy is used to adapt to changing visual acuity. A likely explanation could be the allocation of additional attentional resources to the primary task. The investment of additional attentional resources has been shown to stabilise performance against emotional fluctuations caused by elevated anxiety (Monno *et al.*, 2000; Murray and Janelle, 2003; 2007; Court *et al.*, 2005), and could be the same strategy used to offset perturbation from impaired visual information. Therefore, future research should examine the effect of dioptric blur on both shooting performance and attentional demands. The use of a probe reaction time test to assess attentional demands would also assist with ascertaining whether dioptric blur acts as a source of stochastic resonance. Stochastic resonance has been classically defined by Collins and co-workers (1995; 1996; 1999) as a phenomenon in which the introduction of intermediate levels of noise enhances the response of a non-linear system to a weak signal. If dioptric blur acts as a form of stochastic resonance, the introduction of moderate visual blur may, intuitively, decrease the attention required to complete the primary task. This postulated interaction between dioptric blur, shooting performance and attentional demands is displayed in Figure 38. However, it should be acknowledged that Douglass *et al.* (1993) allude to stochastic resonance as a nonlinear, statistical dynamic, whereby information flow in a multi-state system is enhanced by the presence of optimized, random noise. This emphasis on *random noise* raises the question whether the introduction of dioptric blur actually constitutes a form of stochastic resonance. Consequently, if dioptric blur does not, in fact, act as a form of stochastic resonance, the interaction between shooting performance and attention may be more akin to that depicted in Figure 39. This proposed alternative hypothesis where attentional demands increase and then plateau with increasing dioptric blur would not be too dissimilar from the relationships seen within the power law of practice (see Snoddy, 1926; Stratton *et al.*, 2007), or, Hick's Law (see Hick, 1952).

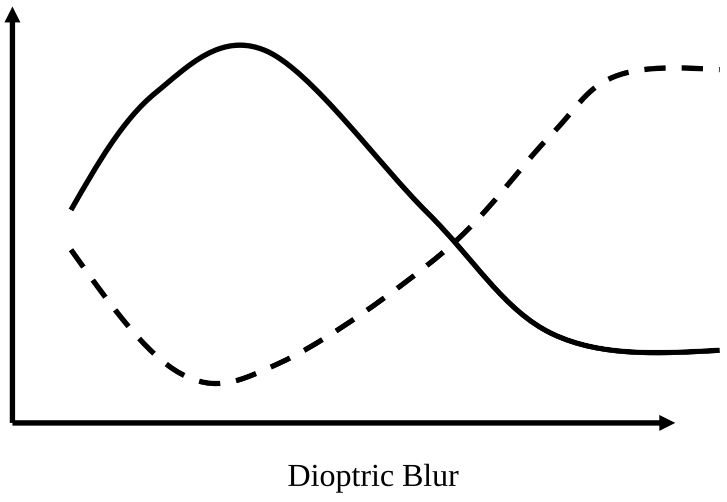

Figure 38. Hypothetical interaction (I) between shooting performance (━) and attentional demands (‒ ‒) as a function of dioptric blur.

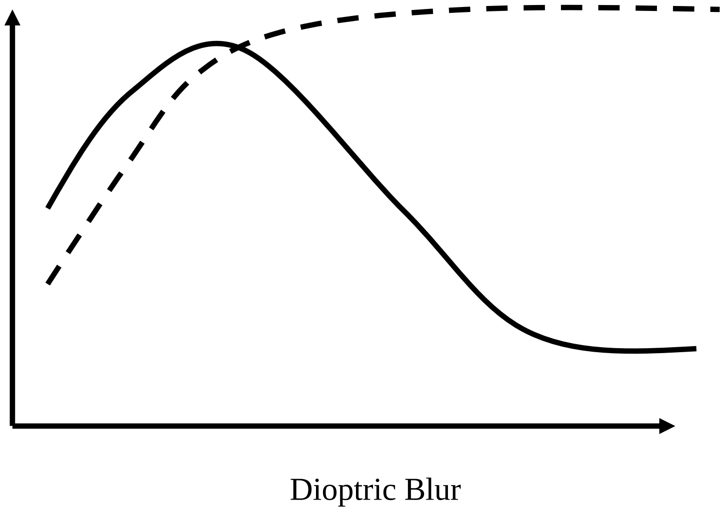

Figure 39. Hypothetical interaction (II) between shooting performance (━) and attentional demands (‒ ‒) as a function of dioptric blur.

An alternative explanation could be the focus of attention adopted. There is an extensive body of research demonstrating the benefits of an external focus of attention on motor performance (e.g. see Wulf *et al.*, 2007a). Moreover, these external focus benefits appear robust across a wide range of movement models, such as basketball shooting (Zachry *et al.*, 2005), golf chipping (Wulf and Su, 2007), and vertical jumping (Wulf and Dukek, 2009). Consequently, it may be that with the introduction of moderate dioptric blur, individuals naturally focus externally to extract the key constraining information guiding action. This external focus therefore permits inherent processes of self-organisation to regulate task performance, thereby enhancing shooting success. As a result, future research should employ qualitative methods, similar to those adopted by Tanaka and Sekiya (2010), to clarify the exact focus of individuals' attention with varying levels of dioptric blur. With that said, anecdotally, several of the participants, particularly within the skilled group, reported to the author after completion of the testing protocol that they preferred to adopt an internal focus of attention when the level of dioptric blur increased. As such, when vision is significantly impaired participants may resort to focussing on a specific pre-performance routine, critical features of the skill, and/or specific body movements as action unfolds. Support for this contention comes from Lanham and Robins (2012) who examined the shooting performance of 8 skilled basketball players in each of four counterbalanced vision conditions. The four conditions used were comparable to the current study i.e. plano, +1.00 D, +2.00 D, and +3.00 D. Upon completion of each vision condition participants completed a focus of attention questionnaire, designed to gain an insight not only into whether participants were focussing internally or externally but also which specific cues they were focussing on. Lanham and Robins (2012) reported no significant difference in focus of attention with respect to myopic blur, but this was caused by the high inter-individual variability. Interestingly though, some participants self-selected internally focussed cues when dioptric blur increased, such as the starting position and the follow through movement.

It is important to note that there were a couple of experimental limitations that warrant consideration. First of all, dioptric blur was induced with the use of trial frames. Spectacle lenses do provide some, albeit small, magnification effect when compared to contact lenses. Therefore, additional research is needed to replicate the current study but manipulate dioptric blur with the use of contact lenses to minimise confounding effects of image magnification on task performance. In addition, although stringent inclusion criteria were in place, the baseline condition was the participants' habitual vision, for instance, - 0.25 D or + 0.5 D. In retrospect, the vision of each participant should have been corrected to 6/6, and this acted as the baseline measure upon which to introduce dioptric over-refraction (see Mann *et al.*, 2007).

In summary, a significant improvement in shooting performance was evident with the introduction of moderate dioptric blur. Furthermore, this performance change was observed in both novice and expert performers, providing preliminary evidence to suggest that the underlying strategy to adapt to such changes is a universal human response. Finally, the introduction of high levels of visual blur was sufficient to instigate reorganisation of the perceptual-motor system. This reorganisation manifested in a reduction in coordination variability, and is a comparable response to performance perturbations such as those evident with emotional fluctuations (e.g. Higuchi *et al.*, 2002).

CHAPTER V

EFFECTS OF EXPERTISE AND ANXIETY ON ATTENTIONAL STRATEGIES AND JOINT KINEMATICS DURING A DISCRETE MULTI-ARTICULAR ACTION

5.1 INTRODUCTION

Anxiety has been classically defined as:

"*...subjective, consciously perceived feelings of tension and apprehension, associated with arousal of the autonomic nervous system*."

(Spielberger, 1966, p. 17)

Weinberg and Gould (1999) offer a more contemporary definition, regarding anxiety as a debilitative psychology state, characterized by worry, apprehension and nervousness, and associated with activation or arousal of the body. The theoretical understanding of anxiety and its implications on sporting performance have advanced tremendously over the years. This progress has culminated in the emergence of many theories attempting to examine the causal link between anxiety and performance, such as drive theory, inverted-U theory, the catastrophe model and processing efficiency theory (for a historical perspective, see Weinberg and Gould, 2010).

Anxiety was originally perceived as a unidimensional construct but is now considered to be multidimensional, and partitioned into cognitive and somatic subcomponents (for an overview, see Hardy, Jones and Gould, 2002). Cognitive anxiety can be operationally defined as the fear of failure which often manifests in negative expectations of performance and can lead to negative self-evaluation. As a consequence, cognitive anxiety is considered to be detrimental to cognitive function, impairing both attention and memory (Davids and Gill, 1995). Somatic anxiety, on the other hand, pertains to a person's perceptions of their physiological state in response to a given stressful situation (Martens *et al.*, 1990a). Research examining physiological measures of performance has reported significantly higher heart rates, more muscle fatigue and higher blood lactate concentrations in high anxiety conditions than in low anxiety conditions (Parfitt and Hardy, 1987; Pijpers *et al.*, 2003; 2004).

It is not only the dimensionality of anxiety that has received attention, a re-consideration of anxiety being solely debilitative for performance in sport has received scrutiny (for a review, see Jones, 1995). Viewing anxiety unidirectionally permits only a partial understanding of its potential effects on performance. Conceptualising anxiety as having a bidirectional influence on performance, either facilitative or debilitative, allows for a more meaningful measure and interpretation to be constructed, one that comprises both the intensity *and* the direction of the anxiety response.

For instance, in a seminal study by Jones *et al.* (1993), the intensity and direction of competitive state anxiety were examined together with its relationship to beam performance in female gymnasts. Although no differences were observed in cognitive and somatic anxiety intensity scores, or on somatic anxiety direction, differences were identified in the direction of cognitive anxiety. Specifically, it was reported that the good performance group perceived anxiety as more facilitative than did the poor performance group. This is further supported by the work of Eubank and co-workers who found that anxiety interpretation plays a crucial role in the processing of information (Eubank *et al.*, 2000; 2002).

Research on anxiety and sport performance has typically focused on issues such as antecedents (Hanton and Jones, 1995), sex influences (Jones *et al.*, 1991), temporal patterning (Parfitt and Hardy, 1987; Hanton *et al.*, 2002), intervention strategies (Dugdale and Eklund, 2002; Liao and Masters, 2002), and performance outcome measures (Jones and Cale, 1989; Parfitt and Hardy, 1987; 1993; Parfitt and Pates, 1999; Fong *et al.*, 2002; Arent and Landers, 2003).

Of particular interest is the body of research that examines the effects of anxiety on performance outcome. A common occurrence within the existing literature is to assess the relationship between anxiety and rather simplistic (and reductionist) outcome measures such as reaction time measures. In a re-examination of the proposed inverted-U hypothesis, Arent and Landers (2003) randomly assigned participants into one of eight mutually exclusive arousal groups. Arousal ranged from 20 – 90% of heart rate reserve. Optimal reaction time performance was reported at 60 – 70% maximal arousal, with degradations in performance apparent at the ‘extremes’ of heart rate reserve. Other research has utilised more representative experimental designs, although still very product-oriented, performance measures. For instance, Parfitt and co-workers investigated the effects of cognitive and somatic anxiety on subcomponents of performance within competitive basketball (Parfitt and Hardy, 1987; 1993; Parfitt and Pates, 1999). Representative tasks in sport, such as rebounding and shooting, were examined as well as cognitive tasks testing letter span memory processes, where participants were required to recall a sequence of letters ranging from three to ten letters long, agility and Sargent jump performance. Specifically, it was observed that cognitive and somatic anxiety promote differential effects. For instance, a positive relationship between cognitive anxiety and both shooting and rebounding performance was found, whereas somatic anxiety had a negative effect upon letter span memory processes.

With the abundant interest in performance outcome measures, many authors have urged human movement scientists to explore the ramifications of anxiety on cognitive, perceptual and motor function (Eubank *et al.*, 2002; Janelle, 2002; Derakshan and Eysenck, 2009). This recommendation for future research to move beyond the assessment of solely outcome measures complements the four stage stress response model proposed by McGrath (1970). Conceptually, stress is a different phenomenon to that of anxiety, and is defined as:

"A substantial imbalance between demand (physical and / or psychological) and response capability, under conditions where failure to meet that demand has important consequences."

(McGrath, 1970, p. 20)

It is clearly evident from Stage 3 of the four stage stress process (see Figure 40) that stress can evoke a response that can be psychological and physical in nature. Consequently, research is needed to examine how stress manifests across a wide spectrum of process-orientated variables, such as joint kinematics and attention. The introduction (Kugler and Turvey, 1987) and recognition (see Davids *et al.*, 2008) of dynamical systems theory as a viable theory for the study of human movement can also assist in this endeavour, offering a framework by which to explain the effects of anxiety on perceptual-motor dynamics. According to dynamical systems theory anxiety acts as an organismic constraint prompting the re-organisation of the perceptual-motor system. As such, a process-oriented approach would be fruitful in supplementing the traditional product-orientated experimental design. This process-oriented approach would facilitate a more sensitive level of analysis and provide insights into the fundamental processes dictating changes in performance outcome. Consequently, anxiety has now been a topic of great interest within the fields of both biomechanics (e.g. Higuchi *et al.*, 2002) and motor control (e.g. Court *et al.*, 2005).

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Figure 40. The four stage stress process (McGrath 1970, cited in Weinberg and Gould, 2010, p. 82).

One of the topics that has received much recent interest is the effect of anxiety on perceptual processes (Williams and Elliott, 1999; Williams *et al.*, 2002; Murray and Janelle, 2003; Rinck *et al.*, 2003; Wilson *et al.*, 2006). Through examination of visual search strategy, it has been consistently reported that a high state (and trait) anxiety causes a significant change in gaze behaviour. Moreover, elevated anxiety corresponded to an increased search rate, one that was characterised by an increase in the total number of fixations[4] per trial (Williams and Elliott, 1999; Williams *et al.*, 2002; Murray and Janelle, 2003; Wilson *et al.*, 2006). This finding is further supported by Causer *et al.* (2011) who, when analysing elite shotgun shooters, reported shorter quiet eye durations and subsequently decreased performance outcome under high compared to low anxiety conditions. The explanation for this change in perceptual strategy is that anxiety promotes a phenomenon known as hypervigilance whereby the participants exhibit more ‘scattered’ gaze behaviour due to an increased susceptibility to task irrelevant information (Williams *et al.*, 2002). This finding is exemplified by Wilson *et al.* (2006) who manipulated anxiety during a simulated rally driving task. Twenty-four male students participated in the study and each was categorised as either high or low trait anxious. Furthermore, each participant raced under two experimental conditions (low and high threat) and a counterbalanced design was implemented. The high threat condition was induced by means of a financial incentive and peer-ranking system. In terms of performance completion time, there was a significant trait grouping * condition interaction as well as a main effect for condition. Specifically, the drivers took longer in the elevated anxiety (high pressure) condition and the high-trait anxious group was more affected by this condition than their low-trait anxious counterparts. A significantly greater search rate was also demonstrated by the high-trait anxious participants. As a consequence, quiet eye training has been offered as a tool for aiding performance under heightened anxiety, and has shown promising results (Moore *et al.*, 2012). A reduction in performance with anxiety has also been reported in table tennis (Williams *et al.*, 2002). However, stabilisation of performance or, in some cases, even enhanced performance has been observed in simulated driving (Murray and Janelle, 2003; 2007) and karate (Williams and Elliott, 1999), respectively.

[4] A fixation was defined as the stabilisation of gaze on a single location for 100 – 120 ms.

The enhanced performance reported by Williams and Elliott (1999) can be explained by the potential motivational role associated with anxiety, which is suggested to modulate effort (see Janelle, 2002). Furthermore, the apparent discrepancy in the findings between the studies of Murray and Janelle (2003) and Wilson *et al.* (2006) can be attributed to differences in experimental design. First, although both studies used comparable ego and motivational instructional sets, state anxiety was assessed by differing inventories, the competitive state anxiety inventory-2 (CSAI-2) and the Mental Readiness Form-Likert (MRF-L). As such, it is difficult to ascertain whether the change in anxiety response between the two conditions is homogeneous across studies. Intuitively, the severity of the anxiety response could dictate the magnitude of performance change. Second, Wilson *et al.* (2006) inferred mental effort by means of papillary dilation and The Rating Scale for Mental Effort. Murray and Janelle (2003), on the other hand, implemented a dual-task paradigm where participants were required to react to the onset of a target light-emitting diode (LED). This dual-task, or probe reaction time test as it is commonly referred to (see Girouard *et al.*, 1984), is often used to assess the attentional demands of a particular primary task. From the empirical data presented by Murray and Janelle (2003), it could be argued that the allocation of additional attentional resources to the primary driving task permitted the stabilisation of performance outcome. A similar conclusion cannot be inferred from the Wilson *et al.* (2006) study. This explanation draws upon the central tenets of processing efficiency theory (Eysenck and Calvo, 1992) and is discussed in greater detail later.

Another avenue of research explored the effects of anxiety on motor behaviour. With that said, there is currently limited evidence examining movement kinematics (Beuter and Duda, 1985; Beuter *et al.*, 1989; van Loon *et al.*, 2001; Williams *et al.*, 2002; Gage *et al.*, 2003; Delval *et al.*, 2008; Tanaka and Sekiya, 2010; Cooke *et al.*, 2011), movement variability (Higuchi *et al.*, 2002) or coordination dynamics (Court *et al.*, 2005). Moreover, the literature pertaining to effects of anxiety on movement kinematics appears to be equivocal. For instance, Beuter and co-workers (1985; 1989) have reported that when children performed stepping motions over three obstacles of varying heights under low and high anxiety conditions, the kinematics of the knee and hip altered very little, and that these joints remained very tightly coupled. The ankle, however, appeared to be much more variable, with these authors advocating that the most distal joints along the kinematic chain appeared to be more strongly influenced by elevated anxiety (Beuter and Duda, 1985; Beuter *et al.*, 1989).

The findings reported by Beuter and co-workers (1985; 1989) are, however, contrary to those observed by both Higuchi *et al.* (2002) and Tanaka and Sekiya (2010) who have analysed the effects of anxiety on computer-simulated batting and golf-putting performance respectively. For instance, within the study by Higuchi *et al.* (2002) fourteen participants were required to perform a computer-simulated batting task which required the manipulation of a horizontal lever. Participants performed four blocks of 30 practice trials that allowed for baseline measures to be created. Subsequently, a final block of 30 trials was undertaken with elevated psychological stress. Psychological stress was induced by means of an electric shock that was administered if the participant failed to hit the target three times successively. Higuchi *et al.* (2002) reported reduced amplitude of joint movement, coupled with a decrease in variability of spatial kinematics. The authors proposed that anxiety caused participants to freeze motor system degrees of freedom to achieve the task goal. These findings corroborate those reported by Tanaka and Sekiya (2010) where the amplitude of arm and club movements decreased on the backswing of a golf-putting action when anxious. Interestingly, this reduced amplitude of motion was apparent for both expert and novice golfers, signifying that the anxiety response was not mediated by task expertise. Moreover, these results are also comparable to those that have observed increases in limb stiffness under conditions of mental stress (van Loon *et al.*, 2001), and under conditions of high accuracy demand (Sidaway *et al.*, 1995b). For example, Sidaway *et al.* (1995b) identified a reduction in movement variability with a corresponding decrease in target size during a serial aiming task.

Despite the apparent stress-induced changes in movement kinematics reported within the existing literature, there is also growing evidence to suggest that individuals can stabilise movement kinematics under conditions of elevated anxiety. This is exemplified by Williams *et al.* (2002) who reported no significant difference in movement kinematics during the execution of a table-tennis shot when exposed to either low or high anxiety conditions. This finding could have been a consequence of the variables examined because no coordination profiling or joint angle calculations were performed, and the kinematic analysis was restricted to movement time, mean ball speed, initial position, arm velocity at contact, and peak arm velocity. Nonetheless, additional support can be found in data reported by Court *et al.* (2005) who corroborated previous work and observed that participants were able to stabilise preferred patterns of rhythmical bimanual coordination by dedicating additional attentional resources to the task when anxious. Moreover, both in-phase (0°) and anti-phase (180°) modes of coordination became more stable under moderate levels of anxiety.

The stabilisation of perceptual-motor processes and, in particular, task goal accomplishment has routinely been explained using processing efficiency theory, originally proposed by Eysenck and Calvo (1992). Although processing efficiency theory has been superseded by, and is the precursor to, attentional control theory (Eysenck *et al.*, 2007), both theories share several important commonalities that warrant consideration. Both theories are predicated on the principles of traditional cognitive psychology, and consider the brain to be a 'device' with a finite attentional capacity. Performance is partitioned into two distinct categories: 1. performance effectiveness; 2. performance efficiency, with the theories advocating a hierarchical structure whereby a central executive governs functions such as planning, strategy selection and attentional control (for a review, see Derakshan and Eysenck, 2009). Performance effectiveness is considered to reflect the quality of the performance outcome, whereas performance efficiency represents the amount of effort or (attentional) resources used to achieve a specific task goal. Performance efficiency is typically examined by using a probe reaction time test. This requires participants to respond to a visual or auditory stimulus (acting as a secondary task) while simultaneously completing a primary performance task.

Several studies have provided empirical support for processing efficiency theory and demonstrated that, when anxious, performance efficiency is impaired to a greater extent than performance effectiveness (Williams *et al.*, 2002), and that the allocation of attentional resources to the primary task stabilises performance accomplishment (Williams and Elliott, 1999; Gage *et al.*, 2003; Murray and Janelle, 2003; 2007; Coombes *et al.*, 2009). For instance, in a recent study by Coombes *et al.* (2009), participants performed targeted force contractions at both 10% and 35% of maximal voluntary contraction. Reaction time was used to assess performance efficiency whereas performance effectiveness was calculated using root mean square error of force production. It was found that elevated anxiety corresponded with reduced performance efficiency but not performance effectiveness. Increasing task complexity, specifically relating to reaching movements in rock climbing, has also been shown to require additional attentional resources (Bourdin *et al.*, 1998). However, no significant difference in attentional demands was found between an exhausting session and control session when performing a rhythmical bimanual coordination task (Murian *et al.*, 2008). This led Murian *et al.* (2008) to hypothesise that the effects of muscle exhaustion may manifest at a more peripheral level.

An alternative theoretical interpretation as to the role of attention and the effects of anxiety on perceptual-motor processes has been proposed by Monno and co-workers (Monno *et al.*, 2000; 2002) and supported by Court *et al.* (2005). Monno *et al.* (2000; 2002) found that focusing attention on the performance of a rhythmical bimanual coordination task increased probe reaction time but delayed the transition from anti-phase to in-phase coordination modes. Hence, allocation of additional attentional resources appeared to stabilise preferred patterns of coordination. Corroborating evidence has been reported by Hiraga *et al.* (2004) who examined attentional costs of in-phase and anti-phase rhythmical bimanual coordination under homologous (left arm – right arm), contralateral (left arm – right leg) and ipsilateral (right arm – right leg) limb combinations. Two important findings were discussed, replicating those initially reported by Zanone *et al.* (2001). First, there was an inverse relationship between coordination mode stability and probe reaction time. Second, the allocation of attention to the primary task further stabilised patterns of coordination.

Encompassing the ideas from non-linear dynamical systems theory, Monno *et al.* (2000) proposed that the allocation of attention was an important organismic constraint for stabilising an anti-phase pattern of coordination during rhythmical bimanual coordination. Furthermore, a comparable explanation can also be considered under conditions of elevated anxiety. For instance, Court *et al.* (2005) argued that anxiety acted as a source of behavioural information capable of stabilising coordination through an increase in coupling strength between oscillating limbs in rhythmical task performance. In other words, anxiety acted as an organismic constraint that required individuals to invest additional attentional resources in the task to override the intrinsic dynamics of the motor system.

It is currently unclear whether attentional resources can be used in the same way to stabilise performance of discrete actions, such as basketball shooting, to negate effects of anxiety on motor system intrinsic dynamics. Key differences between rhythmical and discrete actions have been noted in the movement sciences literature, indicating the need to study effects of organismic and task constraints on stability and variability of movement coordination in both types of tasks (Chow *et al.*, 2007).

Therefore, the first aim of this study was to examine whether successful outcomes and joint kinematics could be preserved under conditions of anxiety by participants investing additional attentional resources during performance of a discrete shooting task. The second aim of the study sought to ascertain whether performance expertise plays a mediating role in the capacity to stabilise a discrete pattern of movement coordination against perturbation from emotional fluctuations. Janelle (2002) has postulated that experts may be more capable of regulating emotional fluctuations than non-expert performers. However, there is currently very limited substantive evidence to support this view (Williams and Elliott, 1999; Janelle *et al.*, 2000; for a review, see Janelle and Hatfield, 2008). One such study examined gaze behaviour and cortical activation of expert and non-expert small-bore rifle shooters (Janelle *et al.*, 2000). Through examination of electroencephalographic activity it was found that experts exhibited a significant increase in left-hemisphere alpha and beta power, accompanied by a reduction in right-hemisphere alpha and beta power. This asymmetry occurred during the preparation phase before to the shot and was more pronounced in comparison to their non-expert counterparts. The authors, therefore, suggested that experts were better able to achieve an optimal state of relaxation and that this capability may permit intervening effects of elevated anxiety to be attenuated. However, although the protocol implemented by Janelle *et al.* (2000) mirrored that of competition, with 40 shots over the course of 80 minutes, no formal anxiety intervention was conducted. As such, any inference that anxiety is mediated by task expertise appears tenuous. In addition, Tanaka and Sekiya (2010) found that both expert and novice performers responded in a uniform manner, demonstrating decreased amplitude of club and arm movement when anxious. Consequently, the second aim of this study was to identify variations in attentional strategies between expert and novice performers to stabilise shooting performance.

5.2 METHODS

5.2.1 PARTICIPANTS

Twenty male participants with a mean (± SD) age, height and mass of 22.6 (± 2.6) years, 1.83 (± 0.05) m and 78.1 (± 6.6) kg respectively provided written voluntary informed consent to participate in the study. Furthermore, each participant completed a health screening questionnaire (see Appendix 2) and all procedures were risk assessed (see Appendix 17) and approved by the local institutional research ethics committee (see Appendix 18). Participants were categorised as either expert (n = 10) or novice (n = 10) using the same procedures and inclusion criteria outlined within Section 3.2.1.

5.2.2 PROCEDURES

After a thorough warm-up of the involved musculature, participants were required to complete thirty trials of a basketball free-throw from a distance of 4.25 m under two experimental conditions: a control condition and an anxiety condition. A counterbalanced design was implemented to minimise potential confounding order effects. Furthermore, the two experimental conditions were separated by approximately one week and occurred at the same time of day to reduce possible differences due to diurnal variation. For instance, significant time-of-day effects in both aerobic (Hill, 1996) and anaerobic (Kin-Isler, 2006) performance have been reported within the physiological literature that could potentially impact upon movement kinematics and the validity of subsequent research findings. Anxiety was induced by way of a financial incentive and social evaluation effects through the presence of an independent assessor. Specifically, a peer-ranking system was used within each expertise group with the participant who achieved the greatest shooting performance score awarded a prize of £50. Furthermore, a qualified sport and exercise scientist was used to assess each participant's basketball shooting technique. As such, an ego-threatening instructional set (independent assessor) and motivational instructional set (reward) were used to facilitate the desired emotional response. Both of these approaches have been used routinely within the existing literature (Williams and Elliott, 1999; Murray and Janelle, 2003; Mullen *et al.*, 2005), and represent effective ways to evoke a performance perturbation through emotional fluctuations.

To verify empirically the manipulation of anxiety, the competitive state anxiety inventory-2 (CSAI-2: Martens *et al.*, 1990b) was administrated immediately before and after the test protocol for both control and anxiety conditions. The CSAI-2 represents a valid and reliable tool used to measure cognitive anxiety, somatic anxiety and self-confidence during a specific situational context, such as during sporting competition. The CSAI-2 comprised 27 statements, nine pertaining to each of the three psychological sub-components (see Appendix 15). The response to each question was graded numerically using a Likert scale i.e. not at all = 1, somewhat = 2, moderately so = 3, very much so = 4. As such, the possible range for intensity scores was 9 to 36. The CSAI-2 was administrated both before and after to verify whether the intervention persisted throughout the duration of the test protocols.

For the control and anxiety conditions, both basketball shooting performance and kinematic data were collected using the procedures previously outlined in Sections 3.2.1 and 3.2.2 respectively. However, the attentional demands for each condition were also measured using a probe reaction-time task. A probe reaction-time test constitutes an accepted method to assess the attention invested in a given primary movement task (see Girouard *et al.*, 1984; Williams *et al.*, 2002). Attentional demands were examined by inputting a buzzer and voice-activated switch as analogue signals into the motion analysis system (Motion Analysis Corporation, Santa Rosa, CA). The buzzer was initiated at an instant between movement initiation and ball release, and participants were instructed to react as quickly as possible by shouting the word 'shot'. The analogue signals were sampled at a frequency of 1000 Hz and reaction time was calculated as the time difference between the two voltage offsets.

5.2.3 DATA ANALYSIS

Retro-reflective marker reconstruction and generation of three-dimensional joint coordinate system angles for the wrist, elbow and shoulder joints and ball release parameters were achieved using the same processes outlined in Section 3.2.3. The dependent variables of interest included the following: shooting performance score, variability of ball release parameters, reaction time, joint range of movement of the wrist, elbow and shoulder, wrist, elbow and shoulder joint angle variability at the instant of ball release, and coordination variability of the shooting arm using the normalised root mean squared difference technique (NoRMS) proposed by Sidaway *et al.* (1995b). Coordination variability was calculated for the following joint couplings: wrist flexion and elbow extension, elbow extension and shoulder extension, and wrist flexion and shoulder extension.

5.2.4 STATISTICAL ANALYSIS

Cognitive anxiety, somatic anxiety and self-confidence were analysed using a 2 (expertise) * 2 (timing) * 2 (condition) analysis of variance (ANOVA) with expertise as the between-individuals factor and both timing and experimental condition as within-individuals factors. All other variables of interest were subjected to a 2 (expertise) * 2 (condition) analysis of variance with expertise as the between-individuals factor and experimental condition as the within-individuals factor. An alpha level of 0.05 was selected as a compromise between committing type I and type II errors (see Franks and Huck, 1986; 1987). After a statistically significant difference, *post-hoc* pairwise comparisons were conducted using a Bonferroni correction. All assumptions underpinning use of parametric tests were tested for and verified. As per Section 3.2.4, normality, homogeneity of variance and sphericity were again tested using an Anderson-Darling test, Levene's test and Mauchly's test of sphericity respectively. Inferential statistics were also supplemented with measures of effect size (η^2) to quantify the meaningfulness of the differences. It should be noted that, due to a motion tracking problem during data collection, one novice participant was excluded from the statistical analysis, resulting in 9 novice performers being entered into the analysis.

5.2.5 NULL HYPOTHESES

H_{01} There will be no significant effect of task expertise on basketball shooting performance score.

H_{02} There will be no significant effect of task expertise on movement kinematics of the basketball free-throw.

H_{03} There will be no significant effect of task expertise on probe reaction time.

H_{04} There will be no significant effect of elevated anxiety on CSAI-2 scores.

H_{05} There will be no significant effect of elevated anxiety on basketball shooting performance score.

H_{06} There will be no significant effect of elevated anxiety on movement kinematics of the basketball free-throw.

H_{07} There will be no significant effect of elevated anxiety on probe reaction time.

5.3 RESULTS

5.3.1 CSAI-2 SCORES

The changes in cognitive anxiety, somatic anxiety and self confidence as a function of expertise and condition are presented in Table 9.

Table 9. Mean (± SD) CSAI-2 scores as a function of expertise and experimental condition.

	Novice		Expert	
Dependent Variable	Control	Anxiety	Control	Anxiety
Cognitive Anxiety (Pre)	12 ± 3	14 ± 3	12 ± 3	15 ± 4
Cognitive Anxiety (Post)	13 ± 3	15 ± 4	12 ± 3	14 ± 4
Somatic Anxiety (Pre)	10 ± 2	12 ± 1	11 ± 2	13 ± 3
Somatic Anxiety (Post)	11 ± 2	12 ± 2	11 ± 2	13 ± 2
Self-Confidence (Pre)	28 ± 5	26 ± 5	31 ± 3	27 ± 4
Self-Confidence (Post)	28 ± 6	26 ± 5	29 ± 3	27 ± 4

5.3.1.1 COGNITIVE ANXIETY

No significant expertise * condition * timing, condition * expertise, timing * expertise, condition * timing or condition * timing * expertise interactions were found for cognitive anxiety ($P > 0.07$, $\eta^2 < 0.177$). There were also no significant main effects for either timing ($P = 0.260$, $\eta^2 = 0.074$) or expertise ($P = 0.871$, $\eta^2 = 0.002$). The failure to detect a difference between the pre- and post-test scores suggests that the intervention was effectively maintained throughout the entirety of each thirty trial data collection session. There was, however, a significant main effect for condition ($P = 0.0001$, $\eta^2 = 0.548$), with both the expert and novice participants experiencing elevated cognitive anxiety during the anxiety condition when compared to the control condition ($P < 0.05$). The difference between the control and anxiety conditions indicates that the use of both ego-threatening (independent assessor) and motivational (reward) instructional sets was sufficient to elicit the appropriate psychological response.

5.3.1.2 SOMATIC ANXIETY

No significant interactions were found for somatic anxiety ($P > 0.208$, $\eta^2 < 0.091$). There were also no significant main effects for either timing ($P = 0.611$, $\eta^2 = 0.016$) or expertise ($P = 0.506$, $\eta^2 = 0.026$). Once again, the failure to detect a difference between the pre- and post-test scores suggests that the intervention was effectively maintained throughout the entirety of the thirty trial data collection session. Importantly, there was a significant main effect for condition (P = 0.0001, $\eta^2 = 0.566$), with both the expert and novice participants experiencing elevated somatic anxiety during the anxiety condition when compared to the control condition ($P < 0.05$).

5.3.1.3 SELF CONFIDENCE

No significant interactions were found for self confidence (P > 0.102, η^2 < 0.150). There were also no significant main effects for either timing (P = 0.457, η^2 = 0.033) or expertise (P = 0.362, η^2 = 0.049). A significant main effect was found, however, for condition (P = 0.007, η^2 = 0.359), with both the expert and novice participants experiencing a reduction in self confidence during the anxiety condition when compared to the control condition (P < 0.05).

5.3.2 SHOOTING PERFORMANCE

The mean (± SD) shooting performance scores as a function of expertise and experimental condition are presented in Figure 41. The two-way ANOVA with condition as the within-individuals factor and expertise as the between-individuals factor revealed no significant condition * expertise interaction for shooting performance (P = 0.810, η^2 = 0.004). There was also no significant main effect for condition (P = 0.638, η^2 = 0.013). However, a significant main effect was found for expertise (P = 0.0001, η^2 = 0.671), with *post-hoc* tests revealing that the expert participants performed better than their novice counterparts during both the control and anxiety conditions (P < 0.0001).

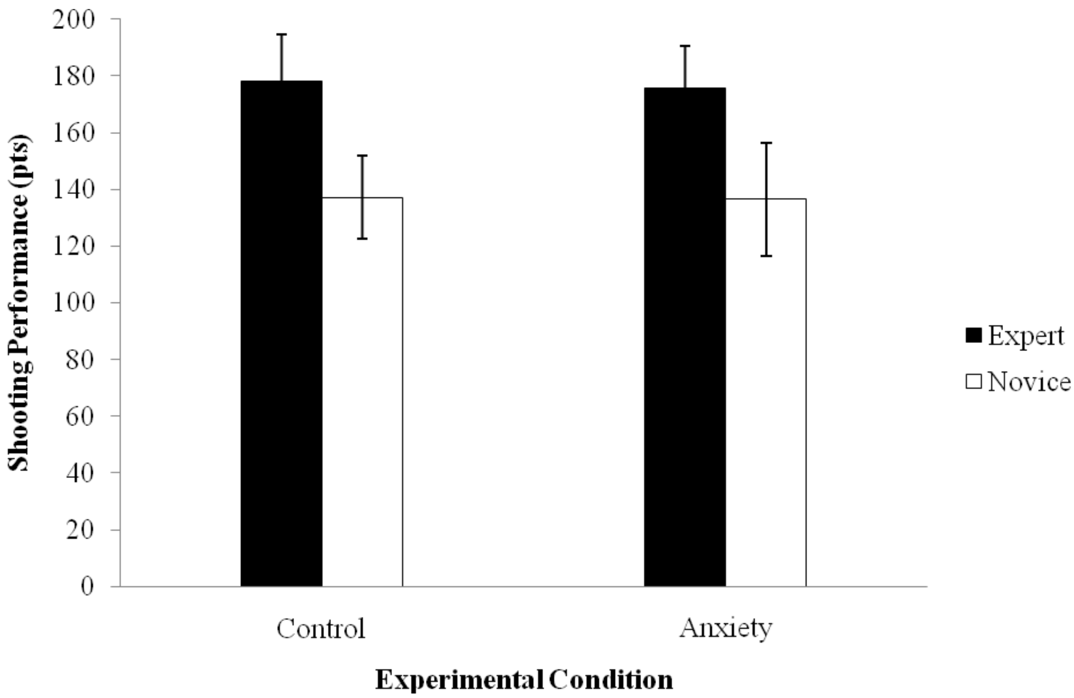

Figure 41. Mean (± SD) shooting performance scores as a function of expertise and experimental condition.

5.3.3 VARIABILITY OF BALL RELEASE PARAMETERS

5.3.3.1 HEIGHT OF RELEASE

The mean (± SD) variability of height of release is displayed in Figure 42. No expertise * experimental condition interaction was observed (P = 0.522, η^2 = 0.026). Neither were there significant main effects for experimental condition (P = 0.176, η^2 = 0.111) or expertise (P = 0.131, η^2 = 0.136).

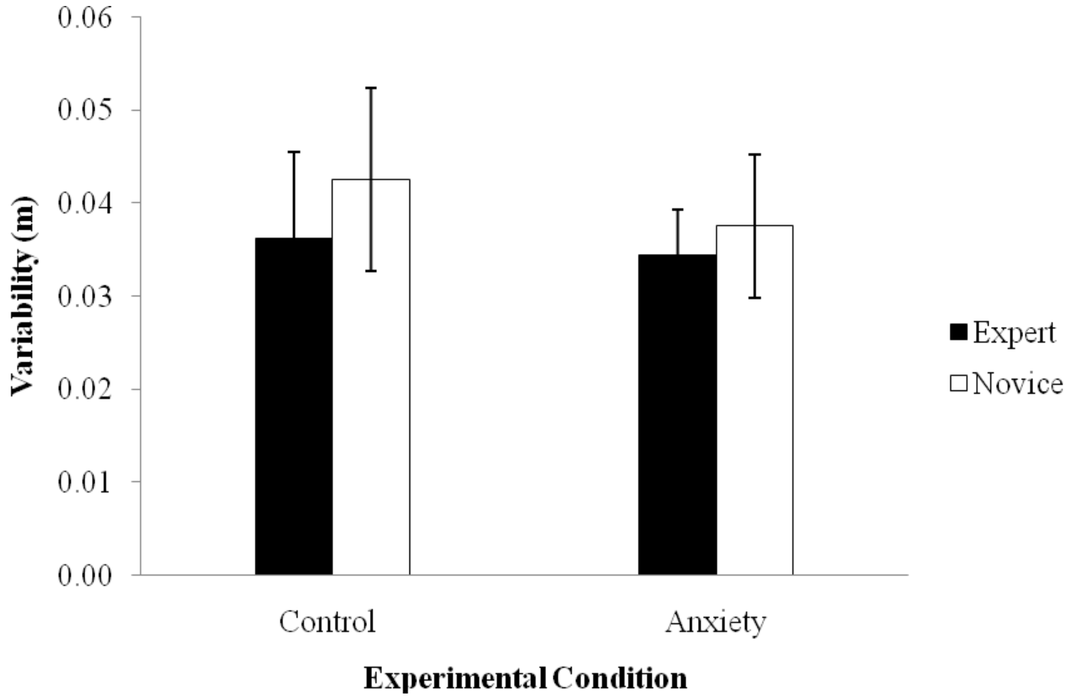

Figure 42. Mean (± SD) variability of height of release as a function of expertise and experimental condition.

5.3.3.2 SPEED OF RELEASE

The mean (± SD) variability of speed of release is displayed in Figure 43. There was no significant expertise * experimental condition interaction (P = 0.853; η^2 = 0.002) or main effect for experimental condition (P = 0.556; η^2 = 0.022). A significant main effect was evident for expertise (P = 0.001; η^2 = 0.479), with the expert participants demonstrating less variability in speed of release across both the control and anxiety condition (P < 0.05). This finding is exemplified by the (mean ± SD) 44.6 ± 1.0% increase in speed of release variability across the two conditions for the novices when compared to their expert counterparts.

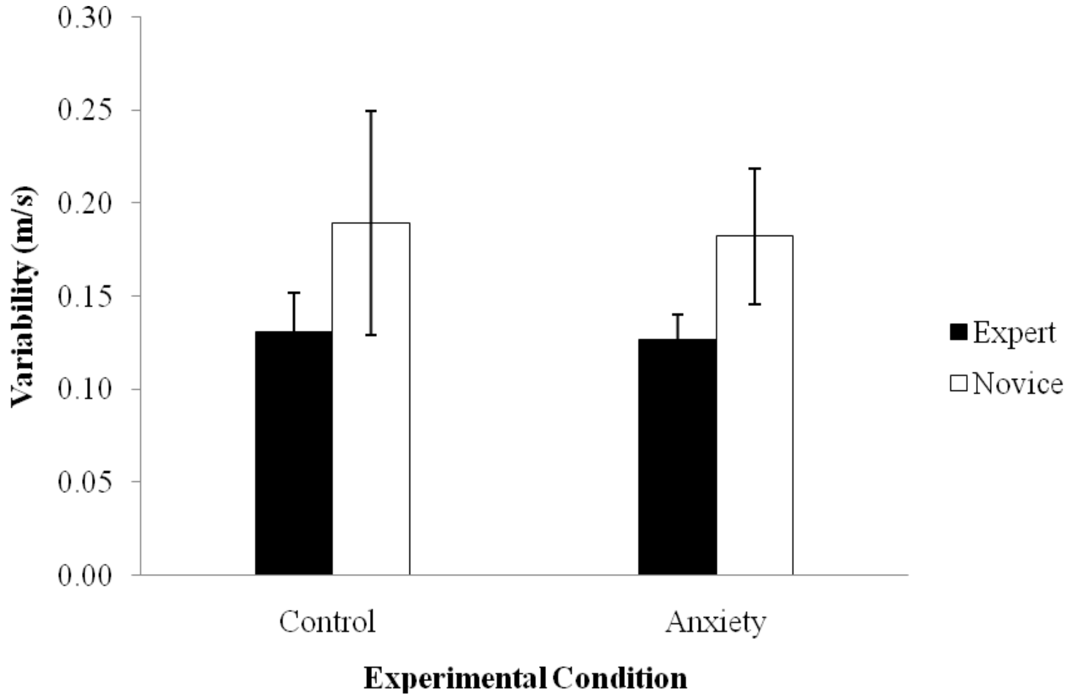

Figure 43. Mean (± SD) variability of speed of release as a function of expertise and experimental condition.

5.3.3.3 ANGLE OF RELEASE

The mean (± SD) variability of angle of release is displayed in Figure 44. No significant expertise * experimental condition interaction was found for angle of release (P = 0.473, η^2 = 0.033). There was also no significant main effect for condition (P = 0.354, η^2 = 0.054). There was, however, a main effect for expertise with the expert participants exhibiting significantly less variability than their novice counterparts for both conditions (P = 0.019, η^2 = 0.299). Specifically, in comparison to the expert participants, the variability of angle of release for the novices was, on average, 26.3% (± 6.4%) larger.

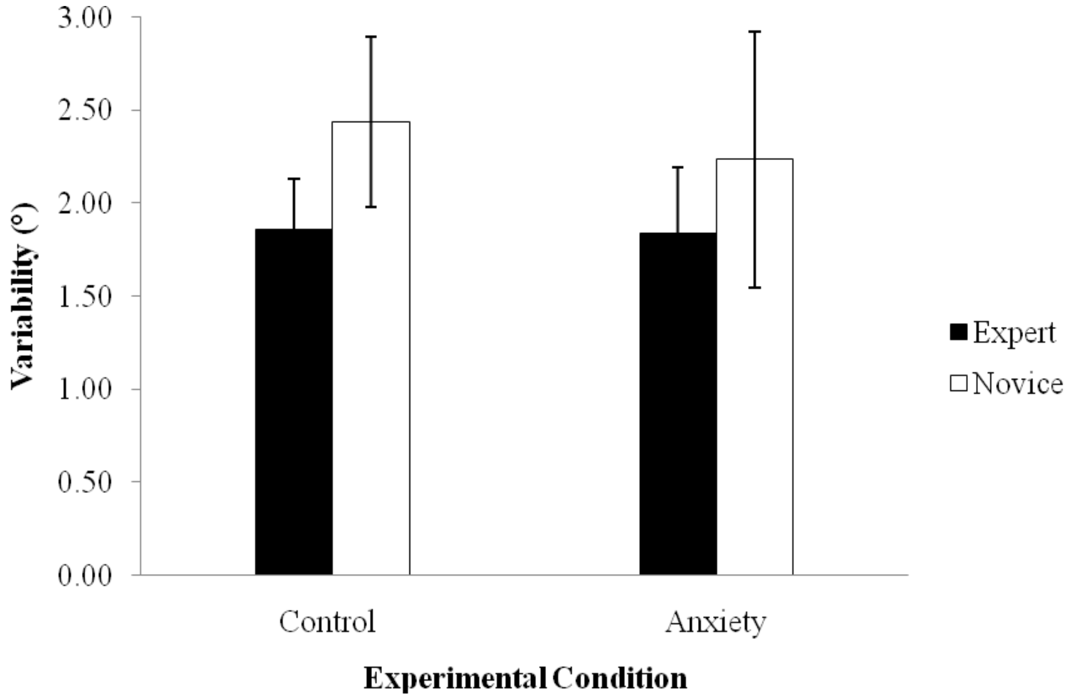

Figure 44. Mean (± SD) variability of angle of release as a function of expertise and experimental condition.

5.3.4 DISCRETE VARIABLES OF INTEREST

5.3.4.1 REACTION TIME

The two-way ANOVA revealed no significant condition * expertise interaction (P = 0.635, η^2 = 0.014). Furthermore, no significant main effect was found for expertise (P = 0.131, η^2 = 0.129). There was, however, a significant main effect for condition (P = 0.006, η^2 = 0.364). The lack of an interaction effect indicates that reaction time increased for both the expert and novice participants during the anxiety condition when compared to the control condition. This finding is supported in Figure 45, where mean reaction time increased from 472 ms (control) to 532 ms (anxiety) for the novice participants, with values of 426 ms (control) and 470 ms (anxiety) observed for the expert participants.

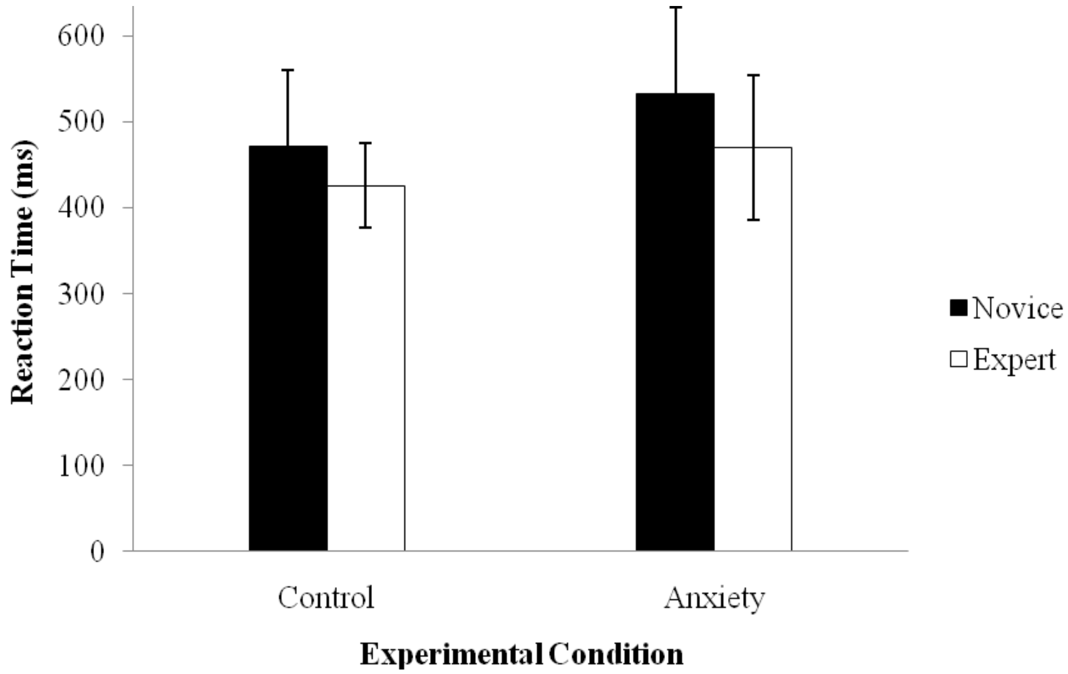

Figure 45. Mean (± SD) reaction time as a function of expertise and experimental condition.

5.3.4.2 JOINT RANGE OF MOVEMENT (ROM)

The mean (± SD) joint ROM as a function of expertise and experimental condition is presented in Table 10. The two-way ANOVA revealed no significant condition * expertise interactions for the ROM of any of the three joints of interest e.g. wrist, elbow and shoulder ($P > 0.534$, $\eta^2 < 0.023$). No significant main effect for condition was found for ROM of the wrist, elbow and shoulder ($P > 0.303$, $\eta^2 < 0.062$). There was, however, a significant main effect for expertise for both wrist and elbow ROM ($P < 0.002$, $\eta^2 > 0.441$). *Post-hoc* tests indicated that the expert participants exhibited greater ROMs at the wrist and elbow during both conditions ($P < 0.006$). Interestingly, no main effect for expertise was observed for the shoulder joint ($P = 0.185$, $\eta^2 > 0.101$). This failure to attain statistical significance could be a consequence of the large standard deviations, particularly for the novice participants. Specifically, standard deviations for shoulder joint ROM of 22.6° and 24.8° were found for the control and anxiety condition respectively.

Table 10. Mean (± SD) range of movement as a function of expertise and experimental condition.

	Novices		Experts	
Dependent Variable	Control	Anxiety	Control	Anxiety
Wrist RoM (°)	89 ± 17	87 ± 17	120 ± 15	119 ± 15
Elbow RoM (°)	83 ± 11	82 ± 12	102 ± 10	101 ± 14
Shoulder RoM (°)	88 ± 23	89 ± 25	100 ± 11	100 ±11

5.3.4.3 JOINT ANGLE VARIABILITY AT RELEASE

The mean (± SD) variability of joint angle at ball release as a function of expertise and experimental condition is displayed in Table 11. The two-way ANOVA revealed no significant condition * expertise interactions for the variability of any of the three joints at ball release ($P > 0.186$, $\eta^2 > 0.100$). There was also no significant main effect for condition for the variability of either of the wrist and elbow joints at ball release ($P > 0.091$, $\eta^2 > 0.159$). There was, however, a significant main effect for condition for shoulder joint variability at release ($P = 0.034$, $\eta^2 = 0.239$), with a decreased shoulder joint variability occurring for the anxiety condition. Importantly, this reduction occurred regardless of expertise. Finally, a significant main effect for expertise was found for wrist joint variability at ball release ($P = 0.001$, $\eta^2 = 0.499$), with the expert participants demonstrating greater variability during both the control and anxiety condition ($P < 0.005$). No significant main effect for expertise was attained for either the elbow or the shoulder joint ($P > 0.082$, $\eta^2 = 0.167$).

Table 11. Mean (± SD) variability of joint angle as a function of expertise and experimental condition.

Joint Angle at Ball Release	Novices		Experts	
	Control	Anxiety	Control	Anxiety
Wrist (°)	9.4 ± 1.8	8.7 ± 1.6	11.9 ± 1.8	11.2 ± 1.6
Elbow (°)	7.4 ± 1.2	7.9 ± 1.7	8.8 ± 1.1	9.0 ± 1.6
Shoulder (°)	4.2 ± 1.6	3.3 ± 1.3	3.4 ± 1.4	3.1 ± 1.2

5.3.5 COORDINATION VARIABILITY

The mean (± SD) values for measures of coordination variability as a function of both expertise and anxiety condition are presented in Table 12.

Table 12. Mean (± SD) coordination variability (NoRMS) as a function of both expertise and experimental condition.

Dependent Variable	Novices		Experts	
	Control	Anxiety	Control	Anxiety
Wrist-Elbow Coupling (°)	10.3 ± 4.0	9.7 ± 2.5	6.00 ± 2.5	5.8 ± 2.0
Elbow-Shoulder Coupling (°)	7.9 ± 3.0	7.0 ± 1.5	5.40 ± 2.4	4.9 ± 1.5
Wrist-Shoulder Coupling (°)	10.4 ± 4.2	8.9 ± 2.1	5.77 ± 1.6	5.9 ± 1.6

The two-way ANOVA revealed no significant condition * expertise interactions for the variability of any of the joint couplings of interest ($P > 0.102$, $\eta^2 < 0.149$). No significant main effects for condition were found either for the wrist-elbow, elbow-shoulder and wrist-shoulder joint couplings ($P > 0.138$, $\eta^2 < 0.125$). There was, however, a significant main effect for expertise for all three joint couplings ($P < 0.015$, $\eta^2 > 0.299$). The *post-hoc* tests revealed that, in comparison to the expert participants, the novice participants demonstrated greater variability at all three joint couplings regardless of condition ($P < 0.05$). Exemplar angle-angle plots are presented in Figures 46-49. It is clearly evident from the angle-angle plots that the expert performer is less variable than the novice performer throughout all phases of the movement.

Interestingly, the novice performer appears to be more variable at the beginning of the movement, with the magnitude of variability decreasing as the movement progresses (see Figures 48 and 49). Finally, rather than synchronous movements of the elbow and shoulder joints, the angle-angle plots for both expert and novice participants indicate relatively isolated joint movements whereby elbow extension follows shoulder extension.

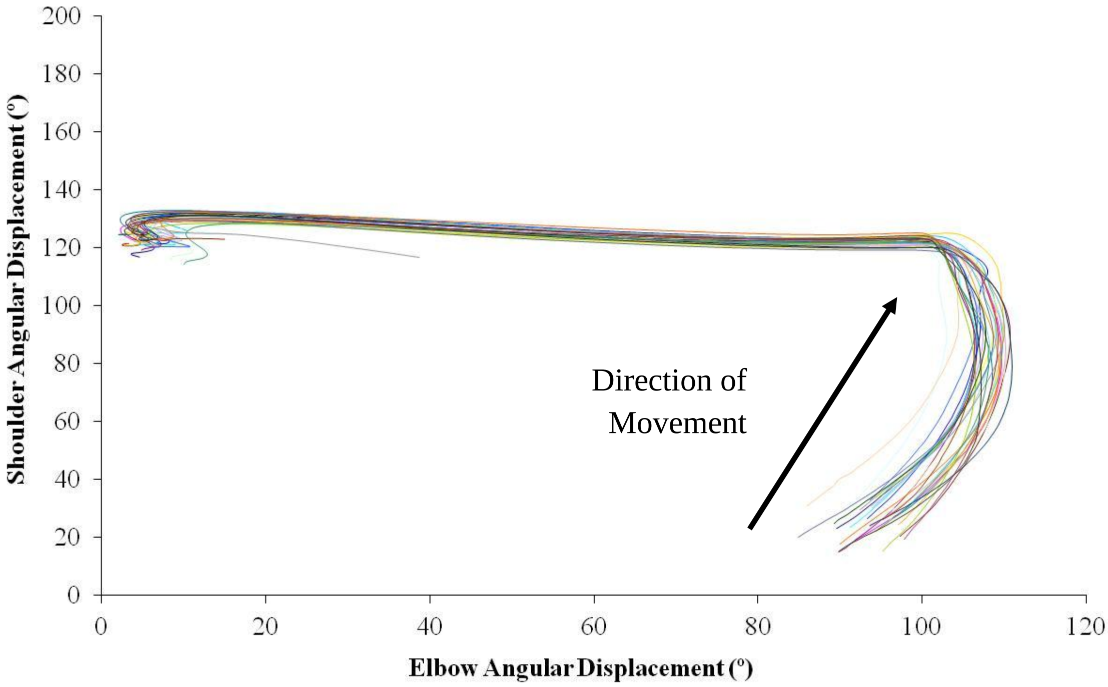

Figure 46. Angle-angle plot for an exemplar expert participant during the control condition.

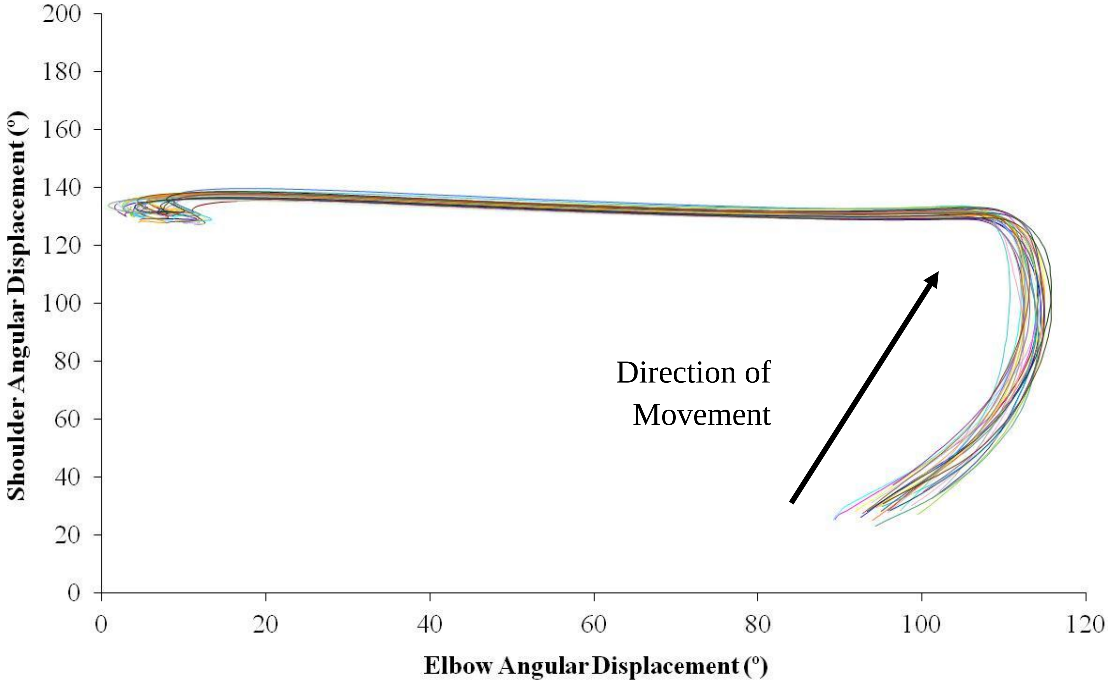

Figure 47. Angle-angle plot for an exemplar expert participant during the anxiety condition.

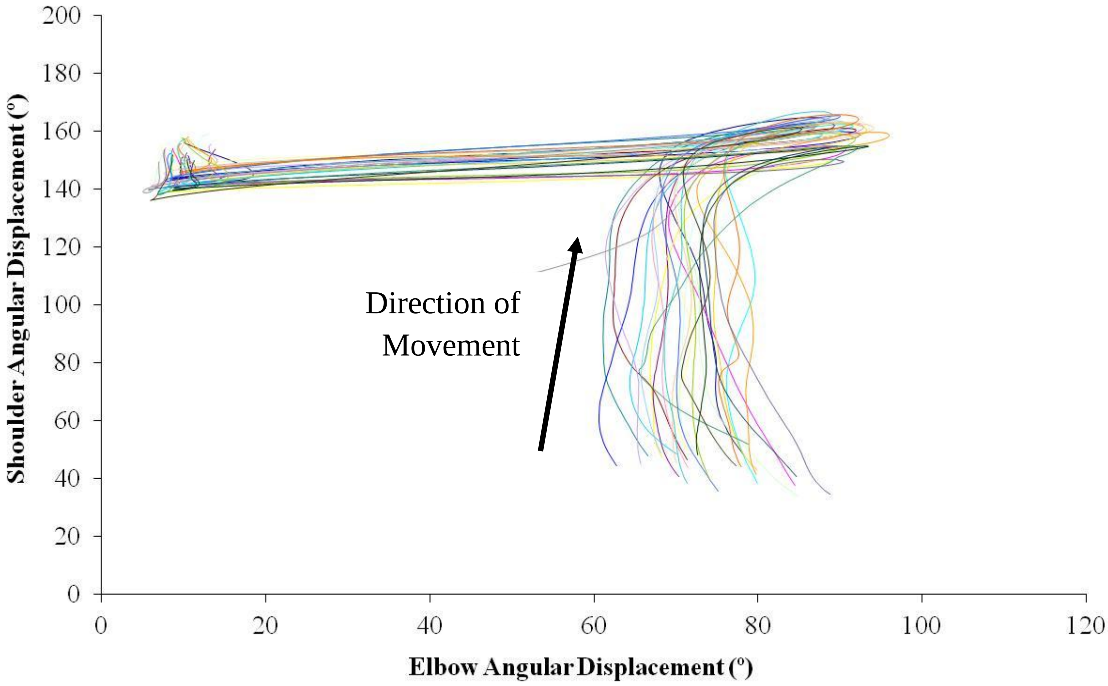

Figure 48. Angle-angle plot for an exemplar novice participant during the control condition.

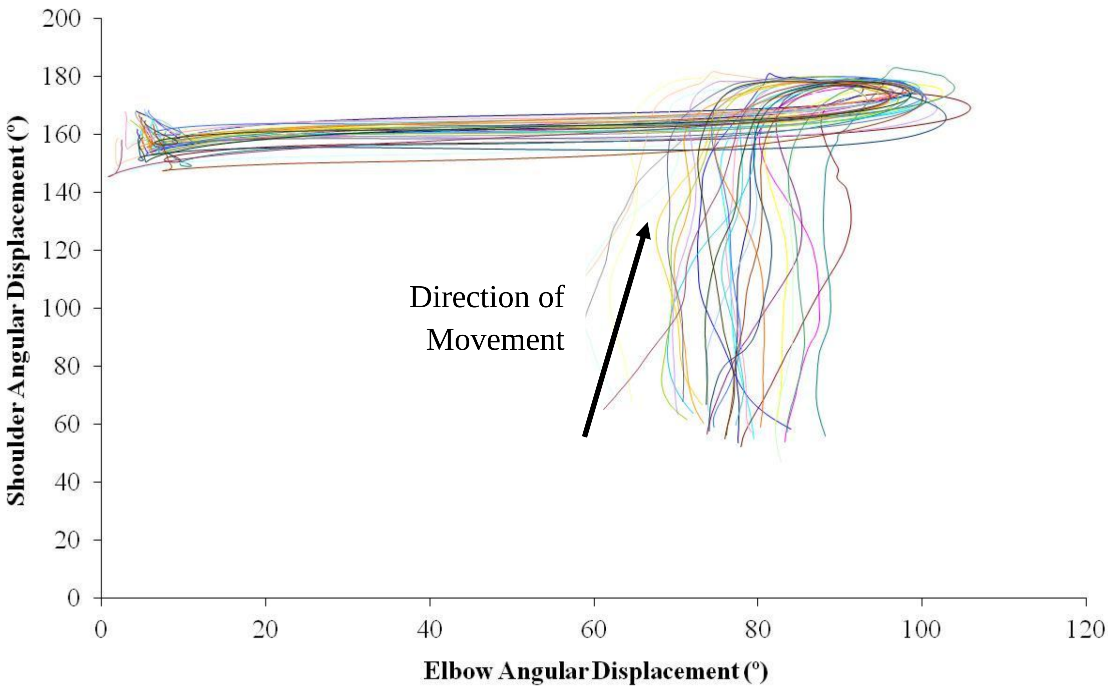

Figure 49. Angle-angle plot for an exemplar novice participant during the anxiety condition.

5.4 DISCUSSION

The study had two aims. The first aim was to examine whether successful outcomes and joint kinematics could be preserved under conditions of anxiety by participants investing additional attentional resources during performance of a discrete shooting task. The second aim sought to ascertain whether performance expertise plays a mediating role in the capacity to stabilise a discrete pattern of movement coordination against perturbation from emotional fluctuations. In agreement with the data presented in Section 3.3.1 and 4.3.1, experts performed significantly better than novices in both control and anxiety conditions. Furthermore, the experts also exhibited greater ranges of movement about the wrist and elbow joints. However, novices appeared to reduce (freeze) the involved number of degrees of freedom at the periphery, thereby decreasing motor system complexity and minimising the number of component parts involved in task goal accomplishment (see Newell and Vaillancourt, 2001). This finding is commensurate with the insights of Bernstein (1967) and existing literature suggesting that individuals release the biomechanical degrees of freedom with practice (Vereijken *et al.*, 1992; 1997; Anderson and Sidaway, 1994). For example, Anderson and Sidaway (1994) reported significant increases in hip and knee joint range of movement after twenty practice sessions of a soccer kicking task. This increased range of movement arguably enhances task performance by allowing learners to scale and refine kinematic solutions according to specific constraints on action.

The greater range of movement evident in experts was coupled with a smaller magnitude of coordination variability for all three joint couplings. This finding substantiates existing data from this programme of work and provides additional empirical support for characterising expertise as the development of stable movement patterns within the perceptual-motor workspace. Furthermore, the functional role of movement variability within expert participants is exemplified by the significant reduction in variability of both speed and angle of release when compared to their novice counterparts. Although there was no significant difference between experts and novices in the variability of elbow and shoulder joint angles at ball release, experts appeared to use inherent motor system variability functionally to preserve invariance in ball release parameters. This cooperative and synergistic interaction between joints along the kinematic chain provides additional credence to the notion of compensatory variability (see Kudo *et al.*, 2000; Muller and Sternad, 2004), and supports the data presented previously in Study 1 (Chapter 3) of the programme of work. Furthermore, experts demonstrated significantly more variability of wrist joint angle at ball release suggesting that human movement scientists should be cautious when drawing conclusions about performance based purely upon the *magnitude* of discrete movement variability scores. In opposition to the views of traditional cognitive psychology, the sentiment that the *magnitude* of movement variability dictates performance success therefore appears no longer tenable (see Glazier and Davids, 2009).

Interestingly, no significant differences for experimental condition were observed for either shooting performance or joint kinematics in the current study. The only exception was the reduction in variability of shoulder joint angle at ball release during the anxiety condition. A reduction in shoulder joint angle variability is interesting because it opposes the work of Beuter and colleagues (Beuter and Duda, 1985; Beuter *et al.*, 1989) who reported that the distal joints appeared to be more strongly influenced by elevated anxiety. Consequently, there is tentative evidence from the current study to suggest that, under these specific constraints on action, the proximal joints are more strongly influenced by elevated anxiety, not the distal joints. Although the stabilisation of task performance corroborates existing research from Murray and Janelle (2003; 2007), the lack of change in joint kinematics between control and anxiety conditions contrasts with previous work by both Higuchi *et al.* (2003) and Tanaka and Sekiya (2010). Specifically, these studies reported a decreased range of movement during a computer-simulated batting and golf-putting task respectively. This apparent disparity in research findings could be attributed to the severity of the anxiety intervention. The current study implemented ego-threatening (independent assessor) and motivational (financial incentive) instructional sets whereas Higuchi *et al.* (2003) elicited psychological stress by means of a mild electric stimulus after poor performance. However, this assertion is difficult to confirm because each study used a different inventory quantifying psychological stress. For instance, the current study used the Competitive State Anxiety Inventory-2, whereas, Higuchi and colleagues (2003) used the State Trait Anxiety Inventory-S.

Nonetheless, the stabilisation of task performance and basketball shooting kinematics could be explained by the significant main effect observed for reaction time. Furthermore, the lack of a significant interaction for reaction time by expertise indicates that this was a homogeneous response irrespective of task expertise. The increased reaction time during the anxiety condition signifies that additional attentional resources were allocated to the primary movement task, corroborating other research within the movement sciences literature (see Williams *et al.*, 2002; Murray and Janelle, 2003). For example, when using an auto racing simulation Murray and Janelle (2003) reported little change in driving performance from baseline to competition but significant differences in performance efficiency, denoted by changes in response time. In addition, Monno *et al.* (2000; 2002) found that focusing attention on the performance of a rhythmical bimanual coordination task increased probe reaction time but delayed the transition from anti-phase to in-phase coordination modes. Hence, allocation of additional attentional resources appeared to stabilise preferred patterns of coordination. From a dynamical systems perspective, it could be argued that the allocation of attention constitutes an important functional organismic constraint for stabilising both task performance and intrinsic dynamics. Moreover, these findings are consistent with the arguments of Court *et al.* (2005) who suggested that anxiety caused participants to invest additional effort to override the intrinsic dynamics of the human motor system. Specifically, Court and colleagues reported that both in-phase and anti-phase modes of a bimanual rhythmic coordination task became more stable under moderate anxiety. In other words, the allocation of attention was used to resist potential re-organisation of the perceptual-motor system. As such, it appears that the stabilisation of task performance through the investment of additional attentional resources is a robust phenomenon, one that can be generalised to both rhythmical and discrete actions.

A novel contribution to the literature was the observation that both experts and novices were able to invest additional attentional resources when anxious to stabilise performance against emotional fluctuations caused by financial incentives and social evaluation. This universal human response to performance perturbations countered previous suggestions that experts may be more capable of regulating emotional fluctuations than non-expert performers (Janelle, 2002). Based upon examination of electroencephalographic activity of expert and non-expert small-bore rifle shooters, Janelle *et al.* (2000) postulated that experts were better able to achieve an optimal state of relaxation, and that this capability may permit intervening effects of elevated anxiety to be attenuated. This intimation was predicated on the finding that experts exhibited greater asymmetry in alpha and beta power between the left and right hemispheres when compared to non-experts. However, no quantification of attentional demands was undertaken. Consequently, in light of the current findings, the assumption of expertise-related differences in response to emotional perturbations appears tenuous, if not, erroneous.

In summary, the findings of this study suggest that expert and novice performers were able to maintain performance and attenuate effects of anxiety by investing additional attentional resources to performance of a discrete action. There are, however, several limitations that warrant consideration. For instance, both the complexity of the task and the severity of the anxiety intervention may not have been sufficient to fully elicit any expertise differences in anxiety response. In addition, only the magnitude of cognitive anxiety, somatic anxiety and self-confidence were examined, and not whether the participants' viewed anxiety to be facilitative or debilitative. Therefore, further research is needed to clarify the role of organismic constraints and individual intrinsic dynamics on performance of multi-articular discrete and rhythmical movements. Specifically, research should investigate the interactive effects of task expertise, task complexity and severity of psychological stress on stabilisation of task performance and coordination dynamics. Furthermore, additional research is warranted into whether the capability to offset emotional perturbations is mediated by anxiety interpretation i.e. facilitative or debilitative.

CHAPTER VI

FOCUS OF ATTENTION AND DISCRETE ACTION PERFORMANCE: A PROCESS-ORIENTED APPROACH

6.1 INTRODUCTION

Learning is central to psychology and a fundamental concept for motor control theorists. Learning is defined as a relatively permanent change in behaviour and emerges as a direct consequence of practice or experience (Schmidt and Lee, 2005). A pertinent issue within motor skill learning is to determine the most appropriate informational support for optimising the acquisition of skill (McGinnis and Newell, 1982). Consequently, there has been a large body of research dedicated to elucidating the role of augmented feedback (e.g. Chiviacowsky and Wulf, 2007), verbal instruction (e.g. Wulf *et al.*, 2009) and visual demonstration (e.g. Ashford *et al.*, 2007) upon the acquisition and retention of skilled motor performance (for a review, see Wulf *et al.*, 2010). With regards to the role of augmented feedback, research has investigated two pivotal dimensions, frequency (Schmidt *et al.*, 1989; 1990; Winstein *et al.*, 1994; Weeks and Kordus, 1998; Wulf *et al.*, 1998b; Park *et al.*, 2000; Mononen *et al.*, 2003; Anderson *et al.*, 2005) and timing (Swinnen *et al.*, 1990; Liu and Wrisberg, 1997). Findings from the literature have typically revealed that participants given a high relative frequency of feedback, e.g. 100%, perform better during the acquisition phase than those who are afforded a low relative frequency of feedback, e.g. 50% or 33%. However, the opposite trend is commonly reported for learning during the retention phase, with the low frequency group outperforming their high frequency counterparts. These findings are exemplified by Anderson *et al.* (2005) who examined the effect of knowledge of results scheduling on performance and learning of a self-paced, blind aiming movement towards a target. Fifty-six participants were randomly assigned into two experimental groups: Delay-0 (feedback after each trial) and Delay-2 (feedback delayed over two trials), and were required to complete 160 trials. Retention tests were undertaken at 1 min and 24 h post-acquisition. It was reported that the Delay-0 group were significantly more accurate during the first and last blocks of the acquisition phase, but showed a greater performance decline from acquisition to retention.

Commensurate findings are also reported in relation to the timing of feedback (Swinnen *et al.*, 1990; Liu and Wrisberg, 1997). For instance, Liu and Wrisberg (1997) investigated the effect of knowledge of results (KR) delay on the acquisition and retention of a targeted throwing task. The task involved throwing a ball underarm with the non-preferred hand towards a target located at a distance of 3 m. Performance was assessed using 10 concentric target zones, with each zone assigned a particular numerical value, 10, 9, 8, 7 6 etc. Participants were randomly allocated into immediate KR and delayed-KR experimental groups. The immediate KR group were provided with instantaneous information about performance outcome and ball flight trajectory. Conversely, the delayed KR group were issued with knowledge of results 13 s after ball release. In comparison to the delayed KR group, the data revealed that throwing accuracy was significantly better during acquisition but significantly worse during retention for the immediate KR participants.

The potent effects of frequency and timing of feedback can be explained using the guidance hypothesis, originally proposed by Salmoni *et al.* (1984), who suggested that feedback possessed both positive and negative properties. Although there are many documented benefits associated to the provision of feedback, such as positive reinforcement, motivation and guidance properties (for a review, see Wulf and Shea, 2003), a high frequency of feedback is considered to promote maladaptive short-term corrections and information dependency. Specifically, participants adjust even small response errors that may be indicative of neuro-motor variability inherent within complex neurobiological systems. Moreover, individuals can become over-reliant on augmented feedback and bypass available sources of intrinsic feedback used to develop error detection and correction mechanisms. As a consequence, several techniques have been proposed which attempt to alleviate this issue of dependency, such as the fading technique (Winstein and Schmidt, 1990) and performance-based bandwidths (Sherwood *et al.*, 1988; Goodwin and Meeuwsen, 1995; Smith *et al.*, 1997). Furthermore, there is growing substantive evidence to support the use of self-controlled feedback, whereby the provision of feedback is contingent on 'participant needs' rather than an arbitrary, prescribed feedback schedule (see Chiviacowsky and Wulf, 2002; 2005).

It is clearly evident that the strategy associated with the provision of augmented feedback plays a fundamental role in facilitating the acquisition of skilled motor performance. Another factor that appears to have considerable influence is the participant's focus of attention. Two focuses of attention have been documented within the motor learning literature: internal and external, and are manipulated through the use of verbal instruction. Verbal instruction has been classically defined by Landin (1994) as concise phrases, or statements, that either direct a learner's attention to relevant task stimuli or prompt key movement pattern elements of a motor skill. Focuses of attention can be manipulated through the use of specific verbal cues, such as concentrate on the swinging motion of the arms *or* the pendulum-like motion of the golf club, thereby directing attention to either the action itself (internal focus) or the effects of the action (external focus) respectively (Wulf *et al.*, 1999).

This particular research theme developed from the pioneering insights of Singer (1988). Singer (1988) postulated that one way to help beginners learn new skills was to "distract them" from their own movements. Subsequently, Singer devised a psychological intervention referred to as the Five-Step Approach (see Table 13). The five steps included: (1) Readying, (2) Imaging, (3) Focusing, (4) Executing, (5) Evaluating. Within the execution phase, individuals were explicitly discouraged from "thinking about the act itself." This Five-Step Approach quickly gained empirical support (Singer *et al.*, 1989; 1993), with Singer and colleagues reporting that participants who were not consciously attending to the movement itself performed better during both acquisition and transfer. The efficacy of such attentional focus instructions has more recently received extensive appraisal by Wulf and co-workers (for a review, see Wulf, 2007a).

Table 13. Singer's (1988) Five-Step Approach.

Stage	Cues
Readying	Think positively as to performance expectations; attain an optimal attitudinal-emotional state; attempt to do things in preparation for performance that are associated with previous best performances; try to attain consistency as to preparatory mechanics.
Imaging	Briefly mentally picture performing the act - how it should be done, and how you can do it at your very best; visualise from the results of the act to its initiation; feel the movement.
Focusing	Concentrating intensely on one relevant feature of the situation, such as the seams of the tennis ball to be hit, think only of this cue, which will block out all other thoughts.
Executing	Do it when you feel you are ready; do not think of anything about the act itself.
Evaluating	If time permits, use the available feedback to learn from; assess the performance outcome and the effectiveness of each step in the routine; adjust any procedure next time, if needed.

The seminal study pertaining to the effect of focus of attention on motor skill learning was conducted by Wulf *et al.* (1998a). Specifically, thirty-three participants were randomly assigned into one of three groups: internal focus, external focus and control, and performed undulating movements on a ski-simulator. The internal and external focus groups were instructed to exert force on the outer foot and wheels respectively for the duration the platform moved in the respective direction. The control group did not receive any verbal cues. Participants completed eights trials on each of two successive days, with a retention test comprising six trials undertaken on day three. Performance was assessed by the amplitude and frequency of slalom movements. A significant main effect for group was observed with the external focus group demonstrating larger movement amplitude than the internal focus group. A comparable finding was also evident during the delayed retention test. Interestingly, the control group were also found to exhibit superior performance during the acquisition phase when compared to their internal-focus counterparts. Corroborating evidence was reported within a second experiment examining balance on a stabilometer. Participants were again assigned into either an internal or external focus group and instructed to focus on keeping their feet (internal) or strategically placed markers (external) at the same height. A total of seven 90 s trials were completed and performance was quantified using root mean square error. In agreement with the first experiment, the external focus group demonstrated better performance during the retention test, thereby indicating more effective motor learning.

Following the initial work by Wulf *et al.* (1998a), there has been much research proposing the beneficial effects of an external focus of attention. An external focus has been suggested to improve motor performance (Zachry *et al.*, 2005; Wulf *et al.*, 2007; Wulf, 2008; Wulf and Dufek, 2009), motor skill retention (Shea and Wulf, 1999; Wulf *et al.*, 1999; Wulf *et al.*, 2002; Wulf and Su, 2007; Chiviacowsky *et al.*, 2010), and motor skill transfer (Totsika and Wulf, 2003; Lohse, 2012). Moreover, adopting a distal external focus appears to be particularly favourable and more effective than a proximal external focus (Nevin *et al.*, 2003; McKay and Wulf, 2012). The focus research has also explored an extensive range of tasks, including isometric force productions tasks (Lohse, 2012), sporting e.g. long jump (Porter *et al.*, 2010) and swimming (Stoate and Wulf, 2011), and 'non-sporting' e.g. keyboard playing (Duke *et al.*, 2011) actions. Thus, external focus effects appear to be a robust phenomenon. Wulf and Su (2007) investigated how attentional focus effects manifest during complex discrete action performance. Specifically, participants, categorised as experts or beginners, were required to chip golf balls towards concentric targets located at a distance of 15 m. Participants were randomly assigned into a control, internal focus or external focus group. The internal focus group were directed towards the swinging motion of the arms whereas the external focus group focused on the pendulum-like motion of the club. Although no significant difference was observed during the acquisition phase, the external focus group demonstrated significantly higher accuracy scores during the retention test than either the control or internal focus groups. The lack of statistically significant findings during the acquisition phase may have been a consequence of the method used to quantify performance outcome. Target zones were used with incremental radii of 1.5, 2.5, 3.5 and 4.5 m. This approach arguably lacks sufficient measurement sensitivity and could mask important performance differences. Other measures, such as radial error, have been used within the literature (see Perkins-Ceccato *et al.*, 2003) and could have further differentiated task performance in relation to attentional focus instruction.

The benefits of an external focus of attention also pervade the clinical domain. For instance, increased postural stability has been observed for individuals with Parkinson's disease (Landers *et al.*, 2004; Wulf *et al.*, 2009), and after ankle sprain (Laufer *et al.*, 2007). Moreover, improvements in oral-motor performance (Freedman *et al.*, 2007) and functional reach in persons after cerebrovascular accident (Fasoli *et al.*, 2002) have also been reported, as well as enhanced motor learning in children with intellectual disabilities during a targeted throwing task (Chiviacowsky *et al.*, in press). This extension from a sporting to a rehabilitation perspective is exemplified by Wulf *et al.* (2009). Fourteen participants with idiopathic Parkinson's disease balanced on an inflated rubber disk under three counterbalanced attentional focus conditions: focus on reducing movements of the feet (internal), of the disk (external), or no attentional focus instruction (control). Postural sway was quantified using the root mean square error (RMSE) of the centre of pressure. A significant main effect for attentional focus was observed with a reduced RMSE evident during the external focus condition. No difference was found between the control and internal focus conditions.

The benefits associated with external focus of attention have been explained using the constrained action hypothesis (Wulf *et al.*, 2001b; McNevin *et al.*, 2003). The constrained action hypothesis superseded the common-coding principle which incorporated ideas from cognitive psychology to generate a theoretical framework for perception and action planning (Prinz, 1997). The common-coding principle argued that perceived events and planned actions share a common representational domain (see Figure 50). As such, compatibility between afferent and efferent information was suggested to enhance task goal accomplishment. In other words, individuals should direct attention towards the effects of their movements, such as a specific target, outcome or goal, because this permits a commensurate relationship with information derived from the sensory systems. Stated more simply, if the goal of the movement is to score a basket in basketball, then the performer should focus solely on achieving this objective.

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Figure 50. The common-coding principle (Prinz, 1997, pp. 130).

The constrained action hypothesis formed a logical extension to the common coding principle and advocates that an external focus of attention permits unconscious or automatic processes to control movement. An internal focus of attention, conversely, causes participants to consciously intervene in these control processes and inadvertently disrupt the coordination of reflexive and self-organising processes (McNevin *et al.*, 2003). This theoretical explanation is congruent with existing empirical data pertaining to focus dependent changes in postural control (McNevin and Wulf, 2002; Wulf *et al.*, 2003; Chiviacowsky *et al.*, 2010), attentional cost (Wulf *et al.*, 2001a), and movement economy (Vance *et al.*, 2004; Zachry *et al.*, 2005; Marchant *et al.*, 2009; Wulf *et al.*, 2010). For example, an external focus of attention has been shown to promote high frequency, low amplitude postural adjustments, indicative of enhanced postural control achieved through heightened reflexive mechanisms (see McNevin and Wulf, 2002). Greater automaticity of movement production has also been reported during a dynamic balance task. In particular, external focus participants exhibited reduced probe reaction times during a secondary task when compared to their internal focus counterparts (Wulf *et al.*, 2001a). Furthermore, a reduction in eletromyographic activity has been observed in both single degree of freedom (Vance *et al.*, 2004; Marchant *et al.*, 2009) and complex multi-articular actions (Zachry *et al.*, 2005; Wulf *et al.*, 2010) when adopting an external focus, suggesting enhanced neuromuscular coordination.

Despite the abundance of empirical support advocating the use of an external focus of attention, there are both theoretical and methodological issues that warrant attention. From a theoretical perspective, the constrained action hypothesis encapsulates ideas from both cognitive psychology (automaticity) and non-linear dynamical systems theory (self-organisation), which Davids (2007, pp. 286) argues are “uneasy theoretical companions to juxtapose”. An alternative explanation as to attentional focus effects can be derived from dynamical systems theory using the concepts of self-organisation, intrinsic pattern dynamics and constraints, a contention that has previously been alluded to within the human movement sciences (Davids, 2007; Wulf, 2007b; Peh *et al.*, 2010; Southard, 2011). Specifically, from a dynamical systems perspective instruction acts as a potent informational constraint, used to shape the emergence of goal-directed behaviour. It can be used to channel the learner’s search towards a functional, task-specific attractor within the perceptual-motor workspace (see Newell, 1991). Therefore, it is a prerogative of the coach to understand the role of instructional (informational) constraints in facilitating the assembly and refinement of optimal movement solutions. Furthermore, theoretically it could be argued that the benefits of an external focus of attention arise because it permits emergent processes to regulate task performance and learning inherently (Araújo *et al.*, 2004). In other words, an external focus allows individuals to harness inherent self-organisation processes in the movement system as they adapt to the confluence of constraints on action. Conversely, impaired task performance and retention, evident when adopting an internal focus, can be explained by individuals consciously overriding the inherent self-organising intrinsic pattern dynamics of the motor system.

From a methodological perspective, one of the challenges for experimentation on focus of attention is the exploration of potential internal focus benefits. The practical implications derived from the attentional focus research appear to signify that coaches should refrain from giving instructions relating to body movements, and instead, encourage participants to focus on the effects of their movements (see James, 2012). However, there is still a lack of clarity as to whether an external focus of attention is *universally* advantageous irrespective of task expertise. The basis for this argument is predicated on the stages of learning proposed by Newell (1985), i.e. coordination, control and skill. Newell (1985) postulated that the first problem encountered by learners was to assemble the appropriate topological dynamics - establishing basic relationships amongst component parts. This process is commonly referred to as 'soft assembly' (for a review, see Handford *et al.*, 1997). Once the appropriate inter-segmental coordination patterns emerge, individuals are then 'free' to scale and parameterise the movement based upon personal constraints (control stage). It is, therefore, feasible that an internal focus of attention, containing sufficient task-relevant information, can act as an instructional constraint, channelling the search during exploratory learning. This strategy is deemed particularly pertinent from a coaching perspective because Newell (1991) argued that exploratory learning can be a rather lengthy process and that the attractor located within the perceptual-motor workspace may not be the most conducive for optimising task performance. This hypothesis requires additional investigation because the existing programme of attentional focus research routinely uses rather vague internal focus statements, such as focus on the swinging motion of the arms (Wulf and Su, 2007), or on the 'snapping' motion of the wrist (Zachry *et al.*, 2005). Therefore, it is debateable whether such instruction provides sufficient task-specific guidance to instigate re-organisation of the perceptual-motor system, consequently inhibiting task performance and learning. This opinion is supported by James (2012) who argues that the focus of attention research has not utilised instructions relating to proper body movement, and that, importantly, the verbal instructions given must be offered in terms of specific optimisation criteria defined by the constraints of the task. In other words, task relevant information that guides the performer towards critical features of the skill need to be conveyed within internal focus instruction. These sentiments were supported by the empirical work conducted of James (2012) who found a significant increase in motor learning for the participants given body movement instructions when compared to those who received movement outcome instructions. However, the action of interest was a seated turning range of movement task so it is yet to be explored whether these findings translate to more complex, discrete sporting actions.

This challenge is further exacerbated by the distinct lack of research examining focus-dependent changes in movement kinematics (Zentgrag and Munzert, 2009; Lohse *et al.*, 2010; Southard, 2011), and the complete absence of research relating to coordination or coordination variability. This paucity of research is clearly evidenced by Gray (2011) who provided an excellent review of the attention literature, and identified the need to examine the role of attention on movement variability and changes in multi-joint coordination. In light of these limitations, Peh *et al.* (2011) argue that the over-emphasis on a product-oriented experimental approach has afforded an undue credibility to the efficacy of external focus instructions. As such, a more process-orientated approach examining the focus-dependent changes on movement kinematics is certainly warranted. This proposal complements previous calls for better integration of biomechanical data collection techniques with motor control theory (Buttfield *et al.*, 2009) and examination of movement kinematics and coordination changes with motor skill learning (Davids *et al.*, 2000).

From inspection of the research literature, there is very limited research that has thus far adopted a process-oriented experimental design and examined the impact of attentional focus instruction on movement kinematics (Zentgrag and Munzert, 2009; Lohse *et al.*, 2010, Southard, 2011). Zentgraf and Munzert (2009) investigated the effect of attentional-focus instructions on a two-ball juggling task. Participants were randomly assigned into internal, external or control groups. Bespoke instructions were provided to each group - focus on the balls (external), or focus on your hands (internal) - and all participants received the same generic instructional set and viewed an expert model demonstration. Participants completed 50 trials during the acquisition phase and 20 trials during the delayed retention test. Although juggling performance improved homogeneously across all three treatment groups, there were distinct differences between the internal and external groups in movement kinematics, particularly in relation to elbow displacement during ball tossing and the zenith of ball height. The authors suggested that task-relevant information was picked up independently of verbal instructions and that internal focus instructions may, indeed, act as a source of intervening information. However, the use of a model visual demonstration may act as a confounding variable as observational learning has been suggested to act as a rate enhancer for changes in movement kinematics (Horn *et al.*, 2007). This is particularly the case with actions such as juggling where there is strong compatibility between the outcome and the process used to achieve the outcome i.e. there is less opportunity for sensorimotor equivalence because successful performance requires a small number, or range, of kinematic solutions (see Hayes *et al.*, 2008). Therefore, it is important to identify how the provision of task-relevant information in the form of verbal instruction, and presented in the absence of a model demonstration, impacts upon emerging patterns of coordination, joint kinematics and movement variability.

More recently, Lohse and co-workers (2010) identified changes in performance, joint kinematics and electromyography during a dart throw. Participants were required to complete twenty-one dart throws under both internal and external focus conditions. The order of the conditions presented was counterbalanced across participants. Under an external focus, participants were found to perform better, as evidenced by reduced radial error scores, and exhibited decreased EMG activity in the triceps brachii. With regards to joint kinematics, interestingly, the only statistically significant difference reported was the increased variability of shoulder angular displacement during the extension phase when adopting an external focus of attention. This finding provides putative evidence that external focus instruction permits individuals to explore the available phase space for appropriate movement solutions. Conversely, the reduced variability apparent when adopting an internal focus suggests that the search is constrained or narrowed towards particular regions of the perceptual-motor workspace. Alternatively, it could be that the movement pattern is constrained by explicit monitoring of the action (Gray, 2011). However, these conclusions require further empirical study.

Southard (2011) examined the role of external and internal focus instruction on accuracy and limb coordination during a throwing task with the non-dominant arm. Intra-limb coordination was assessed by calculating the temporal lag between adjacent joints along the kinetic chain i.e. the time difference in peak velocity between proximal and distal joints. Comparable to past research, it was found that an external focus yielded better performance during practice when compared to an internal focus. In addition, an external focus resulted in a more frequent elbow lag than an internal focus, indicating a more effective use of the open kinetic chain and transfer of speed from the proximal to distal joints.

Despite the proposed hypothesis that attentional focus instruction may be expertise dependent, several studies, although restricted to examination of accuracy scores, have nonetheless reported mutually beneficial effects of external focus instructions for participants differing in expertise (Wulf *et al.*, 2002; Wulf and Su, 2007). In one such study, Wulf *et al.* (2002) investigated the effects of external-focus feedback on the acquisition and retention of a tennis serve. Novice and advanced volleyball players were recruited and all were given initial instructions about aspects of serving technique. Participants were then allocated into either internal or external groups and given group-specific feedback statements throughout acquisition (see Table 14). Performance outcome was assessed as well as movement quality (form), which represented a novel contribution to the literature. Form was quantified using eight technique criteria, such as does the participant adopt the correct stance, or, does the participant show a sufficient backswing with a high elbow?

Table 14. Focus-dependent feedback statements (Wulf *et al.*, 2002, pp. 174).

Internal-focus feedback
Toss the ball high enough in front of the hitting arm.
Snap our wrist while hitting the ball to produce a forward rotation of the ball.
Shortly before hitting the ball, shift your weight from the back leg to the front leg.
Arch your back and accelerate first the shoulder, then the upper arm, the lower arm, and finally your hand.

External-focus feedback
Toss the ball straight up.
Imagine holding a bowl in your hand and cupping the ball with it to produce a forward rotation of the ball.
Shortly before hitting the ball, shift your weight toward the target.
Hit the ball as if using a whip, like a horseman driving horses.

Consistent with previous data, accuracy scores were found to be significantly better during practice and retention when adopting an external focus. Moreover, this finding was apparent in both expertise groups. Interestingly, the external-focus feedback groups also demonstrated higher form scores than the internal-focus groups during practice. There was, however, no clear difference in form between the focus groups in retention. In fact, within this phase the novice-internal group exhibited a relatively large improvement with form scores approaching that of their novice-external counterparts. Ostensibly, these findings support the contention that external focus instructions encourage processes of self-organisation to inherently regulate the emergence of task-specific movement solutions (see Araújo *et al.*, 2004). However, only 50 practice trials were completed in total over a period of two weeks. Therefore, a more longitudinal practice intervention is required to identify how focus-dependent changes in movement kinematics, specifically coordination and coordination variability, manifest over time. This sentiment is supported by existing research that suggests a much larger practice period is required to instigate a change in coordination pattern during discrete multi-articular actions (McDonald *et al.*, 1989; Anderson and Sidaway, 1994).

There is a growing body of research findings that counter those presented by Wulf and colleagues. For example, Poolton *et al.* (2006) found no significant attentional focus effect during acquisition or retention following 300 trials of a golf putting task. Differences only became apparent with the introduction of a secondary task load, with the external focus group scores remaining robust. The contrasting findings between Poolton and co-workers and previous research (i.e. Wulf *et al.*, 1999; Wulf and Su, 2007) could be attributed to differences in practice duration, task complexity – chipping or putting – or the method used to quantify performance outcome. A second study published by Uehara *et al.* (2008) investigated the effects of focus of attention instructions on novices learning a soccer chip. In opposition to the findings of Wulf *et al.* (2002), Uehara and co-workers reported no significant differences in either outcome score or movement form. The authors suggested that instructions directing attention towards the movement itself or the effects of the movement were equally beneficial.

There is also another line of scientific enquiry that advocates the potential differential effect of attentional focus instructions (Beilock *et al.*, 2002; Perkins-Ceccato *et al.*, 2003; Gray, 2004; Ford *et al.*, 2005; Castaneda and Gray, 2007). One such study was conducted by Perkins-Ceccato *et al.* (2003) who examined the interactive effect of task expertise and attentional focus instruction on golf chipping performance. Participants were assigned into either high-skill or low-skill groups based on golfing handicap. Furthermore, each participant performed 10 shots towards each of four target locations under both focus conditions. A counterbalanced design was implemented to reduce intervening order effects. During the internal focus condition, participants were instructed to concentrate on the form of the golf swing whereas the external focus condition directed attention towards hitting the ball as close to the target as possible. With regards to average radial error scores, main effects for both skill and distance were observed, with *post-hoc* testing revealing greater errors for both low skilled golfers and as target distance increased. However, no significant main effect for focus condition was observed. Nonetheless, there were important differences evident from examination of the descriptive statistics for the low-skilled group that warrant consideration. During the internal focus condition, mean error scores of 226, 270, 402 and 446 cm were reported for each of the four target distances. This contrasts with errors of 273, 333, 475 and 522 cm respectively when adopting an external focus. Therefore, although failing to reach statistical significance there was tentative evidence to suggest that attentional focus effects may be expertise dependent. This corroborates data pertaining to variable error scores from the same study whereby the low-skilled group were significantly more consistent after internal-focus instruction.

Commensurate findings also emerge when examining research utilising a skill-focused versus divided-focus experimental approach (Beilock *et al.*, 2002; Gray, 2004; Ford *et al.*, 2005; Castaneda and Gray, 2007). Moreover, findings from this programme of work suggest that skilled participants perform better during dual-task conditions, whereas a skill-focused strategy may be more conducive for novice performers. This sentiment is encapsulated by Castaneda and Gray (2007, pp. 60) who argued that:

"...the optimal focus of attention for highly skilled (baseball) batters is one that permits attention to the perceptual effect of the action, whereas the optimal focus of attention

for less-skilled batters is one that allows attention to the step-by-step execution of the swing."

As a result, the present study emerged because of the apparent discrepancies in attentional focus findings in relation to task expertise and the inherent gaps within the attentional focus literature. The latter include limited practice duration, provision of insufficient task-relevant internal focus instruction, and lack of data pertaining to focus dependent changes in movement kinematics. Therefore, the study had two aims. The first was to examine the interactive effects of practice and focus of attention on both performance and learning of a discrete multi-articular action. The second was to identify potential focus-dependent changes on the emergence of the basketball shooting action through examination of joint kinematics, intra-limb coordination and coordination variability.

6.2 METHODS

6.2.1 PARTICIPANTS

Fifteen male participants with a mean (± SD) age, height and mass of 22.13 (± 4.39) years, 1.80 (± 0.07) m and 71.80 (± 7.18) kg respectively provided written voluntary informed consent to participate in the study. Each participant completed a health screening questionnaire (see Appendix 2) and all procedures were risk assessed (see Appendix 21) and approved by the local institutional ethics committee (see Appendix 22). Stringent inclusion criteria were again used to ensure random stratified samples, something which is rarely used, and quantitatively verified within attentional focus research (see Davids, 2007). Each participant was categorised as novice in accordance with the procedures outlined in Section 3.2.1.

6.2.2 PROCEDURES

After the initial performance pre-test participants were randomly assigned into one of three mutually exclusive experimental groups: internal-external, external-external or control. The rationale for the cross-over design within the internal-external group was to explore whether the benefits of attentional focus instruction may be contingent upon the stage of learning. For those learners at the coordination stage of learning, it was hypothesised that an internal focus would initially channel the learners' search towards appropriate topological dynamics, whereas switching to an external focus later in practice would permit parameterisation of the movement based upon individual personal constraints (see Newell, 1985; 1991). Each participant within both the internal-external and external-external groups performed a total of 840 practice trials of a basketball free-throw from a regulation distance of 4.25 m. The 840 practice trials were divided into twelve equal sessions of 70 free-throws. The 70 practice trials were undertaken in seven blocks of 10 trials with adequate rest permitted between blocks to minimise confounding fatigue effects. Moreover, two sessions were completed in each week with the total practice duration therefore spanning a six week period (see Table 15). The control group did not undertake any basketball free-throw practice throughout the intervention.

Table 15. Practice and data collection schedule.

Week	Phase
1	Performance Pre-Test (1)
2	Practice Session 1 & 2
3	Practice Session 3 & 4
4	Practice Session 5 & 6
5	Acquisition Test (2)
6	Practice Session 7 & 8
7	Practice Session 9 & 10
8	Practice Session 11 & 12
9	Acquisition Test (3)
10	Retention Test

During each of the first six practice sessions (i.e. Weeks 2-4 inclusive), the internal-external group were provided with task-relevant information. Specifically, participants were instructed to focus on: extending the shoulder, extending the shooting arm completely at the elbow, and flexing the wrist and fingers forward and down (see Wissel, 2004). These are common coaching points within the sport of basketball and are suggested to facilitate two critical features of basketball shooting technique, a high height of release and imparting spin onto the basketball to permit greater control. A high height of release is considered advantageous because a smaller speed of release is required (minimum speed principle), allowing greater control of the basketball, and is also a contributory factor towards a steeper angle of entry into the basket, affording a larger margin for error (see Miller and Bartlett, 1996). During the final six remaining practice sessions (Weeks 6-8 inclusive), the internal-external group were given an external focus of attention, and instructed to concentrate solely on the basketball ring and achieving a successful outcome. The external-external group, conversely, were instructed to focus on the basketball ring and scoring a successful shot during all 12 practice sessions.

To ensure adherence to the instructional cues, attentional focus instructions were reiterated at the beginning of each block and after every fifth trial (see Uehara *et al.*, 2008; Southard, 2011). Standardising the timing of focus instructions was deemed particularly important in light of the reported interactive effect of feedback frequency and focus direction (Wulf *et al.*, 2002). For instance, Wulf *et al.* (2002) reported that a reduced frequency of feedback was more effective for the internal-focus group, whereas feedback frequency had no significant impact when adopting an external focus. No visual demonstrations were provided throughout the intervention because demonstrations have been shown to be an effective rate enhancer for emerging patterns of coordination (Al-Abood *et al.*, 2001a; Horn *et al.*, 2007).

Changes in performance outcome and movement kinematics were assessed at four specific times during the practice intervention, specifically, during Weeks 1 (Pre-test), 5 (denoted as ‘1’ in Section 6.3), 9 (denoted as ‘2’ in Section 6.3) and 10 (Retention). A delayed retention test was used one week post-acquisition to ascertain the relative permanence of changes in goal-directed behaviour. Within each of these four testing sessions, participants were required to complete thirty free-throws towards a portable, regulation basketball ring elevated to a height of 3.05 m and located at a distance of 4.25 m. No attentional focus instruction was provided. Before data collection, participants completed five habituation trials. Basketball shooting performance and kinematic data were collected using the procedures previously outlined in Sections 3.2.1 and 3.2.2 respectively.

6.2.3 DATA ANALYSIS

Retro-reflective marker reconstruction and generation of three-dimensional joint coordinate system angles for the wrist, elbow and shoulder joints and ball release parameters were achieved using the same processes outlined in Section 3.2.3. The dependent variables of interest included the following: shooting performance score, variability of ball release parameters, joint range of movement of the wrist, elbow and shoulder, wrist, elbow and shoulder angle at the instant of ball release, variability of wrist, elbow and shoulder joint angle at ball release, intra-limb coordination captured by relative motion (angle-angle) plots, and coordination variability of the shooting arm, quantified using the normalised root mean squared difference technique (NoRMS) proposed by Sidaway *et al.* (1995b). Coordination variability was calculated for the following joint couplings: wrist flexion and elbow extension, elbow extension and shoulder extension, and wrist flexion and shoulder extension.

6.2.4 STATISTICAL ANALYSIS

Each dependent variable was subjected to a 3 (focus) * 4 (practice) analysis of variance with attentional focus as the between-individuals factor and practice as the within-individuals factor. An alpha level of 0.05 was selected. Following a statistically significant difference, *post-hoc* pairwise comparisons were conducted using a Bonferroni correction. All assumptions underpinning use of parametric tests were tested for and verified. As per Section 3.2.4, normality, homogeneity of variance and sphericity were again tested using an Anderson-Darling test, Levene's test and Mauchly's test of sphericity respectively. Inferential statistics were also supplemented with measures of effect size (η^2) to quantify the meaningfulness of the differences.

6.2.5 NULL HYPOTHESES

H_{01} There will be no significant effect of focus of attention on basketball shooting performance score.

H_{02} There will be no significant effect of focus of attention on movement kinematics.

H_{03} There will be no significant effect of practice on basketball shooting performance score.

H_{04} There will be no significant effect of practice on movement kinematics.

6.3 RESULTS

6.3.1 SHOOTING PERFORMANCE

The changes in mean (± SD) shooting performance with respect to practice and attentional focus are presented in Figure 51. The two-way ANOVA revealed a significant practice * focus interaction for shooting performance score (P = 0.001, η^2 = 0.509). Furthermore, there was also a significant main effect for practice (P = 0.001, η^2 = 0.419). *Post-hoc* tests identified significant differences between the control group and external-external group for acquisition 1 (P = 0.05), and between the control group and internal-external group for the acquisition 2 (P = 0.04). Moreover, significant differences were noted between the pre-test and acquisition 2 as well as between the acquisition 1 and acquisition 2 for the internal-internal group (P < 0.02). In addition, statistical differences were found between the pre-test and acquisition 1 for the external-external group (P = 0.05). No other significant differences were observed for any of the other planned comparisons (P > 0.09).

The focus-dependent changes in shooting performance are further supported by the descriptive statistics. For instance, percentage increases of 6% and 18% were observed for the internal-external group when comparing the pre-test score to the first and second acquisition test respectively. Moreover, a 10% decrease was apparent between second acquisition and retention. In contrast, the external-external group demonstrated percentage increases of 27% and 24% respectively for the same two comparisons, and a percentage decrease of only 3% from acquisition 2 to retention. Finally, the lack of a statistical difference between the groups at the pre-test provides empirical support for the homogeneous nature of the participant sample.

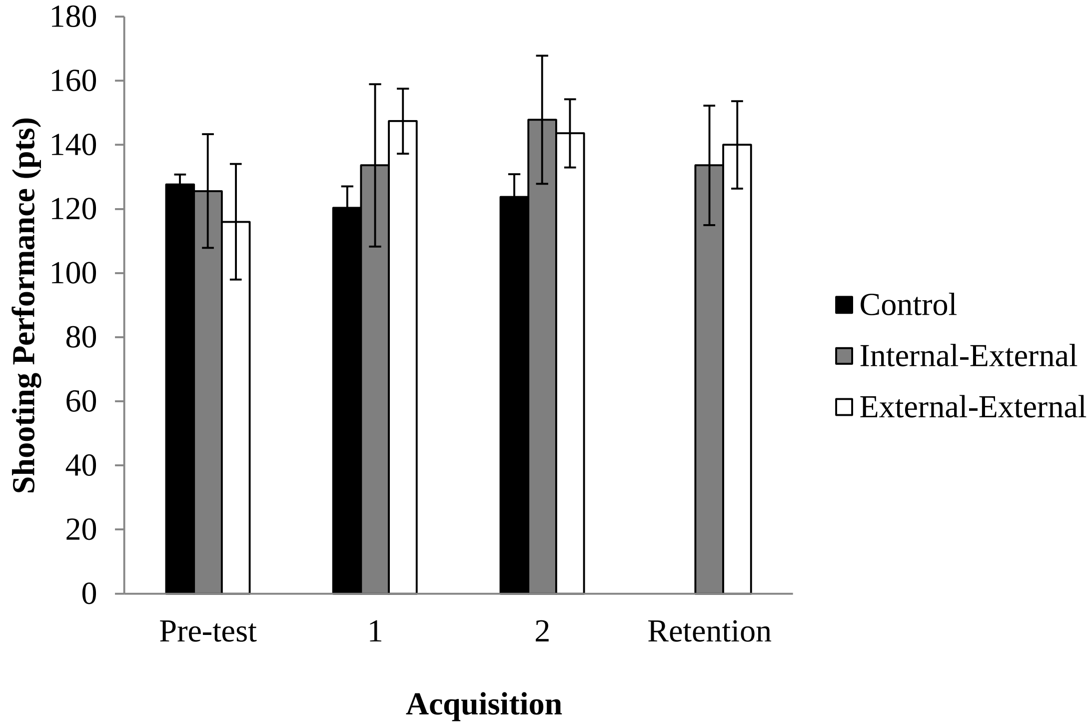

Figure 51. Mean (± SD) shooting performance scores as a function of practice and attentional focus.

6.3.2 VARIABILITY OF BALL RELEASE PARAMETERS

6.3.2.1 HEIGHT OF RELEASE

The changes in mean (± SD) variability of height of release as a function of practice and attentional focus are presented in Figure 52. There was no significant practice * group interaction for the variability of height of release (P = 0.667; η^2 = 0.091). There were also no significant main effects for either practice (P = 0.293; η^2 = 0.097) or group (P = 0.293; η^2 = 0.185).

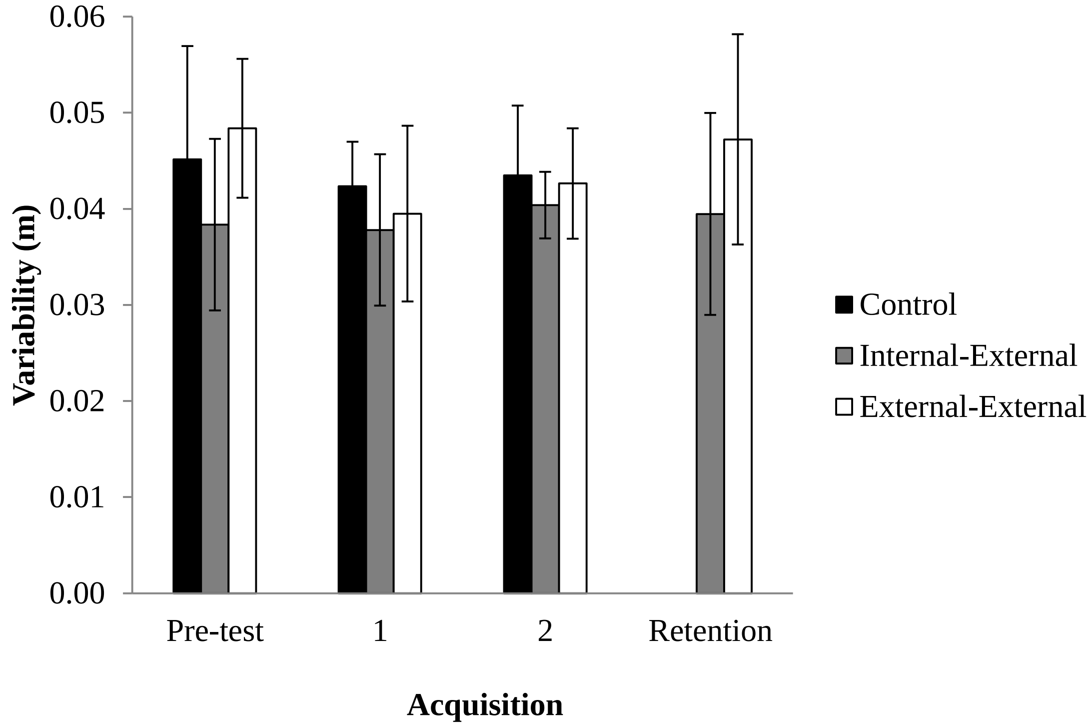

Figure 52. Mean (± SD) variability of height of release as a function of practice and attentional focus.

6.3.2.2 SPEED OF RELEASE

The mean (± SD) variability of speed of release is presented in Figure 53. There was no significant practice * group interaction (P = 0.114, η^2 = 0.258) or main effect for group (P = 0.272, η^2 = 0.195). There was a significant main effect for practice (P = 0.002, η^2 = 0.398). *Post-hoc* pairwise comparisons revealed that the variability of speed of release for the internal-external group between the pre-test and first acquisition session marginally missed the required level of statistical significance (P = 0.062). Furthermore, no other comparisons were statistically significant (P > 0.100).

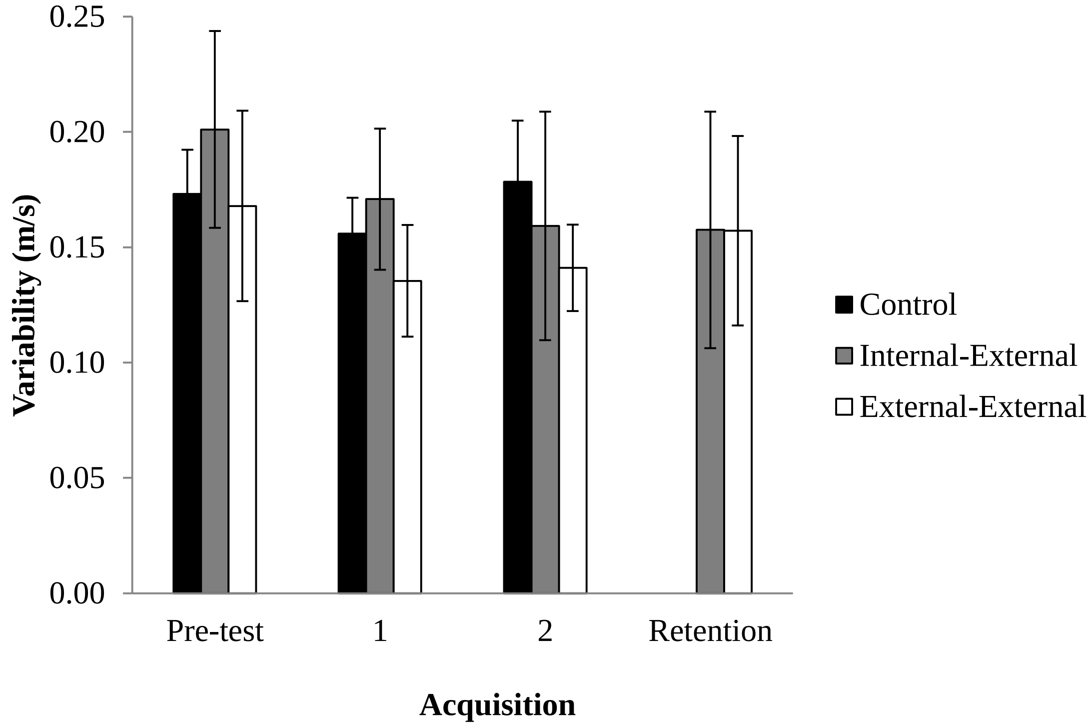

Figure 53. Mean (± SD) variability of speed of release as a function of practice and attentional focus.

6.3.2.3 ANGLE OF RELEASE

The mean (± SD) variability of angle of release is presented in Figure 54. No significant practice * group interaction was found for variability of angle of release (P = 0.310, η^2 = 0.175). There was also no significant main effect for group (P = 0.737, η^2 = 0.050). There was, however, a significant main effect for practice (P = 0.021, η^2 = 0.277), with the internal-external group displaying decreased variability in angle of release from the performance pre-test to acquisition 2 (P = 0.014). No other pairwise comparisons attained statistical significance.

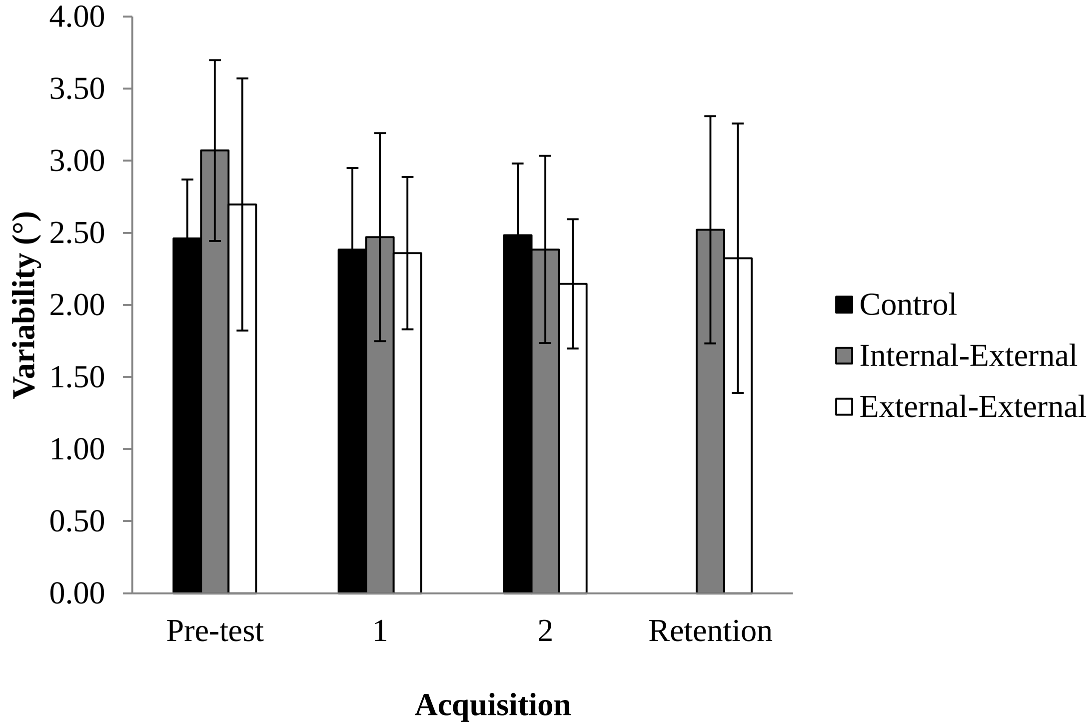

Figure 54. Mean (± SD) variability of angle of release as a function of practice and attentional focus.

6.3.3 JOINT RANGE OF MOVEMENT (ROM)

The mean (± SD) values for ROM of the wrist, elbow and shoulder as a function of practice and attentional focus are presented in Table 16. There were no significant practice * focus interactions for the ROM of any of the joints of interest e.g. wrist, elbow and shoulder ($P > 0.466$, $\eta^2 < 0.133$). Furthermore, there were no significant main effects for either practice ($P > 0.086$, $\eta^2 < 0.185$) or focus ($P > 0.339$, $\eta^2 < 0.165$). Despite the lack of statistical significance there was a 29% increase in shoulder ROM from the pre-test to retention for the internal-external group. This is in contrast to the external-external group who exhibited a 7% increase. The failure to attain statistical significance for this specific variable of interest could be due, in part, to the large within group standard deviations. For instance, the within-group variability for the internal-external and external-external groups was > 14° and > 23° respectively, thereby limiting statistical power. In addition, effect sizes ranging from 0.102 – 0.185, although representative of a small but meaningful effect, suggest that statistical significance may have been attained with additional participants.

Table 16. Mean (± SD) values for ROM of wrist, elbow and shoulder motion as a function of practice and attentional focus.

		Joint Range of Motion (°)		
Focus Group	Practice	Wrist	Elbow	Shoulder
Control	Pre-test	83 ± 29	72 ± 19	84 ± 24
	1	77 ± 25	72 ± 17	85 ± 20
	2	80 ± 26	75 ± 14	89 ± 18
Internal-External	Pre-test	103 ± 22	88 ± 12	83 ± 31
	1	97 ± 18	85 ± 17	104 ± 18
	2	99 ± 18	89 ± 14	102 ± 16
	Retention	109 ± 21	87 ± 17	107 ± 14
External-External	Pre-test	101 ± 23	87 ± 14	86 ± 23
	1	95 ± 32	82 ± 16	85 ± 30
	2	97 ± 29	83 ± 16	88 ± 39
	Retention	100 ± 29	82 ± 18	92 ± 37

6.3.4.1 JOINT ANGLE AT RELEASE

The mean (± SD) values for joint angle at release of the wrist, elbow and shoulder as a function of practice and attentional focus are presented in Table 17. The two-way ANOVA revealed no significant practice * focus interactions for wrist, elbow and shoulder angle at ball release (P > 0.235, η^2 < 0.2). Furthermore, there were no significant main effects for either practice (P > 0.072, η^2 < 0.197) or focus (P > 0.451, η^2 < 0.124). However, commensurate with the data for ROM, the effect size values indicate a small but meaningful effect, particularly evident for elbow and shoulder angle at ball release as a function of practice (η^2 values of 0.197 and 0.172 respectively). The lack of statistical significance could again be a consequence of the small sample size coupled with large standard deviation values e.g. 100.5 ° ± 24.2 ° for shoulder angle at ball release for the internal-external during the performance pre-test.

Table 17. Mean (± SD) values for joint angle at release for the wrist, elbow and shoulder as a function of practice and attentional focus.

		Joint Angle at Release (°)		
Focus Group	Practice	Wrist	Elbow	Shoulder
Control	Pre-test	-48.8 ± 9.3	54.8 ± 16.3	116.3 ± 13.5
	1	-52.4 ± 10.5	57.2 ± 15.6	119.7 ± 17.9
	2	-50.0 ± 12.6	56.0 ± 18.5	112.6 ± 14.1
Internal-External	Pre-test	-56.5 ± 5.3	53.6 ± 5.2	100.5 ± 24.2
	1	-55.1± 5.4	58.2 ± 5.0	111.6 ± 17.9
	2	-56.8 ± 4.8	54.4 ± 4.4	105.4 ± 11.9
	Retention	-52.1 ± 7.4	58.3 ± 4.0	106.9 ± 13.5
External-External	Pre-test	-53.3 ± 6.2	56.8 ± 9.9	101.6 ± 14.6
	1	-51.1 ± 4.3	58.6 ± 10.3	102.7 ± 22.9
	2	-54.0 ± 5.8	59.6 ± 7.7	105.1 ± 17.8
	Retention	-32.0 ± 5.9	71.3 ± 7.9	110.1 ± 19.9

6.3.4.2 JOINT ANGLE VARIABILITY AT RELEASE

The mean (± SD) values for joint angle variability of the wrist, elbow and shoulder at ball release as a function of practice and attentional focus are presented in Table 18. No significant practice * focus interactions were observed for wrist, elbow and shoulder joint variability at ball release ($P > 0.209$, $\eta^2 < 0.21$). Moreover, no significant main effects for either practice ($P > 0.127$, $\eta^2 < 0.158$) or focus ($P > 0.087$, $\eta^2 < 0.332$) were apparent for all three joints of interest.

Table 18. Mean (± SD) values for joint angle variability at release for the wrist, elbow and shoulder as a function of practice and attentional focus.

		Joint Angle Variability at Release (°)		
Focus Group	Practice	Wrist	Elbow	Shoulder
Control	Pre-test	11.8 ± 5.3	7.3 ± 2.1	2.9 ± 0.5
	1	9.4 ± 1.9	7.0 ± 2.3	3.3 ± 2.2
	2	10.4 ± 1.7	7.8 ± 2.0	3.5 ± 2.0
Internal-External	Pre-test	10.0 ± 2.1	8.8 ± 0.8	4.7 ± 0.9
	1	9.6 ± 1.5	8.2 ± 1.0	4.0 ± 1.4
	2	8.9 ± 1.2	8.3 ± 2.5	3.9 ± 1.7
	Retention	9.8 ± 2.2	8.5 ± 2.4	4.3 ± 1.6
External-External	Pre-test	10.1 ± 2.2	9.3 ± 2.0	6.1 ± 1.7
	1	8.8± 1.6	11.0 ± 4.6	5.3 ± 2.2
	2	8.6 ± 1.4	7.9 ± 1.2	5.0 ± 2.1
	Retention	10.0 ± 2.1	8.5 ± 1.8	5.4 ± 2.3

6.3.5 COORDINATION VARIABILITY

The mean (± SD) normalised root mean squared difference values for the wrist-elbow, elbow-shoulder and wrist-shoulder joint couplings as a function of practice and attentional focus are presented in Table 19. No significant practice * focus interactions ($P > 0.203$, $\eta^2 < 0.212$) or main effects ($P > 0.126$, $\eta^2 < 0.181$) were found for either the wrist-elbow or wrist-shoulder joint couplings. However, a significant practice * focus interaction was found for the elbow-shoulder joint coupling ($P = 0.023$, $\eta^2 = 0.364$). Furthermore, significant main effects for both practice ($P = 0.019$, $\eta^2 = 0.281$) and focus ($P = 0.05$, $\eta^2 = 0.348$) were also observed for the elbow-shoulder joint coupling. *Post-hoc* tests revealed that, in comparison to the external-external group, the internal-external group demonstrated reduced coordination variability for the elbow-shoulder joint coupling during acquisition 2 and retention tests ($P < 0.04$). Moreover, the internal-external group exhibited a decrease in coordination variability for all three joint-couplings with practice. Specifically, differences were found between the pre-test and acquisition 2 and retention ($P < 0.04$).

Table 19. Mean (± SD) joint-coupling variability (NoRMS) as a function of practice and attentional focus.

Focus Group	Practice	Coordination Variability (°)		
		Wrist-Elbow Coupling	Elbow-Shoulder Coupling	Wrist-Shoulder Coupling
Control	Pre-test	10.7 ± 1.2	7.7 ± 1.2	10.5 ± 3.1
	1	11.6 ± 2.3	8.3 ± 1.2	10.8 ± 2.2
	2	10.4 ± 1.7	7.4 ± 0.3	9.8 ± 1.7
Internal-External	Pre-test	10.1 ± 2.2	9.3 ± 3.0	10.0 ± 2.9
	1	9.1 ± 4.0	6.3 ± 1.8	8.4 ± 3.0
	2	7.4 ± 2.3	4.8 ± 0.3	6.9 ± 1.6
	Retention	7.5 ± 1.8	5.3 ± 0.3	7.1 ± 1.0
External-External	Pre-test	11.0 ± 3.2	9.55 ± 3.7	9.74 ± 2.7
	1	10.6 ± 3.7	8.14 ± 0.9	9.12 ± 1.9
	2	11.0 ± 1.9	9.11 ± 1.5	9.81 ± 1.7
	Retention	8.6 ± 2.4	6.45 ± 1.7	7.79 ± 2.1

Angle-angle plots for one exemplar participant from the control, external-external and internal-external groups are presented in Figures 55-65. From visual inspection of the figures, two important differences are evident. The first is in relation to the emerging patterns of intra-limb coordination. The second relates to the change in coordination variability. From examination of Figures 55-57, there is no discernible change in either the pattern of intra-limb coordination or the magnitude of coordination variability under control conditions. All three figures demonstrate a similar pattern of motion, where essentially, relatively isolated movements occur of the shoulder and elbow joint, coupled with a consistent amount of coordination variability across data collection sessions. A similar finding is also evident for the external-external group (see Figures 58-61). There is very little, if any, noticeable change in the profile of intra-limb coordination with practice, and the magnitude of variability is again homogeneous from pre-test to retention. There is, however, a distinct change in the pattern of intra-limb coordination for the participant within the internal-external group. Specifically, during the pre-test, movement principally occurred from the elbow and there was very restricted movement from the shoulder. Yet, during acquisition 1 there was a marked increase in shoulder range of motion that is maintained throughout acquisition 2 and retention. In addition, there is a noticeable decrease in coordination variability, particularly from acquisition 1 to acquisition 2, which is indicated by the tighter clustering of lines on the angle-angle diagram (see Figures 63-64).

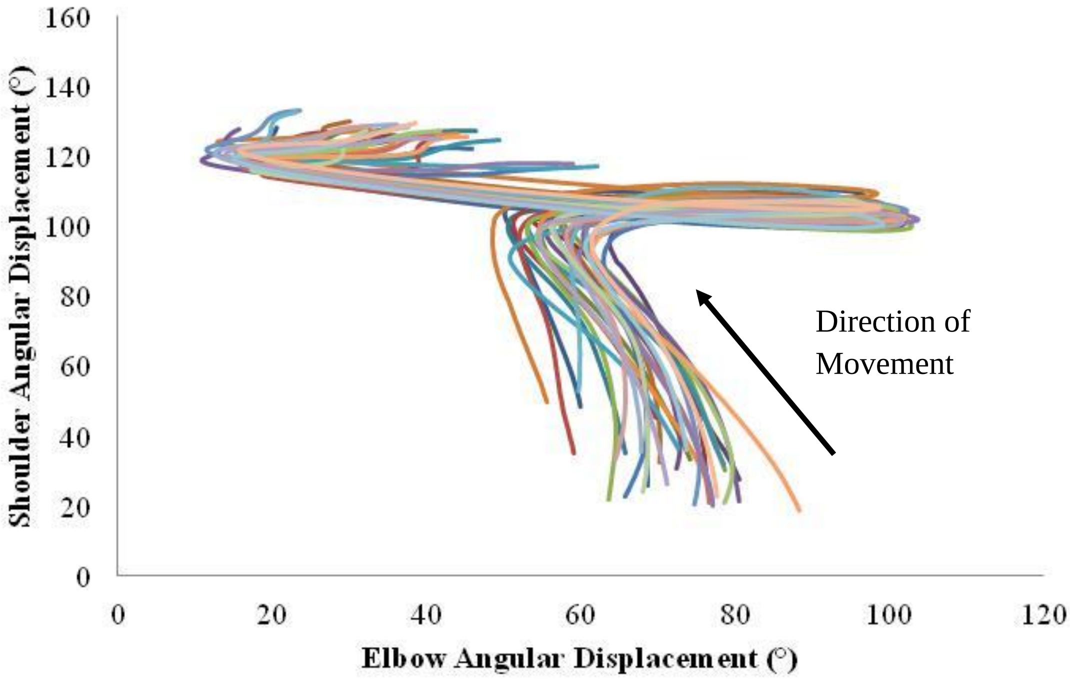

Figure 55. Angle-angle plot for an exemplar control participant during the pre-test.

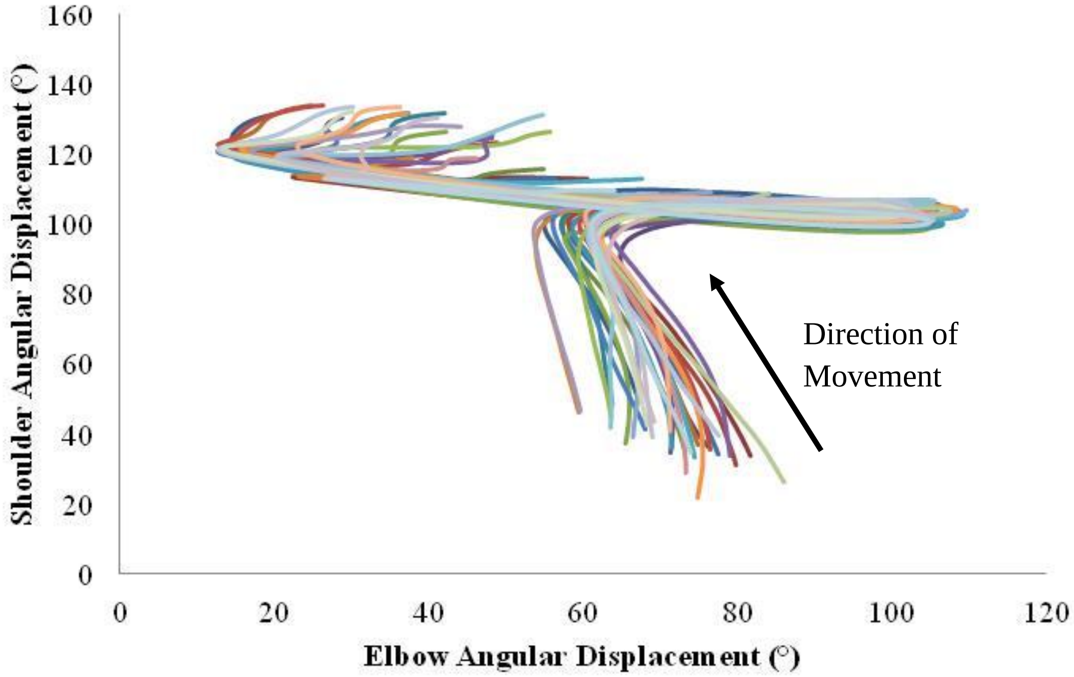

Figure 56. Angle-angle plot for an exemplar control participant during acquisition 1.

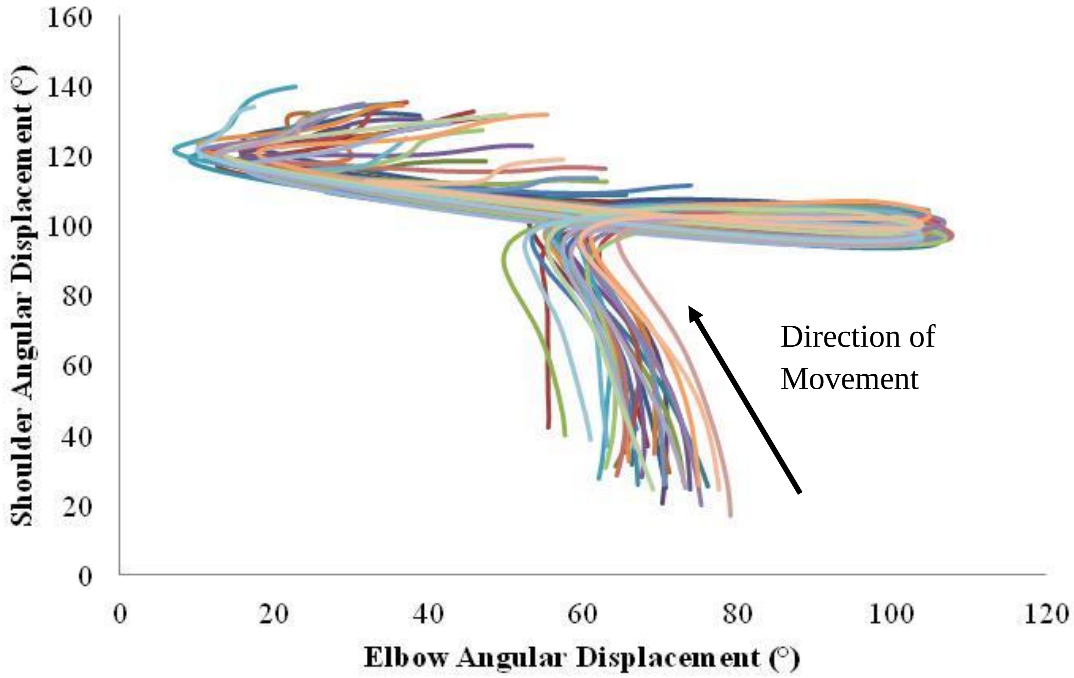

Figure 57. Angle-angle plot for an exemplar control participant during acquisition 2.

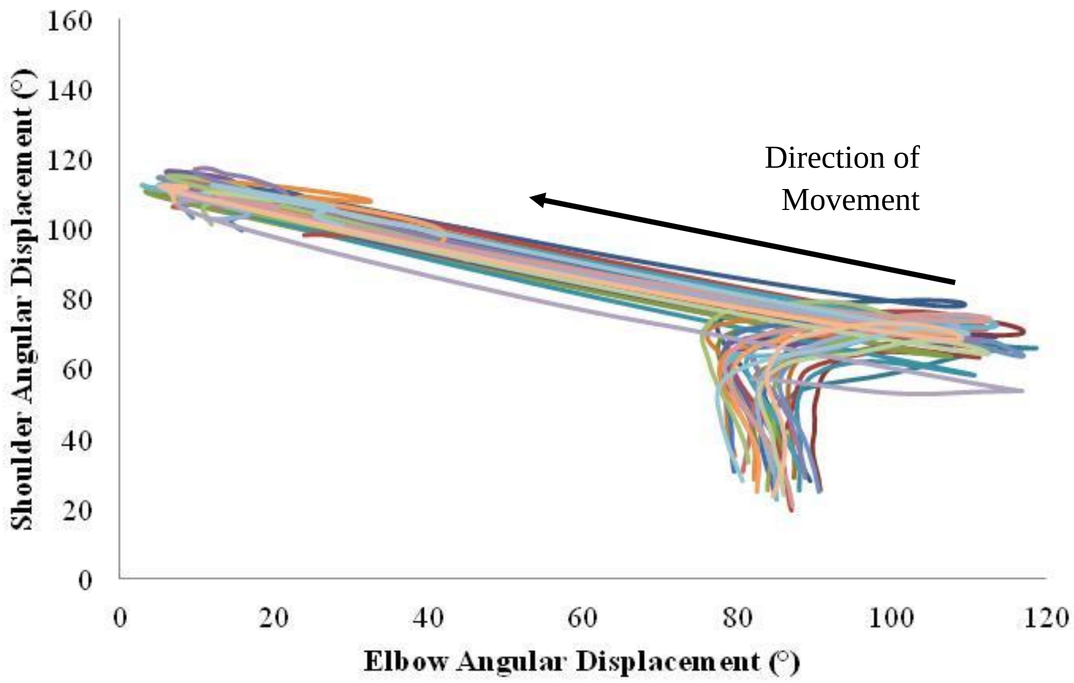

Figure 58. Angle-angle plot for an exemplar external-external participant during the pre-test.

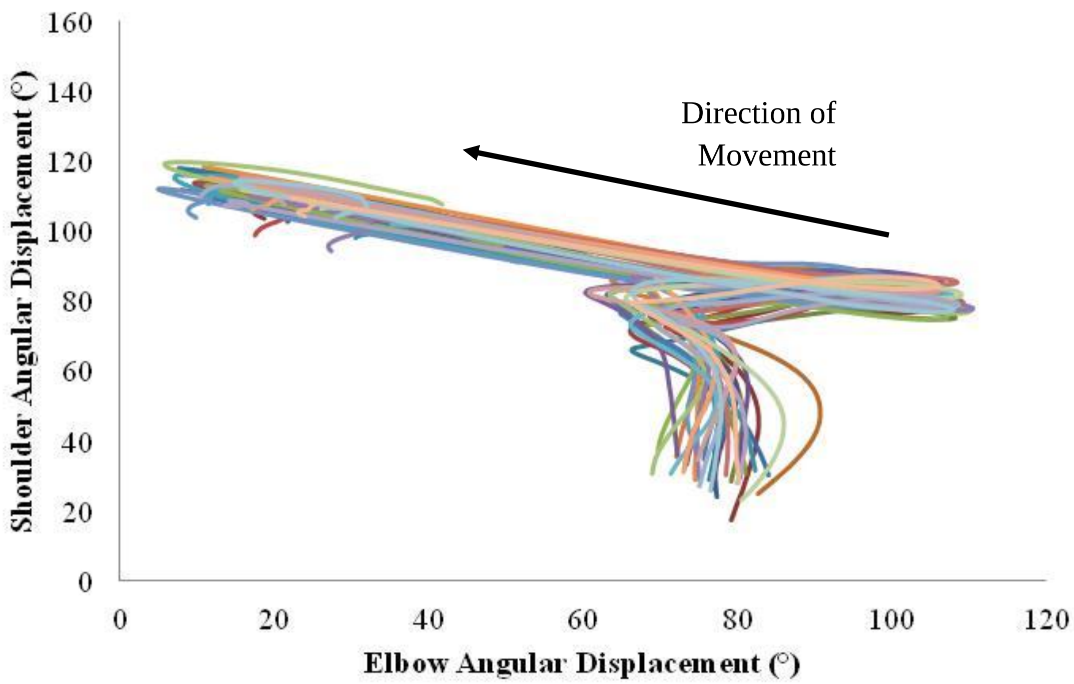

Figure 59. Angle-angle plot for an exemplar external-external participant during acquisition 1.

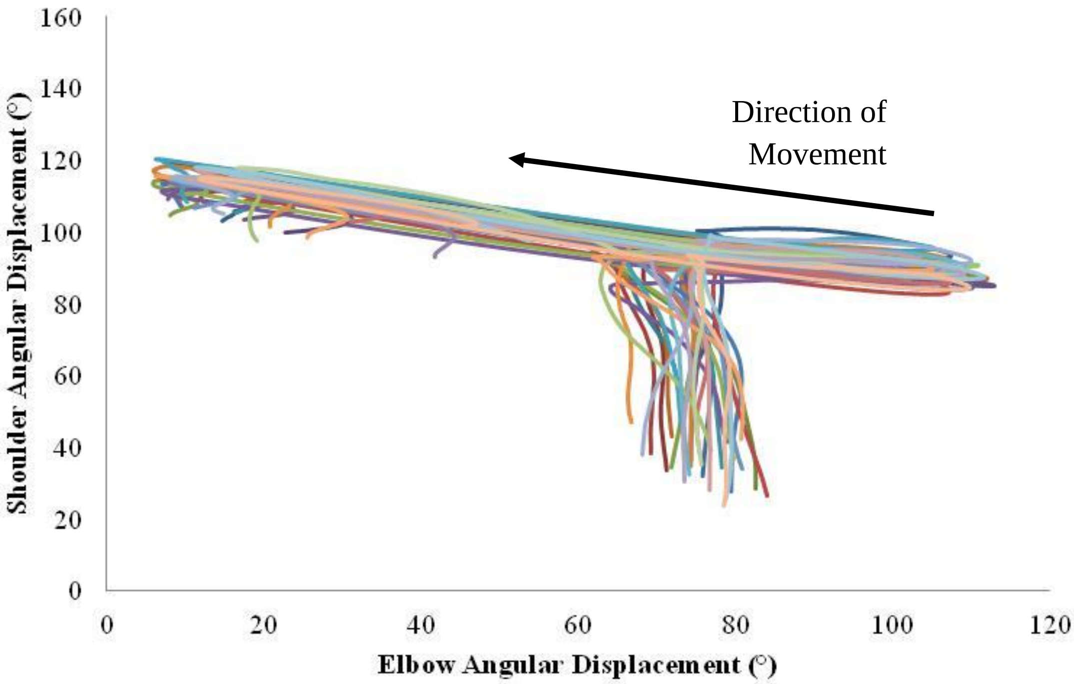

Figure 60. Angle-angle plot for an exemplar external-external participant during acquisition 2.

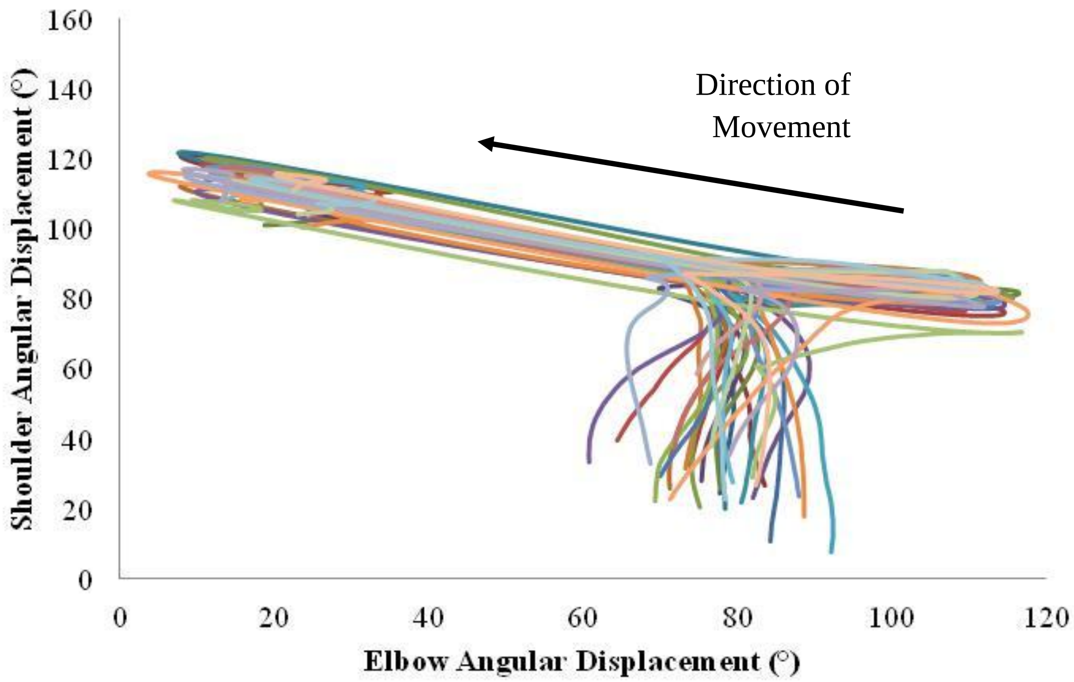

Figure 61. Angle-angle plot for an exemplar external-external participant during retention.

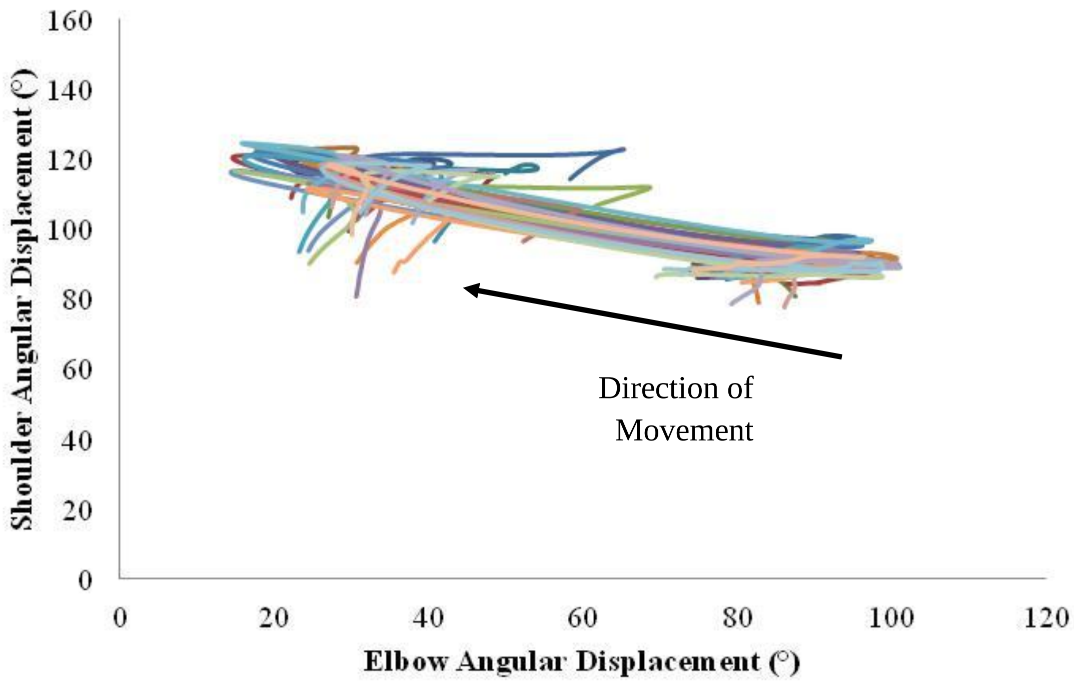

Figure 62. Angle-angle plot for an exemplar internal-external participant during the pre-test.

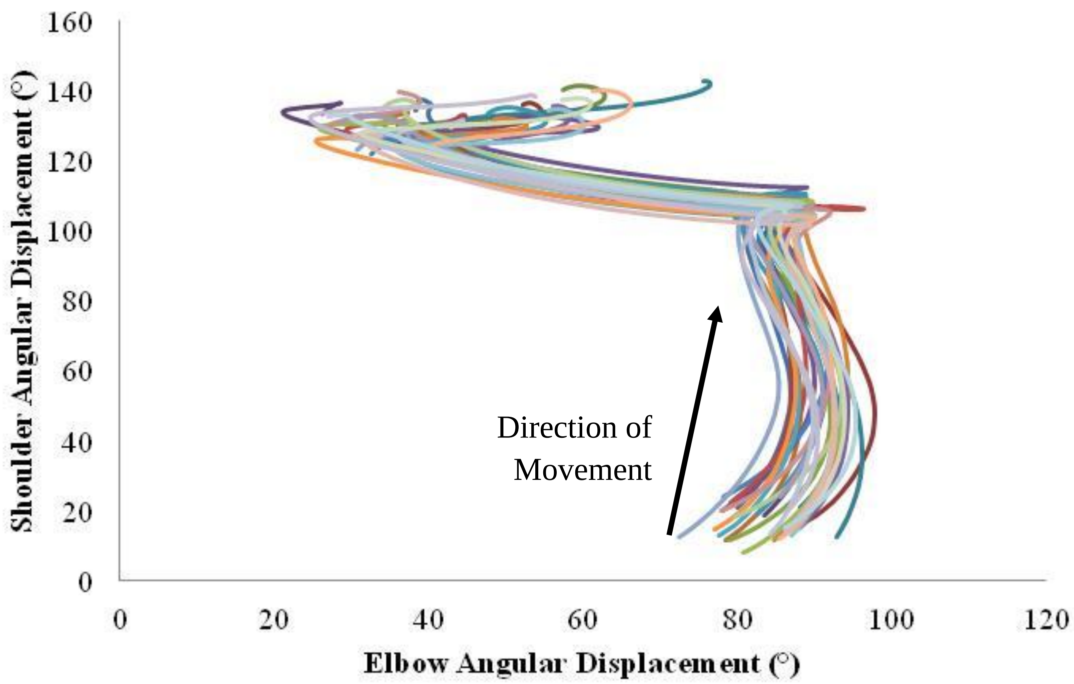

Figure 63. Angle-angle plot for an exemplar internal-external participant during acquisition 1.

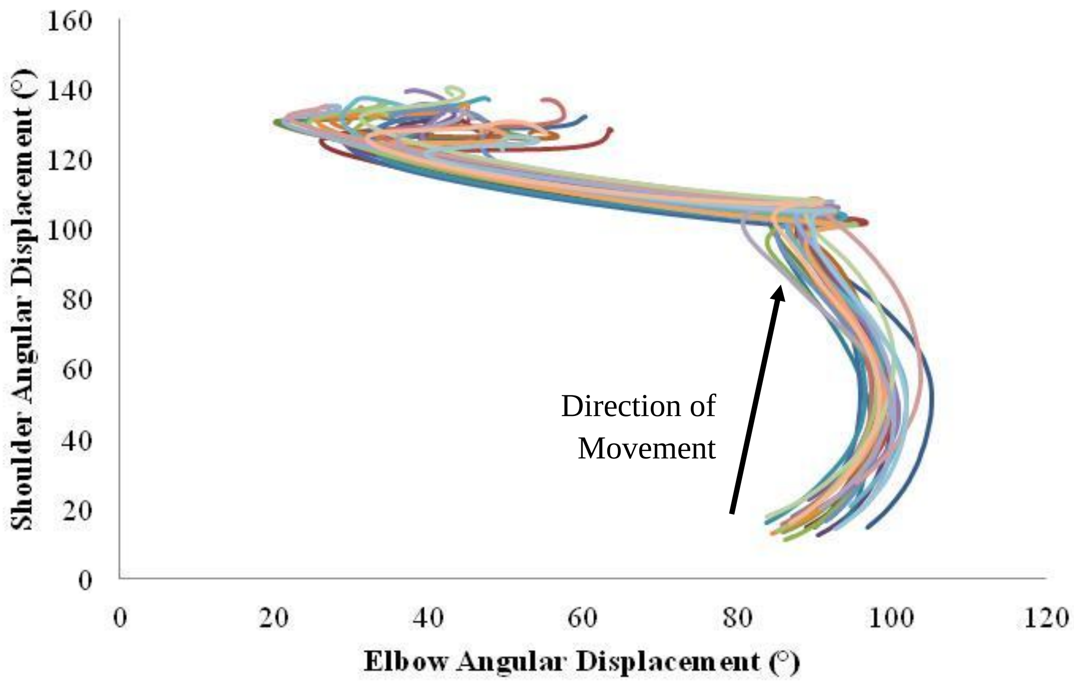

Figure 64. Angle-angle plot for an exemplar internal-external participant during acquisition 2.

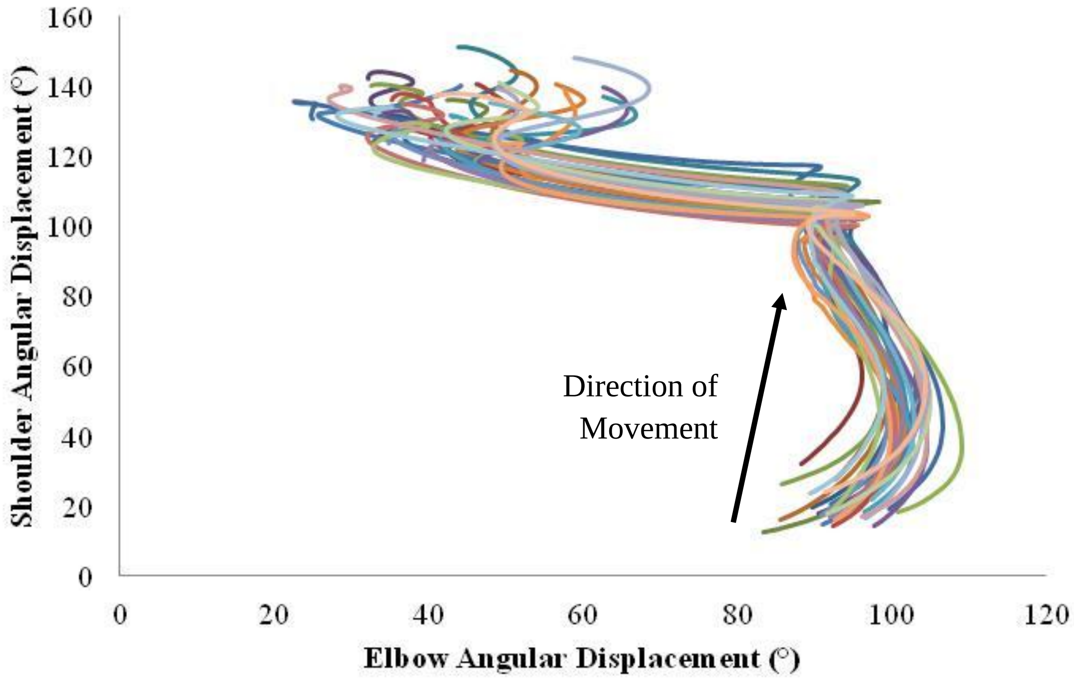

Figure 65. Angle-angle plot for an exemplar internal-external participant during retention.

6.4 DISCUSSION

The study had two aims. The first was to examine the interactive effects of practice and focus of attention on both performance and learning of a discrete multi-articular action. The second was to identify potential focus-dependent changes on joint kinematics, coordination and coordination variability. These aims were examined by means of three novel contributions to the literature: (1) a longitudinal practice period comprising 840 practice trials, (2) the provision of task-relevant information for the internal focus group, and, (3) the use of a cross-over design, allowing the integration of both internal and external focus instructions within a single treatment group.

Although there were no discernible differences between the internal-external and external-external groups across the acquisition phase, the increase in shooting performance score from pre-test to acquisition 1 for the external-external group, together with the increase in shooting performance from acquisition 1 to acquisition 2 for the internal-external group provide additional empirical support for the benefits of an external focus of attention. Specifically, the external-external and internal-external groups demonstrated, on average, a 27% and 12% increase in shooting performance respectively during these specific phases of the intervention. These performance changes also equated to effect sizes (Cohen's D) of 2.84 and 2.07 respectively, indicating large effects, and quantified using the equation proposed by Morris and DeShon (2002) that corrects for dependence between means when performing within-subject analyses. This finding agrees with previous research by Wulf and colleagues who have also reported improvements in motor performance when adopting an external focus of attention (Zachry *et al.*, 2005; Wulf *et al.*, 2007; Wulf, 2008; Wulf and Dufek, 2009; Wulf *et al.*, 2010). For instance, Wulf *et al.* (2010) observed increased vertical jump height under external focus conditions, whereas Zachry *et al.* (2005) showed improved basketball free-throw accuracy when adopting an external compared to an internal focus of attention.

In addition, although not reaching statistical significance, the external-external group appeared to demonstrate better motor skill retention in contrast to the internal-external group. This conclusion is derived from inspection of the percentage decreases in shooting performance from acquisition 2 to retention. The external-external group showed only a 3% reduction in shooting performance, which compared to a 10% decrease exhibited by the internal-external group. Furthermore, the effect size (Cohen's D) of the difference between internal-external and external-external groups at retention was 0.4, which is approaching a moderate effect (Thomas and Nelson, 1996). Although this result appears somewhat tentative, it is, nonetheless, commensurate with existing research showing enhanced motor skill learning when adopting an external focus (Shea and Wulf, 1999; Wulf *et al.*, 1999; Wulf *et al.*, 2002; Wulf and Su, 2007; Chiviacowsky *et al.*, in press). For example, Wulf and Su (2007) analysed the accuracy of golf chipping and found that the external focus group performed significantly better during the delayed retention test than the control and internal focus groups. Moreover, this finding was consistent for both novice and expert performers, demonstrating a robust effect irrespective of task expertise.

Consequently, the findings from the current study appear to reinforce the beneficial effects of external focus instruction on both motor performance and motor learning. Traditionally, these focus-dependent changes in performance outcome have been interpreted using the common-coding principle (Prinz, 1997), and more recently, the constrained-action hypothesis (Wulf *et al.*, 2001b; McNevin *et al.*, 2003). The constrained-action hypothesis advocates that an external focus of attention permits unconscious or automatic processes to control movement, whereas an internal focus of attention, conversely, causes participants to consciously intervene in these control processes and inadvertently disrupt the coordination of reflexive and self-organising processes. However, a more appropriate theoretical interpretation can be generated using the central tenets of dynamical systems theory. From a dynamical systems perspective, it could be argued that an external focus of attention permits emergent processes to regulate task performance and learning inherently (Araújo *et al.*, 2004). In other words, an external focus allows individuals to self-organise based upon the confluence of constraints on action, manifesting in improved performance and motor skill retention. Conversely, impaired task performance and retention, evident when adopting an internal focus, can be explained by individuals consciously overriding the intrinsic pattern dynamics of the motor system.

Despite the aforementioned changes in shooting performance, there were, interestingly, no significant effects, either by attentional focus or practice, on joint configuration at ball release or for the variability of joint configuration at ball release. Intuitively, an increase in shooting performance should be instigated by a change in joint configuration at ball release, which in turn, creates more favourable ball release parameters. For instance, increased shoulder angular displacement at ball release is considered advantageous because it causes a corresponding increase in height of release. A greater height of release means that a smaller speed of release is required (minimum speed principle), allowing greater control of the basketball, and is also a contributory factor towards a steeper angle of entry into the basket, thereby increasing the margin for error (see Miller and Bartlett, 1996). Moreover, height of release, typically generated through increased shoulder angular displacement at ball release, has been shown to increase with task-expertise. Specifically, Hudson (1985) previously reported height of release ratios of 1.23 ± 0.06, 1.25 ± 0.05 and 1.30 ± 0.04 for poor, good and elite basketball players respectively.

Ostensibly, this lack of change in joint kinematics counters previous work by Wulf *et al.* (2002). Wulf *et al.* (2002) found the external focus feedback groups (expert and novice) to have higher movement form scores than their internal focus counterparts during the acquisition phase. However, this difference was not evident during the retention test. This apparent disparity in research findings between the current study and that of Wulf and co-workers (2002) could be explained by the differing approaches used when analysing participants' technique. Wulf *et al.* (2002) assessed movement form using independent raters, with each trial scored using a fifteen point nominal scale. Participants were awarded points if their movement pattern satisfied particular expected criteria, such as, if the arch of the back released quickly and forcefully or if hip flexion was visible This somewhat subjective and robust measurement approach may, therefore, not provide an accurate reflection of the emerging patterns of behaviour.

The lack of change found within the current study does, however, corroborate existing research from Lohse *et al.* (2010). Lohse *et al.* (2010) examined the effect of focus of attention on joint kinematics in dart throwing, and found no significant difference between internal and external focus instruction on elbow or shoulder angular displacement at the instant of retraction (maximum elbow flexion) or release. Collectively, these findings seem to suggest that attentional focus instruction has little impact on joint configuration at release during discrete action performance. However, this may be due to the length of the practice intervention. Despite being considerably longer than the 21 trials used by Lohse *et al.* (2010), 840 trials may not be enough, when learning basketball free-throw shooting, to instigate an observable change in joint configuration at the instant of ball release. This is somewhat surprising in light of the work of Anderson and Sidaway (1994) who observed substantial changes in joint kinematics when participants completed 400 trials of a soccer kicking task. However, when analysing the effects of practice on the kinematics of dart throwing, McDonald and colleagues (1989) suggested that 1,250 trials were insufficient to permit the implementation of a new mode of coordination.

A second contributing factor could be whether the task was truly novel to the participants. This remains one of the key challenges for experimentation on focus of attention. Research has very rarely used innovative, novel movement tasks when assessing the efficacy of particular motor learning interventions. Two such examples are the modified underarm dart-aiming task (Al-Abood *et al.*, 2001a; 2001b) and reversed baseball pitch (Horn *et al.*, 2007), which have been used to examine the effect of visual demonstrations on motor performance and emerging patterns of intra-limb coordination. Although the expertise of participants within the current study was assessed using stringent inclusion criteria, participants were, nevertheless, included or excluded based on their performance during a pre-test. Consequently, although not engaging regularly in basketball competition, and demonstrating a relatively poor standard of shooting performance (< 59%), each participant may have had differing exposure to the sport of basketball. As such, it could be argued that not all the participants were at the coordination stage of learning. Therefore, the internal focus of attention instruction may have been redundant for those participants at the control stage because the desired patterns of intra-limb coordination had already emerged. As such, these participants may have already developed what Bennett (2003) refers to as the required '*common coordination pattern*'. Consequently, more rigorous inclusion criteria for participant recruitment / selection could be used within future research, perhaps in the form of coordination profiling (see Glazier and Robins, 2012). This would provide a formal assessment of intra-limb coordination and permit the careful selection of participants at the coordination stage, thereby enhancing the internal validity of the study.

In addition, the previous experience of basketball shooting may have resulted in pre-existing coordination biases that created some resistance to the proposed intervention. Coordination biases have typically been discussed in relation to the coordination dynamics of bimanual rhythmic coordination tasks (Zanone and Kelso, 1997; Hodges and Franks, 2000; 2002). Nonetheless, this issue can also be extended to the performance of discrete multi-articular actions. Zanone and Kelso (1997) suggest that an individual's coordination tendency before learning is likely to influence the learner's ability to perform the required task during practice. Therefore, the potency of the internal focus instruction, in particular, could be impaired by the existence of a (relatively) stable attractor state developed from previous exposure to basketball shooting.

The final factor dictating the lack of change in joint configuration at release could be the guiding properties of the internal focus instruction. When investigating the effect of attentional-focus instructions on a two-ball juggling task, Zentgraf and Munzert (2009) suggested that task-relevant information was picked up *independently* of verbal instructions and that internal focus instructions may, indeed, act as a source of intervening information. However, the experimental design of Zentgraf and Munzert (2009) required all participants, regardless of treatment group, to watch a model visual demonstration. The use of a model demonstration could act as an intervening factor, and compete, and potentially override, any verbal instruction given. This contention is supported by research from Al-Abood and colleagues (2001b) who reported that a modelling group, who were shown visual demonstrations before and during practice, more closely approximated the model's coordination pattern when compared to the verbally directed group. However, consistent with the current body of knowledge pertaining to focus of attention, it is debateable whether the instructions provided by both Al-Abood *et al.* (2001b) and Zentgraf and Munzert (2009) contain sufficient task-specific guidance to instigate re-organisation of the perceptual-motor system. For example, instructions included, "*Focus on your arms and hands! Juggling should mainly be performed from the forearm, not the whole arm. The upper part of your body is kept still*" (Zentgraf and Munzert, 2009, p.522), whereas, Al-Abood *et al.* (2001b, p.298) instructed participants to "*use only an underarm aiming movement*."

In contrast to these previous studies, task-relevant information was provided to the internal focus group within the current study, based on specific information points commonly found within basketball coaching texts (see Wissel, 2004), such as: extend the shoulder, extend the shooting arm completely at the elbow, and flex the wrist and fingers forward and down. However, these findings appear to suggest that even the provision of task-relevant information, by verbal instruction, may not be sufficient to counteract and override motor-system intrinsic dynamics that inherently regulates task performance throughout processes of self-organisation. As such, additional practice or more specific guidance may be required for focus-dependent changes in joint configuration at ball release to manifest.

With that said, there was indication from the other kinematic variables analysed that internal focus instruction did adequately guide motor skill learning. Despite the lack of change in joint kinematics at ball release, there were significant focus-dependent changes in coordination variability, coupled with tentative evidence suggesting changes in shoulder range of motion (see Table 16), and alterations in the emerging patterns of intra-limb coordination (see Figures 62-65). In light of these kinematic changes as a function of attentional focus, it could be argued that the effects of attentional focus instruction appear to be most apparent when the kinematic variables are continuous - the variables capture the entirety of performance trials rather than at purely discrete instants. For example, although not reaching statistical significance, the internal-external group exhibited a 29% increase in shoulder range of motion from the pre-test to retention. This is in contrast to a 7% increase for the external-external group. The increased amplitude of joint motion at the shoulder also resulted in distinct changes in intra-limb coordination for certain participants within the internal-external group (see Figures 62-63). This finding provides supplementary evidence to support the role of internal focus instruction for those participants at the coordination stage of learning. With regards to coordination variability, the internal-external group demonstrated reduced coordination variability for the elbow-shoulder joint coupling during acquisition 2 and retention when compared to their external-external counterparts ($P < 0.04$). This finding agrees with Lohse *et al.* (2010) who found the standard deviation in shoulder angle during extension of a dart throw to be greater during external than internal focus. Moreover, decreased coordination variability was found for the internal-external group for all three joint-couplings with practice. Differences were found between the pre-test and both acquisition 2 and retention ($P < 0.04$).

Collectively, these findings could be explained by internal focus instructions acting as an informational constraint, channelling the search during exploratory learning. Moreover, it could be suggested that an internal focus of attention, one that contains sufficient task-relevant information, can serve two fundamental purposes. The first purpose is to assemble the appropriate topological dynamics and establish the basic relationships amongst component parts of the human movement system. Consequently, internal focus instruction acts as a highly functional informational constraint for those at the coordination stage of learning. For the basketball shooting action, this was achieved by freeing up the biomechanical degrees of freedom of the shoulder, thereby allowing an appropriate pattern of intra-limb coordination to emerge. As such, the purpose of internal focus instruction can be considered comparable to visual demonstration (e.g. Horn *et al.*, 2007), acting as a rate enhancer during early skill acquisition - the coordination stage of learning (see Newell, 1985). However, it is important to note that rate enhancing, in the aforementioned context, relates to the *process* and not the *product*. In other words, internal focus instruction may act as a rate enhancer for emerging patterns of coordination (process) but, will not or may not, also concurrently act as a rate enhancer for performance outcome (product). From a coaching perspective this may mean that short term performance gains are 'sacrificed' for the potential longer term benefits associated with the performer first developing the critical features and necessary common coordination pattern (see Bennett, 2003) desirable for future performance success. This interactive internal-external approach to skill acquisition may thus afford the most conducive strategy for long term athlete development by tailoring the instruction to the individual's needs and coordination dynamics. Ultimately, it is the prerogative of the coach to understand the role of informational constraints on both product- and process-oriented variables. Specifically, it should be recognised that improvements in performance may, albeit in the short term, be compromised at the expense of ensuring that individuals are guided towards a task-relevant, functional attractor within the perceptual-motor workspace. However, once the functional movement pattern has been achieved, an external focus of attention can then be used so that the individual can scale and parameterise the movement based upon personal constraints.

The second purpose of internal focus instruction is to constrain 'the search', guiding individuals towards a narrower, more confined region of kinematic solutions within the perceptual-motor workspace. This is characterised within the data by the reduction in inter-trial variability for the elbow-shoulder joint coupling of the internal-external group when compared to the external-external group. Conversely, an external focus of attention encourages exploratory behaviour, allowing individuals to search freely and undertake processes of self-organisation that are guided 'naturally' by the confluence of constraints on action. The *guided* discovery approach, facilitated by internal focus instruction, may compensate for some of the limitations inherent when undertaking exploratory learning and focusing solely on external cues. For instance, Newell (1991) postulated that exploratory learning can be a rather lengthy and inefficient process, and that the attractor located within the perceptual-motor workspace may not be the most conducive for optimising task performance. Consequently, these theoretical insights (see also Peh *et al.*, 2010), coupled with the empirical data from the current study provide tentative support for the use of a cross-over design whereby the beneficial effects of internal and external focus instruction can be tailored to the individual's stage of learning.

In summary, the findings of the current study provide additional empirical support for the benefits of external focus instruction for both motor performance and motor learning. However, with the novel use of a process-oriented approach, insights have been revealed that appear to challenge previous contentions that an external focus of attention is a universally beneficial strategy. Specifically, consideration should be given to the role of internal focus instruction on emerging patterns of coordination and channelling the learners' search towards a smaller range of kinematic solutions within the perceptual-motor workspace. There are, nevertheless, several limitations that should be addressed. First of all, each treatment group only comprised five participants leading to limited statistical power. Coupled with the large within-group variance, this may have contributed to the lack of statistical significance for some kinematic variables. Therefore, future research should replicate this study design with a greater participant sample. In addition, the question of task novelty continues to be a challenge for human movement scientists when undertaking skill acquisition studies. To fully ascertain the effects of attentional focus instruction and to reduce any intervening effects of pre-existing coordination bias, future research should use truly novel and innovative movement tasks. Used in conjunction with stringent participant inclusion criteria, such as performance pre-tests and coordination profiling, significant advances in attentional focus research can be made. Finally, this was the first study to use a longitudinal practice intervention to examine changes in movement variability as a function of attentional focus. Therefore, future research is encouraged to examine how coordination and discrete and continuous measures of movement variability change over time, with the emphasis, ultimately, on developing an optimal attentional focus strategy for long-term athlete development. These lines of scientific enquiry will help address two main limitations of attentional focus research: (1) the over-emphasis on product-oriented variables, and, (2) the traditional use of short intervention periods.

CHAPTER VII

GENERAL DISCUSSION

The aim of this programme of work was to examine how the manipulation of organismic and task constraints, specifically, target distance, anxiety, dioptric blur, and focus of attention affected movement variability during a discrete multi-articular action. The action of interest was basketball shooting, a complex accuracy-based task requiring the effective coordination between multiple biomechanical degrees of freedom. Consequently, in agreement with Davids *et al.* (2005), this action represented a valuable task vehicle for the study of coordination and control processes. There were several key themes to emerge from the programme of work, some which corroborated the existing body of knowledge, whereas others provided novel contributions to the literature. These themes will each be discussed in turn and can be broadly categorised as: (1) coordination variability, (2) compensatory variability, (3) adaptation to constraint, and, (4) the role of attentional strategies.

7.1 Coordination Variability

A consistent finding across the programme of work was the significant decrease in coordination variability as a function of task expertise. Specifically, the novice participants displayed significantly more coordination variability than their intermediate and skilled counterparts. Moreover, this result was evident regardless of the joint-coupling of interest or the specific constraints on action, corroborating existing research that has reported reductions in the variability of joint kinematics with practice (Darling and Cooke, 1987; Gabriel, 2002; Chapman *et al.*, 2009; Wagner *et al.*, 2012). From a dynamical systems perspective, the reduction in coordination variability seen with expertise can be explained by the acquisition of stable movement patterns within the perceptual-motor workspace (see Handford *et al.*, 1997). Furthermore, expert performers were able to exploit this inherent motor system variability functionally to satisfy specific constraints on action. This level of variability not only affords dependable and repeatable successful performance outcomes but also offers motor system flexibility and adaptability, allowing effective response to potential perturbations or changing environmental demands. Conversely, the novice participants within this programme of work displayed greater variability, which ostensibly could be interpreted as dysfunctional. However, "high" coordination variability could also be deemed to be functional, permitting the exploration of available phase space for a repertoire of task-relevant kinematic solutions (Glazier and Davids, 2009b). This exploratory behaviour is a characteristic signature of early stages of learning (see Anderson and Sidaway, 1994; Button *et al.*, 2003), also evidenced within Study 4, and should not automatically be disregarded and viewed to be detrimental. Therefore, considerations as to the functional role of movement variability need to move beyond purely its association with positive task accomplishment e.g. successful baskets, because variability in this regard, whether it is during early stages of skill acquisition or as a result of a particular pathology, or (orthopaedic) injury, such as spinal cord injury (see Tepavac and Field-Fote, 2001) plays a key role in the motor (re)learning process by exploring potential kinematic solutions.

With that said, when expressed relative to performance outcome, it could be argued that skilled motor performance is facilitated by a functional bandwidth of movement variability, whereby deviations outside of this bandwidth could, potentially, lead to decrements in performance. This theoretical interpretation is commensurate with the ideas of Fetters (2010) who postulated that a lack of movement variability is a hindrance to the development of skilled human action, possibly because the movement system is constrained thereby inhibiting exploratory behaviour or adaptive and corrective processes. Conversely, excessive movement variability is deemed to be counterproductive and could interfere with the production of typical, functional action. These ideas also align themselves with the "optimal state of movement variability" theoretical model proposed by Stergiou and co-workers (Stergiou *et al.*, 2006; Harbourne and Stergiou, 2009) as well as the sentiments of Buzzi *et al.* (2003) who, when investigating the structure of variability during walking gait, postulated that optimal functioning may reside somewhere between "*complete regularity and complete randomness*" (p. 442). However, in light of the fact that movement variability changes in response to the specific constraints on action (see Newell and James, 2008), whether a functional bandwidth can truly be identified remains to be seen, and certainly warrants additional empirical investigation. This more "conservative" bandwidth-oriented approach to theorising about variability could, arguably, be more appropriate than suggesting that high levels of coordination variability are an indicator of successful task accomplishment (e.g. Wilson *et al.*, 2008), something which may be permeating through the human movement sciences literature in response to the emphasis placed on variability by advocates of dynamical systems theory. In other words, in light of the wealth of empirical evidence outlining the benefits of movement variability, human movement scientists should be cautious not to implicitly assume all variability is beneficial and migrate to the opposing end of the continuum to information-processing accounts, adopting a stance of "more is better".

Interestingly, there was no significant difference in coordination variability between the expert and intermediate performers within Study 1. This trend was further demonstrated by the quadratic regression analyses whereby a plateau was achieved with advancing expertise. It could therefore be argued that the intermediate performers displayed as much variability as their expert counterparts but the variability was less functionally related to performance due to weak adaptation to the specific constraints of the task. This theoretical interpretation highlights the limitations of simply relying on the magnitude of variability and provides credence to the notion that both the magnitude and functionality (determined by the structural composition of variability) of kinematic variability warrant future scientific investigation (see Glazier and Davids, 2009b). This is supported by the research that uses recurrence quantification analyses, approximate entropy or Lyapunov exponents to reveal novel insights into the structure and organisation of movement variability (see Riley and Turvey, 2002; Harbourne and Stergiou, 2009). However, the brief time course and nature of discrete actions such as basketball shooting may prevent the usage of these aforementioned tests, perhaps prompting the exploration of other analytical techniques such as principal components analysis (Daffertshofer *et al.*, 2004).

The reduction in coordination variability within this programme of work does, however, contradict those reported during performance of basketball free-throw shooting (Button *et al.*, 2003), soccer chipping (Chow *et al.*, 2007) and triple jump (Wilson *et al.*, 2008). Nonetheless, these discrepancies could be explained by the differences in experimental design, either in terms of the composition of the participant sample selected (Wilson *et al.*, 2008), the lack of a performance pre-test (Chow *et al.*, 2007), or, the methods by which coordination and its associated variability were quantified (Button *et al.*, 2003). In light of the disparity in expertise-related changes in coordination variability, further research is certainly merited to fully elucidate this relationship. Furthermore, this programme of work examined performance during predominantly a "static" task i.e. a free-throw, and only as task constraints were changing slowly. Consequently, particular attention should be paid to how expertise supports adaptive movement behaviour in more dynamic performance environments. In addition, in comparison to previous research (Sidaway *et al.*, 1995b; Robins *et al.*, 2006), the lack of change in coordination variability with target distance seen in Study 1 also warrants further scientific investigation.

7.2 Compensatory Variability

The second theme of interest relates to that of compensatory variability. Another consistent finding throughout this programme of work was the proximal to distal increase in joint angle variability at the instant of ball release. For instance, exemplar mean variability values for expert performers in Study 2 were 3.6°, 8.9° and 12.3° for the shoulder, elbow and wrist joint respectively. This was in contrast to mean values of 4.5°, 8.2° and 9.1° for the same respective joints in the novice group, signifying that this trend was evident regardless of task expertise. This finding substantiates other research pertaining to targeted throwing tasks (Button *et al.*, 2003; Robins *et al.*, 2006). Traditionally, this increase in joint angle variability may have been explained by impulse-variability theory (e.g. Miller, 2002), in light of the increased joint angular velocities seen at distal joints of the arm during basketball shooting (Miller and Bartlett, 1993; 1996). However, there are several lines of evidence from this programme of work to counter this theoretical interpretation. First, in Study 1 there was no significant increase in joint angle variability with shooting distance, regardless of task expertise. Second, also observed in Study 1, there were no significant differences in joint angle variability at release between experts, intermediates and novices, with the exception of a significant increase in shoulder joint variability at release for the novice group when compared to the intermediate group. Furthermore, and interestingly, the expert performers actually exhibited significantly more wrist angle variability at ball release in Studies 2 and 3 when compared to their novice counterparts. Intuitively, if this joint angle variability was dysfunctional and detrimental to performance, the variability would be transferred to the release parameters of the basketball. However, the variability of basketball release parameters were very low, with mean variability values in height, speed and angle of release for the expert performers in Study 3 less than 0.04 m, 0.15 m/s and 2° respectively. This observation relates to the third and final line of evidence; compensatory behaviour between interacting joints along the kinematic chain. The magnitude of compensatory behaviour in relation to task expertise is clearly evident in Figures 13-15 inclusive, with evidence to suggest that covariance between interacting joints increases with expertise. Although compensatory variability was only formally quantified in Study 1, strong inferences can be made to the other studies within the programme of work based on associations between the calculated joint angle variability at release and resultant variability of ball release parameters. With that said and where possible, future research should attempt to formally quantify the magnitude of covariance to enhance the research design and provide a more comprehensive assessment of movement variability. Nonetheless, this compensatory variability was used to preserve invariance in basketball release parameters. Specifically, the expert participants consistently demonstrated significantly less variability in ball release parameters than the novice participants. Moreover, expert performers demonstrated evidence of cooperative behaviour between joints of the shooting arm whereby errors in execution of the proximal (shoulder) joint can be offset by compensatory adjustments at a more distal joint (wrist or elbow) joint. Conversely, the variability displayed by novices in particular could be interpreted as neuro-motor noise or random processes (Faisal *et al.*, 2008), or perhaps even the exploration of potential solutions within the perceptual-motor workspace. Other research has also alluded to the role of compensatory variability during both postural control (Ko *et al.*, 2003) and discrete action performance (Kudo *et al.*, 2000; Muller and Sternad, 2004; Woo *et al.*, 2007).

There are two important points to mention when reviewing the discrete joint angle variability data. The first relates to control of confounding variables, such as playing position, which may have affected the results. A limitation of this programme of work was to not adequately control and standardise the playing positions of participants recruited. This was particularly the case in Study 1, which may have masked potentially important differences between expert and intermediate level performers. For example, unlike the intermediate group of participants in Study 1 that comprised a more homogeneous sample, i.e. 8 guards and 1 forward, the expert participants consisted of guards (n = 5), forwards (n = 3) and a centre (n = 1). Consequently, the high within group variability seen amongst the expert group could be attributed to the unfamiliarity of some participants with shooting from greater distances. Therefore, it is crucial that future research controls for such confounding variables and implements more stringent participant inclusion criteria.

The second relates to using this data in conjunction with the coordination variability data to implicate variability-task expertise relationships. From the discussion in Section 7.1 it is clearly evident that there was a reduction in coordination variability with advancing task expertise. However, there was no such reduction in discrete measures of variability, such as joint angle variability at ball release. To the contrary, expert participants were shown to possess significantly more variability at certain joints when compared to lesser skilled individuals. Subsequently, human movement scientists should be cautious when drawing conclusions about performance based purely upon the *magnitude* of discrete movement variability scores. In opposition to the views of traditional cognitive psychology, the sentiment that the *magnitude* of movement variability dictates performance success therefore appears no longer tenable (see Glazier and Davids, 2009). In addition, the variability-expertise relationship appears to vary based on the kinematic variable of interest. Therefore, generalisations about the practice-related decreases in movement variability also appear erroneous and no longer tenable. Sufficient distinction needs to be made between continuous e.g. coordination variability, and discrete e.g. joint angle variability at ball release, variables of interest when theorising about variability-task expertise relations.

7.3 Adaptation to Constraint

Perhaps the most novel contribution to the literature formed from this programme of work related to elucidating whether the response to specific organismic or task constraints was mediated by task expertise. There was limited and tentative evidence from the extant research to suggest that expertise plays a mediating role in overcoming perturbations such as anxiety (Janelle *et al.*, 2000). However, the role that expertise plays in using movement variability to satisfy and adapt to changing constraints, and whether increases or decreases in movement variability with changing constraints are mediated by task expertise is a very under-researched area within the human movement sciences. Counter to the suggestions of Janelle *et al.* (2000), the findings from Studies 2 and 3 indicate that a universal human response may exist to stabilise performance against perturbations such as diminished visual acuity (Study 2) or elevated state anxiety (Study 3). Therefore, the perceptual-motor system appears to adjust to combat any alterations in, for instance, informational constraints on action. This sentiment is exemplified by the results of Study 2 that found a significant improvement in shooting performance during the + 1.00 and + 2.00 D conditions when compared to the baseline or + 3.00 D conditions. The lack of a significant expertise by condition interaction indicated that this was a homogeneous response irrespective of task expertise. In addition, there was a significant decrease in coordination variability for the wrist-elbow joint coupling during the + 3.00 D condition in contrast to the + 1.00 and + 2.00 D conditions. Again, there was no significant interaction suggesting that this decrease was consistent across both expertise groups. This implies, therefore, that visual acuity can be considered to act as an organismic constraint shaping the magnitude of coordination variability within both sample groups. With high levels of dioptric blur, individuals, irrespective of task expertise, constrain motor system dynamics, exhibiting less inter-trial variability. Corroborating evidence was found within Study 3 whereby no significant differences were observed in shooting performance or joint kinematics for either participant group with elevated anxiety. However, in light of the very limited research this universal human adaptation needs to be assessed across a wide reaching collection of constraints and movement tasks.

7.4 The Role of Attentional Strategies

The lack of change in shooting performance and movement kinematics noted in Section 7.3 occurred in conjunction with a significant increase in vocal reaction time during a secondary task for the anxiety condition when compared to the control condition (Study 2). The change in attentional demands reflects the important role that attentional strategies play in stabilising rhythmical (e.g. Monno *et al.*, 2000; 2002; Court *et al.*, 2005) and now discrete action performance. The lack of any significant expertise by condition interaction for reaction time, again, indicates that this response was homogeneous regardless of task expertise, providing additional support for the universal human response to changing constraints on action. Therefore, increases in attentional demands were exhibited by both participant groups and used to offset perturbation from emotional fluctuations, a finding that is commonly reported within the literature (e.g. Williams *et al.*, 2002; Murray and Janelle, 2003). Akin, to the increased attentional demands seen with elevated anxiety, a similar response may also have emerged with decreased visual acuity within Study 2. However, at present this is simply conjecture and should be viewed with caution because no formal assessment of attentional demands within Study 2 was undertaken. The findings from both these studies can be explained using a dynamical systems perspective. Specifically, there is evidence to suggest that the allocation of attention constitutes an important functional organismic constraint for stabilising both task performance and intrinsic dynamics. Moreover, collectively these findings are consistent with the arguments of Court *et al.* (2005) who suggested that organismic constraints, such as anxiety, causes participants to invest additional effort to override the intrinsic dynamics of the human motor system. Finally, it would appear that the capacity to stabilise performance appears to be a robust phenomenon regardless of task expertise.

Attentional demands are not the only potent organismic constraint that can be used to harness the perceptual-motor system. The findings from Study 4 appear to indicate that attentional focus instruction also has a powerful effect on motor performance and learning, the emergence of coordinated behaviour and movement variability. With regards to shooting performance, the findings from the study provide additional support for the role an external focus of attention plays in motor skill learning, supporting a wealth of past research (Shea and Wulf, 1999; Wulf *et al.*, 1999; Wulf *et al.*, 2002; Wulf and Su, 2007; Chiviacowsky *et al.*, in press). From a dynamical systems perspective, enhanced motor skill learning could be explained by an external focus of attention permitting emergent processes to regulate task performance and learning inherently (Araújo *et al.*, 2004). In other words, an external focus allowed individuals to self-organise based upon the confluence of constraints on action, manifesting in improved performance and motor skill retention. Conversely, impaired task performance and retention, evident when adopting an internal focus, can be explained by individuals consciously overriding the intrinsic pattern dynamics of the motor system.

In terms of the focus-dependent changes in intra-limb coordination and movement variability, two novel contributions to the literature were reported. First, there was tentative evidence to suggest that an internal focus of attention, one that contained sufficient task-relevant information, released important biomechanical degrees of freedom, exemplified by the increased range of motion at the shoulder joint. This was coupled by a significant decrease in coordination variability with practice for the internal-external group when compared to the external-external focus group. However, in light of the limited sample size and large within group variance, additional research is needed to confirm these findings. Furthermore, the issue of novelty continues to be a challenge for experimentation within motor learning research and should be carefully considered within future studies. Recommendations are made within Section 6.4.

Collectively, these findings offer putative evidence to support the role of internal focus instruction for those participants at the coordination stage of learning. Moreover, it could be suggested that an internal focus of attention can serve two fundamental purposes. The first purpose is to assemble the appropriate topological dynamics and establish the basic relationships amongst component parts of the human movement system. Consequently, internal focus instruction acts as a highly functional informational constraint for those at the coordination stage of learning, acting as a rate enhancer during early skill acquisition (see Newell, 1985). The second purpose of internal focus instruction is to constrain 'the search', guiding individuals towards a narrower, more confined region of kinematic solutions within the perceptual-motor workspace. Conversely, an external focus of attention encourages exploratory behaviour, allowing individuals to search freely and undertake processes of self-organisation that are guided ‘naturally’ by the confluence of constraints on action. The *guided* discovery approach, facilitated by internal focus instruction, may compensate for some of the limitations inherent when undertaking exploratory learning and focusing solely on external cues.

With the novel use of a process-oriented approach, Study 4 has offered insights that appear to challenge previous contentions that an external focus of attention is a universally beneficial strategy. Specifically, consideration should be given to the role of internal focus instruction on emerging patterns of coordination and channelling the learners’ search towards a smaller range of kinematic solutions within the perceptual-motor workspace.

7.5 Practical Implications

As mentioned in Section 2.5, the purposes of selecting shooting distance, visual (myopic) blur, anxiety and attentional focus as the key constraints under investigation were three fold: (1) it offers an opportunity to gain an enhanced theoretical insight into studying movement variability under constraint, (2) from an applied perspective, all of these constraints are pertinent to competitive sport and therefore can be considered to be of high practical importance, and, (3) research within these fields of study typically focus on product-oriented variables, rather than exploring process-related factors such as movement kinematics and movement variability. The findings of the current programme of work reveal several important practical implications. First, there is now compelling evidence to suggest that movement variability serves a functional role in both task accomplishment and for searching the perceptual-motor workspace for a task relevant kinematic solution. As such, the learning environment should be tailored to allow the emergence of a flexible array of functional movement patterns. A varied learning environment, one which manipulates the constraints of the task during practice and allowing performers to search for appropriate solutions to the constraints on action, will afford performers with motor system flexibility and the ability to adapt to changing situational constraints and performance perturbations. This approach is viewed to be more advantageous than one that encourages a stereotypical, invariant movement pattern (see Davids *et al.*, 2008), thereby promoting a dependable yet adaptable movement pattern. Support for this approach comes from the contextual interference research that espouses the benefits of a random practice schedule over a blocked practice regimen (e.g. Ollis *et al.*, 2005), and sometimes goes under the guise of non-linear pedagogy (Chow *et al.*, 2006). Non-linear pedagogy specifically relates to using the ideas and tools of non-linear dynamical systems theory for the study of sporting behaviour and the acquisition and retention of skilled motor performance.

The second practical implication is the body of evidence from Studies, 2, 3 and 4 that appear to highlight the potential role of attentional training for both task performance and motor skill learning. With specific reference to motor skill learning, attentional focus hasbeen shown in Study 4 to have an important effect on both motor performance and learning, and, movement kinematics. Specifically, an internal focus of attention appears to act as an informational constraint, channelling the search during exploratory learning. Moreover, and as mentioned in Section 6.4, it could be suggested that an internal focus of attention, one that contains sufficient task-relevant information, can serve two fundamental purposes. The first purpose is to assemble the appropriate topological dynamics and establish the basic relationships amongst component parts of the human movement system. Consequently, internal focus instruction acts as a highly functional informational constraint for those at the coordination stage of learning. For the basketball shooting action, this was achieved by freeing up the biomechanical degrees of freedom of the shoulder, thereby allowing an appropriate pattern of intra-limb coordination to emerge. As such, the purpose of internal focus instruction can be considered comparable to visual demonstration (e.g. Horn *et al.*, 2007), acting as a rate enhancer during early skill acquisition - the coordination stage of learning (see Newell, 1985). Therefore, coaches should recognise the role that both internal and external focus instructions serve during the skill acquisition process and tailor the nature of instruction accordingly. It may mean that during early stages of learning short term performance gains are sacrificed for the potential longer term benefits associated with the performer first developing the critical features and necessary common coordination pattern (see Bennett, 2003) desirable for future performance success. Therefore, an interactive internal-external approach to skill acquisition may thus afford the most conducive strategy for long term athlete development by tailoring the instruction to the individual's needs and coordination dynamics. Ultimately, it is the prerogative of the coach to understand the role of informational constraints on both product- and process-oriented variables.

The allocation of attention may also play a crucial role in the stabilisation of task performance, especially when faced with a perturbation such as anxiety etc. Collectively, the findings from Study 2 and 3 suggest that the allocation of additional attentional resources to the primary task allows individuals to offset perturbations to the perceptual-motor system. Therefore, the use of attentional training may be used to educate and encourage performers to either focus on particular aspects of the goal / target or movement skill, or, allocate greater attention to the primary task itself. This could be achieved by a psychological intervention programme whereby key attentional instructions and cues are reinforced throughout practice, or, perhaps even artificially through the use of myopic blur. Inducing myopic blur may cause individuals to attend more strongly to the task at hand. This is supported by Mann *et al.* (2010b) who suggested that inducing myopic blur through the use of contact lenses or trial frames may constitute a useful means of attentional training. In light of the fact that impaired vision appears to cause individuals to search more acutely for the key constraining information governing the task, myopic blur could serve as an appropriate means by which to promote this type of visual search and attentional behaviour, without formal verbal instruction. If sufficient time is dedicated to this strategy, one could argue that this attentional strategy would persist even after the myopic blur has been removed and normal vision restored.

7.6 Limitations

There are several limitations from the current programme of work that require acknowledgement, and which can guide future experimentation in the field of movement variability. The first relates to the inclusion criteria by which participants were recruited into the programme of work study and assigned into the different experimental groups. Participants were classified as either experts, intermediates or novices according to the criteria outlined in Table 2 (adapted from Vickers, 1996). To be deemed an expert, participants required a performance pre-test score in excess of 168 points (> 70%). Intermediate and novice performers were classified as those who obtained pre-test scores of 144-167 points (60-69%) and less than 143 points (< 59%) respectively. Although it could be argued that the use of such performance based inclusion criteria was not an issue for Studies 2 and 3, which only included expert and novice performers, or, Study 4 that only required novice participants, there may not be sufficient distinction in performance score to fully elucidate expertise-related differences in movement kinematics and movement variability in Study 1. For instance, an expert and intermediate, or, an intermediate and novice could be separated by only a single point. Now, although there were statistically significant differences in shooting performance score between the groups in Study 1, providing support for the approach used, future research should consider approaches that allow greater differentiation in performance pre-test scores. This continues to be a challenge, however, because other research could also be deemed to suffer the same limitation. Specifically, Button *et al.* (2003) used a multiple single subject design and analysed movement variability during basketball shooting using a 10 shot performance pre-test. The participants were assigned as Senior National Team Captain, Under 18's National Team, High School League Player, Limited Experience, Very Limited Experience and had pre-test scores of 122, 116, 110, 76, 47 respectively.

The next limitation relating to inclusion criteria concerns the playing position of the participants. Some of the results within the current programme of work e.g. strength of inter-segmental covariance and variability of ball release parameters, were affected by high within-group variance. This was caused, in part, by the expertise group being comprised of different playing positions. For example, within Study 1, the intermediate group of participants consisted of a more homogeneous sample i.e. 8 guards and 1 forward, whereas the expert participants consisted of guards (n = 5), forwards (n = 3) and a centre (n = 1). Consequently, the heterogeneous response amongst the expert group could be attributed to the unfamiliarity of some participants with shooting from greater distances. In light of this limitation, future research should standardise playing position and examine the impact of both personal and task constraints on movement variability during basketball shooting performance. Standardisation of playing position would increase the validity of the findings and allow a more accurate assessment of expertise-related differences to emerge.

The final point pertaining to inclusion criteria specifically relates to Study 4. The use of performance pre-tests within motor performance and/or learning research is very rare (e.g. Button *et al.*, 2003), yet even stringent performance-based inclusion criteria may be insufficient to adequately fulfil the aims of the study. Sometimes, at the commencement of a study, participants will be required to demonstrate homogeneity in movement kinematics as well as performance outcome. As such, participants could also be screened based on their underlying movement pattern. This can be achieved through the use of coordination profiling, a recommendation echoed by Glazier and Robins (2013). This would provide a formal assessment of intra-limb coordination and permit the careful selection of participants who demonstrate the necessary movement traits and are at the required stage of learning e.g. coordinate stage, or control stage. This would, again, enhance the validity of findings and provide a truer indication as to the effectiveness of a particular intervention.

Another limitation of the programme of work was the use of skin surface markers as opposed to skeletal (bone) markers. The magnitude of movement variability recorded is a product of the variability inherent within the human movement system as well as any measurement error. Consequently, it should be acknowledged that soft tissue artefact was a key source of measurement error within the current programme. Studies have reported root mean squared errors in the order of 2.1° (Reinschmidt *et al.*, 1997a), 5.3° respectively (Reinschmidt *et al.*, 1997b), and 4.7° (Reinschmidt *et al.*, 1997c) for sagittal plane movements when comparing skin markers to skeletal markers. Therefore, future movement variability research should be encouraged to use skeletal markers to minimise any confounding influence of soft tissue artefact upon the derived movement variability values.

The final limitation concerns the severity, or, intensity of the constraints imposed. This limitation is particularly important for Studies 2 and 3 of the programme of work. Although, there is a large body of research that has used a similar experimental approach when manipulating myopic blur (e.g. Mann *et al.*, 2007; 2010b) and anxiety (Williams and Elliott, 1999; Murray and Janelle, 2003; Mullen *et al.*, 2005), other research has used a more “extreme” approach. For example, Bulson *et al.* (2008) examined the effect of dioptric blur on golf putting accuracy and induced retinal defocus with the use of + 0.50, + 1.00, + 1.50, + 2.00 and + *10.00 D* convex spherical lenses. With regards to anxiety research, Higuchi *et al.* (2002) induced psychological stress by means of an electric shock that was administered if the participant failed to hit the target three times successively. Consequently, the stabilisation of shooting performance and/or movement kinematics observed within Studies 2 and 3 may have been due, in part, to the intensity of the intervention. If the intervention had been stronger, perhaps treatment effects and expertise-related differences may have emerged. Therefore, future constraints-based research should consider carefully the nature and manner of the intervention to ensure it is sufficient to both elicit the desired physiological / psychological response, and allow treatment / expertise-related differences to manifest.

7.7 Conclusion

In conclusion, the programme of work has offered a revealing insight into the effects that constraints have on movement variability, and more broadly, perceptual-motor organisation. Task expertise was characterised by decreased coordination variability and heightened compensatory control, evidenced by stronger covariance between interacting joints along the kinematic chain. Yet, no significant expertise-related difference was found for discrete measures of movement variability. Attentional strategies such as attentional demands and attentional focus have also been seen to play a fundamental role in stabilising performance and shaping movement kinematics e.g. coordination and movement variability, respectively.

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APPENDICES

List of Appendices

Sheffield Hallam University

School of Sport and Leisure Management
Research Ethics Committee

VOLUNTARY INFORMED CONSENT FORM (STUDY 1)

TITLE OF PROJECT: DISTANCE AND TASK EXPERTISE AS CONSTRAINTS ON MOVEMENT VARIABILITY DURING BASKETBALL SHOOTING

The participant should complete the whole of this sheet himself/herself

Have you read the Participant Information Sheet?	YES/NO
Have you had an opportunity to ask questions and discuss this study?	YES/NO
Have you received satisfactory answers to all of your questions?	YES/NO
Have you received enough information about the study?	YES/NO
To whom have you spoken? .... Do you understand that you are free to withdraw from the study: • at any time • without having to give a reason for withdrawing • and without affecting your future medical care	YES/NO
Have you had sufficient time to consider the nature of this project?	YES/NO
Do you agree to take part in this study?	YES/NO

Signed .... Date ....

(NAME IN BLOCK LETTERS)...

Signature of Parent / Guardian in the case of a minor

....

FOR USE WHEN STILL OR MOVING IMAGES WILL BE RECORDED

Consent to scientific illustration
I hereby confirm that I give consent for photographic and/or videotape and sound recordings (the 'material') to be made of me. I confirm that the purpose for which the material would be used has been explained to me in terms which I have understood and I agree to the use of the material in such circumstances. I understand that if the material is required for use in any other way than that explained to me then my consent to this will be specifically sought.
1. I understand that the material will form part of my confidential records and has value in scientific assessment and I agree to this use of the material. Signed.. Date.. Signature of Parent / Guardian in the case of a minor ....
2. I understand the material has value in teaching and I consent to the material being shown to appropriate professional staff for the purpose of education, staff training and professional development. Signed.. Date.. Signature of Parent / Guardian in the case of a minor ....
I hereby give consent for the photographic recording made of me on...................... to be published in an appropriate journal or textbook. It is understood that I have the right to withdraw consent at any time prior to publication but that once the images are in the public domain there may be no opportunity for the effective withdrawal of consent. Signed .... Date .... Signature of Parent / Guardian in the case of a minor ....

Sheffield Hallam University

School of Sport and Leisure Management

Research Ethics Committee

Health Screening Questionnaire (ALL STUDIES)

Name: ....

Date of Birth: .... Age: ....Sex: ....

Please answer the following questions by putting a circle round the appropriate response or filling in the blank.

1. How would you describe your present level of activity?
   Sedentary / Moderately active / Active / Highly active

2. How would you describe you present level of fitness?
   Unfit / Moderately fit / Trained / Highly trained

3. How would you consider your present body weight?
   Underweight / Ideal / Slightly over / Very overweight

4. Smoking Habits

Smoking Habits	Are you currently a smoker?	Yes / No
	How many do you smoke	…….. per day
	Are you a previous smoker?	Yes / No
	How long is it since you stopped?	.... years
	Were you an occasional smoker?	Yes / No
		.... per day
	Were you a regular smoker?	Yes / No
		.... per day

5. Do you drink alcohol? Yes / No
   If you answered **Yes**, do you have?
   An occasional drink / a drink every day / more than one drink a day?

6. Have you had to consult your doctor within the last six months? Yes / No
   If you answered **Yes**, please give details…………………………………….
   ………………………………………………………………………………
   ………………………………………………………………………………

7. Are you presently taking any form of medication? Yes / No
   If you answered **Yes**, please give details…………………………………….
   ………………………………………………………………………………
   ………………………………………………………………………………

8. As far as you are aware, do you suffer or have you ever suffered from:

a Diabetes?	Yes / No	**b** Asthma?	Yes / No
c Epilepsy?	Yes / No	**d** Bronchitis?	Yes / No
e *Any form of heart complaint?	Yes / No	**f** Raynaud's Disease?	Yes / No
g *Marfan's Syndrome?	Yes / No	**h** *Aneurysm/embolism?	Yes / No
I Anaemia	Yes / No		

9. *Is there a history of heart disease in your family? Yes / No

10. *Do you currently have any form of muscle or joint injury? Yes / No
If you answered **Yes**, please give details…………………………………
……………………………………………………………………………………
…………………………………………………………………………… …..

11. Have you had to suspend you normal training in the last two weeks? Yes / No
If the answer is **Yes** please give details……………………………………………
………………………………………………………………………………………..
………………………………………………………………………………………..

12. * Please read the following questions:

a)	Are you suffering from any known serious infection?	Yes / No
b)	Have you had jaundice within the previous year?	Yes / No
c)	Have you ever had any form of hepatitis?	Yes / No
d)	Are you HIV antibody positive	Yes / No
e)	Have you had unprotected sexual intercourse with any person from an HIV high-risk population?	Yes / No
f)	Have you ever been involved in intravenous drug use?	Yes / No
g)	Are you hemophiliac?	Yes / No

13. As far as you are aware, is there anything that might prevent you from successfully completing the tests that have been outlined to you? Yes / No

---

IF THE ANSWER TO ANY OF THE ABOVE IS YES THEN:
a) Discuss with the Centre for Sport and Exercise Science the nature of the problem.
b) Questions indicated by (*) Allow your Doctor to fill out the 'Doctors Consent Form provided.

As far as I am aware the information I have given is accurate.

Signature: ………………………………………………………………...

Signature of Parent or Guardian if the subject is under 18:

…………………………………………………………………... ... ...

Date: ……/……/……

Sheffield Hallam University

School of Sport and Leisure Management

Research Ethics Committee

Participant Information Sheet (STUDY 1)

Project Title	Distance and task expertise as constraints on movement variability during basketball shooting.

Name of Participant	

Supervisor/Director of Studies	Dr. Jonathan Wheat

Principal Investigator	Matthew Robins

Purpose of Study and Brief Description of Procedures
(Not a legal explanation but a simple statement)

The purpose of the study is to identify how movement variability (specifically continuous coordination variability and segment end-point variability), changes with both shooting distance and ability level. This will provide an insight into how participants of differing ability coordinate the biomechanical degrees of freedom when performing a basketball shooting task, and how this impacts upon movement variability of the wrist, elbow and shoulder joints. This investigation will also stress the importance of movement variability for the successful execution of the basketball jump shot by identifying both compensatory variability and exploratory behaviour. The procedure involves using the on-line motion analysis system and attaching reflective markers to the torso and shooting arm. Thirty shots will then be performed from each of three distances towards a regulation basketball ring elevated ten feet in the air. These distances will include 4.25 (free-throw line), 5.25 and 6.25 (three-point line) metres. The outcome of each shot will be rated using an objective assessment scale (modified from Landin *et al.*, 1993). Sufficient rest will be allowed during data collection to prevent any intervening effects of fatigue.

If necessary continue overleaf

It has been made clear to me that, should I feel that these Regulations are being infringed or that my interests are otherwise being ignored, neglected or denied, I should inform Professor Edward Winter, Chair of the School of Sport and Leisure Management Research Ethics Committee (Tel: 0114 225 4333) who will undertake to investigate my complaint.

Sheffield Hallam University

School of Sport and Leisure Management

Research Ethics Committee

Risk Assessment Pro Forma (STUDY 1)

Procedure	Examining how movement variability changes as a function of distance and ability level.

Assessment Number	

Date Assessed	12/2004

Assessed By	Neil Donovan

Signed	**Position**
	Head Technician

Hazards	**Risks and Specific Control Measures**
Muscle injury to participants	Stretching and warm up to be undertaken prior to data collection
Tripping over camera cabling	Cables to be taped to the floor
Damage to equipment within the laboratory from basketball rebounding off ring	A screen will be situated to protect the desktop computers on trolleys. The retractable net will also be used to protect the cameras and equipment behind the basketball ring. A data collection assistant will also be used to obtain rebounds.
Falling off ladder adjusting cameras	Ladder training conducted by university. Ladders only climbed if supported by another individual.

Risk Evaluation (Overall)
Very low level of risk associated with the procedures. Furthermore, specific control measures will be in situ to avoid injury and/or damage to participants and university property.
General Control Measures
All cabling will be tidied and extraneous equipment removed from the lab and/or relocated into the corner, away from the data collection area. Restricted access to the laboratory and access only granted to permitted individuals. Data collection to be undertaken in the middle of the laboratory at an appropriate location with respect to fixed equipment.

Emergency Procedures
To notify the technicians and contact a first aider in the event of any accident or injury to myself and/or the participant. Maintain a record of contact numbers of emergency staff personnel in the event of accident. In the case of a fire, leave all possessions and all individuals exit via the fire exit to the designated meeting point.

Monitoring Procedures
Regular checks will be done before and after each individual data collection session i.e. per participant.

Review Period	N/A

Reviewed By	Date
N/A	N/A

Sheffield Hallam University **School of Sport and Leisure Management** **Research Ethics Committee** APPLICATION FOR APPROVAL OF RESEARCH (STUDY 1)	

In designing research involving humans, principal investigators should be able to demonstrate a clear intention of benefit to society and the research should be based on sound principles. These criteria will be considered by the Ethics Committee before approving a project. ALL of the following details must be provided, either typewritten or word-processed preferably at least in 11 point font. Please either tick the appropriate box or provide the information required.

1. Date of Application	24/03/2004

2. Anticipated Date of Completion	30/11/2006

3. Title of Investigation	An investigation into the nature of movement variability.

4. Subject Area	Biomechanics

5. Principal Investigator	Matthew Robins
Email address	matthewtrobins@hotmail.com
Telephone/mobile number	0114 2252262 / 07941034571

6. Is this		
6.1 a research project? [√]		
	Unit Name	**Unit Number**
6.2 an undergraduate project? [ ]		
6.3 a postgraduate project? [ ]		

7. Director of Studies/ Supervisor/Tutor	Professor Roger Bartlett

8. Intended duration and timing of project	3 years (Full-Time)

9. Location of project (If parts are external to SHU, provide evidence in support in section 19)	SHU

10. Is this study	
10.1 Collaborative? [ ]	**If yes please include appropriate agreements in section 19**
10.2.1 Replication [✓] of	Button *et al.* (2003). Examining movement variability in the basketball free-throw action at different skill levels
10.2.2 New [ ]	

11. Participants	
11.1 Number	10
11.2 Rationale for this number: (eg calculations of sample size)	For the successful analysis of movement variability, it is important to conduct both single-subject and group analyses. Subsequently, both sample and trial sizes are important considerations. Based upon the findings of previous research (Button *et al.*, 2003), appropriate sample and trial sizes can be calculated a-priori using the statistical software package Minitab. With a moderate effect size (0.5) and statistical power (0.6), approximately 300 repetitions are required. However, the high variability (mean standard deviation of 5.0) obviously had implications upon the low power derivative (see Cohen, 1988). Therefore, **Sample size = 10** **Trial size = 30** Trial size was elevated rather than sample size because recruitment of elite basketball players may be problematic.
11.3 Criteria for inclusion and exclusion:	Both novice and elite basketball players are required. This will allow a comparative analysis to be performed upon the variability of shooting performance of each population. Basketball was the chosen vehicle because it is an accuracy based throwing task. The 'functionality' of movement variability can thus be assessed by correlating performance outcome against variability of segmental coordination.
11.4 Does the study have *minors or ‡vulnerable adults as participants?	Yes [ ] No [✓]
11.5 Is CRB disclosure required for the Principal Investigator? *(To be determined by risk assessment)*	Yes [ ] No [✓] If yes, is standard [ ] or enhanced [ ] disclosure required?
*Minors are participants under the age of 18 years. ‡Vulnerable adults are participants over the age of 16 years who are likely to exhibit: a) learning difficulties b) physical illness/impairment c) mental illness/impairment d) advanced age e) any other condition that might render them vulnerable	

12. Purpose and benefit of investigation

Statement of the research problem with any necessary background information.
(No more than 1 side of A4)

Although practice has shown a decrease in variability with practice, variability is an inherent component both within and between all biological systems (Newell and Corcos, 1993). Traditionally, this variability has been viewed negatively, seen either as noise or an erroneous deviation away from a set movement pattern. This has led to the use of repetition drills in training, and to the search for invariant properties of motor behaviour. However, the dynamical systems approach has emerged in opposition to information-processing theory and views variability as functional and adaptive. The dynamical systems approach is predicated upon interacting constraints (task, environmental and organismic), which govern and marshall the appropriate biological subsystems into the observed pattern of behaviour. The proposed study will help to improve understanding of the importance of movement variability, providing evidence for a new perspective on motor behaviour. The insights provided will help in the formulation of new research methods, training, therapeutic and rehabilitation procedures by helping scientists and practitioners to reconceptualise the role of variability in adaptive behaviour and to re-design practical interventions as a consequence.

As individuals move through the stages of motor learning, they release biomechanical degrees of freedom which were previously frozen during earlier stages of learning (Vereijken *et al.*, 1992). This facilitates a wider exploration of phase-space. Therefore, it is becoming apparent that experts should show greater adaptability, as increased variability may lead to greater success in satisfying any given set of constraints. Evidence shows that they can freeze or unfreeze the degrees of freedom in the chain of movement as task constraints demand. Novices, by contrast, mostly tend to freeze degrees of freedom and may show as much or more variability that is not functional, owing to a weak adaptation to task constraints. These phenomena will be identified via the correlation between shooting performance scores and movement variability. For example, do some groups show higher coordination variability and a positive relation with outcome goals, or can these groups also display lower variability under different task constraints and positive relation with outcome goals?

However, individualised plots of novice movement behaviour have revealed differences in coping as some start to unfreeze degrees of freedom. These variations in co-ordination strategy have been envisaged for the volleyball serve (Kingsbury *et al.*, 2003, Temprado *et al.*, 1997). For example, the expert pattern of co-ordination was observed in 30% of the trials by the novice participants (Temprado *et al.*, 1997). This variation in coping strategy for novices warrants further appraisal because it has rarely been addressed in the research literature.

It is important to note that although the issue of variability in basketball shooting has received previous appraisal (Miller, 2002, Button *et al.*, 2003), limitations inherent within both methodologies provide a rationale for further investigation. These weaknesses have included the examination of purely discrete variables of interest (Miller, 2002), the absence of shoulder kinematics, the use of manual digitising, and a limited sample size i.e. one subject from each ability group (Button *et al.*, 2003). Consequently, the use of on-line motion capture, larger sample sizes, and the analysis of shoulder kinematics will expand and progress the existing research base in this area.

References

Button, C., MacLeod, M., Sanders, R. and Coleman, S. (2003). Examining movement variability in the basketball free-throw action at different skill levels. *Research Quarterly for Exercise and Sport*. **74** (3), 257-269.

Kingsbury, D., Bennett, S. and Davids, K. (2003). An analysis of movement behaviour in novices: re-exploring the ‘degrees of freedom’ problem. *Journal of Sport Sciences*. **21** (4), 242-243.

Miller, S.A. (2002). Variability in basketball shooting: Practical implications. In *International Research in Sports Biomechanics* (edited by Hong, Y.). London: Routledge. 27-34.

Newell, K.M. and Corcos, D.M. (1993). Issues in variability and motor control. In *Variability and Motor Control* (edited by Newell, K.M. and Corcos, D.M.). Human Kinetics: Champaign, Illinois, 1-13.

Temprado, J., Della-Grasta, M. Farrell, M. and Laurent, M. (1997). A novice-expert comparison of (intra-limb) coordination subserving the volleyball serve. *Human Movement Science*. **16**, 653-676.

Vereijken, B., Whiting, H.T.A., Newell, K.M. and van Emmerik, R.E.A. (1992). Freezing degrees of freedom in skill acquisition. *Journal of Motor Behavior*. **24** (1), 133-142.

13. Details of the research design and protocol(s)	
13.1 Provide details. This investigation involves comparing expert and novice basketball performers, to assess the possible functionality of movement variability. Participants will be asked to perform multiple trials (see Section 11.2) with the shooting distance being equivalent to the free-throw line. Empirical data suggests that shots are frequently taken from this position during competition (Elliott, 1992). This will increase the external validity of the investigation. Both continuous and discrete variables of interest will be recorded and analysed. The discrete variables of interest will comprise of joint configurations at the point of release e.g. wrist, elbow and shoulder angular displacement, whereas continuous assessment will be performed by calculating the continuous relative phase for the entire time series. Angle-angle plots of the wrist, elbow and shoulder joints will provide an additional method of continuous assessment. Standard deviations will be computed for all variables because it offers a metric for the stability of a system or behaviour e.g. inter-trial variability. Coefficients of variation will also be calculated. The performance outcome of each shot will be recorded, and be based upon an objective assessment scale (as devised by Landin *et al.*, 1993 and used by Button *et al.*, 2003). This will allow the identification of any potential relationship between performance outcome and variability.	
13.2 Are these "minor" procedures as defined in Appendix I of the ethics guidelines?	Yes [✓] No [ ]

14. Indicative methods of analysis
14.1 Provide details of the quantitative and qualitative analysis to be used. It is recommended that single-subject analyses are conducted for studies investigating variability so that subtle nuances are not disguised when collapsing across groups. Therefore, a multiple single-subject design will be implemented. However, in order to conduct statistical tests upon variability the data will have to be collapsed across ability group (if not, there is only one case for each participant i.e. one standard deviation value). Differences between ability groups will be assessed by a one-way analysis of variance (ANOVA), with the alpha level set at $p < 0.05$. Due to the limitations inherent in statistical significance testing, this will be supplemented by both effect size and power. The relationship between variability and performance outcome will be measured by a Pearson Product Moment Correlation Coefficient.

15. Substances to be administered (Refer to Appendix V of the ethics guidelines)
15.1 The protocol does not involve the administration of pharmacologically active substances or nutritional supplements. *(Please tick the box if this statement applies and go to section 16)* [✓] 15.2 Name and state the risk category for each substance. If a COSHH assessment is required state how the risks are to be managed.

16. Degree of discomfort that participants might experience
16.1 To consider the degree of physical or psychological discomfort that will be experienced by the participants. State the details which must be included in the participant information sheet to ensure that the participants are fully informed about any discomfort that they may experience. The experiment involves multiple repetitions, which may predispose the participants to physiological fatigue. The shooting action is also a dynamic throwing task, so the potential for muscle injury should be noted. However, it must be stressed that due to the nature of the task i.e. shooting, the procedure is not *maximal* and does not involve anything which extends beyond regular competition performance. Therefore, the level of fatigue and the likelihood for injury would arguably be negligible. Nonetheless, it should also be stated that there may be a difference with regards to the level of discomfort experienced by each ability group because novices may be more susceptible because they are unaccustomed to the task.

17. Outcomes of Risk Assessment	
17.1 Provide details of the control measures arising out of the assessment of risk including the nature of supervision and support required during the experimental phase of the project. During the entire data collection process is it imperative that full supervision and support are provided. Due to the potential risks outlined above (section 16.1), all participants will be continually monitored to ensure they are happy to proceed with the investigation. Appropriate rest intervals will be given to minimise the risk of fatigue and associated injury. It is important to note that longer rest intervals may be appropriate for the novice group. Due to the dynamic nature of the task, the beginning of each session will be dedicated to a thorough warm-up. This ensures that the participants are fully prepared for the task and again minimises the likelihood of injury. Prior to data collection all instructions and guidelines will be given so that the participants are made fully aware of the procedure, and that they understand they are able to withdraw at any time during the experiment.	

18. Safe System of Work	

18.1 Indicate how the control measures outlined in section 17.1 will be implemented to minimise the risks in undertaking the research protocol (refer to 13.1). State the technical skills needed by the Principal Investigator to ensure safe working.

The principal investigator will undertake/instruct a thorough warm-up procedure prior to data collection to ensure the participants are fully prepared to undertake testing. The principal investigator will also allow appropriate time for rest to allow the participant to recover in between bouts of shooting performance. However, it should be noted that this is purely a precautionary measure, and does not infer that the testing procedure is 'dangerous'. The technical skills needed would be a competent knowledge of the on-line motion capture system. In terms of 'participant preparation', this involves a good knowledge of marker placements, and to ensure that the participant is comfortable with the data collection attire.

19. Attachments
(Place a tick in the appropriate description)

19.1 Risk Assessment(s) [ ]
(Include CRB risk assessment)

19.2 COSHH Assessment [ ]

19.2 Participant Information Sheet [ ]

19.3 Informed Consent Form [ ]

19.4 Pre-Test Medical Questionnaire [ ]

19.5 Collaboration evidence/support (see 10) [ ]

19.6 Collaboration facilities (see 9) [ ]

19.7 Clinical Trials Form (FIN 12) [ ]

20. Signature Principal Investigator	**Once this application is approved, I will undertake the study as approved.** **If circumstances necessitate that changes are made to the approved protocol, I will discuss these with my Project Supervisor. If the supervisor advises that there should be a resubmission to the Ethics Committee, I** **agree that no work will be carried out using the changed protocol until** **approval has been sought and formally received.** **..................Matthew Robins..Principal Investigator**

21. Approval Project Supervisor to sign off **<u>EITHER</u>** box A **<u>OR</u>** box B as applicable. *(refer to Appendix I and the flowchart in appendix VI of the ethics guidelines)*	**Box A:** **I confirm that the experimental protocol contained in this proposal is based solely on 'minor' procedures, as outlined in Appendix 1 of the School's Ethics Procedures for the Use of Humans in Research document, and therefore does not need to be submitted to the SLMREC.** **In terms of ethics approval, I agree the 'minor' procedures proposed here and confirm that the Principal Investigator may proceed with the study as designed.** **Project Supervisor …………………………………….............Date …………...**
	Box B: **I confirm that the experimental protocol contained in this proposal is <u>not</u> based solely on 'minor' procedures, as outlined in Appendix 1 of the School's Ethics Procedures for the Use of Humans in Research document, and therefore <u>must</u> be submitted to the SLMREC for approval.** **I confirm that the appropriate preparatory work has been undertaken and that this document is in a fit state for submission to SLMREC.** **Project Supervisor……………………………………………. Date …………....**

PARTICIPANT INFORMATION QUESTIONNAIRE

Name: Signature:

Date: Age:

Height: Mass:

Basketball Playing Position:

Highest Level of Performance:

Current Level of Performance:

PARTICIPANT SCORING RECORD SHEET

Name	Distance (m)	Shooting Score 1 - 8	Success /Failure
JK	4.25	8	1
		8	1
		4	0
		6	1
		4	0
		5	1
		7	1
		7	1
		3	0
		8	1
		7	1
		6	1
		3	0
		1	0
		4	0
		6	1
		7	1
		8	1
		4	0
		6	1
		7	1
		8	1
		3	0
		5	1
		8	1
		8	1
		6	1
		3	0
		8	1
		8	1
	5.25	4	0
		3	0
		3	0
		7	1
		8	1

JOINT COORDINATE SYSTEM INFORMATION

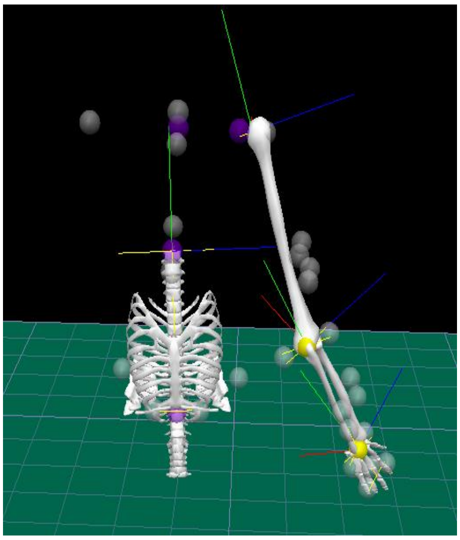
The laboratory coordinate system was defined as follows:

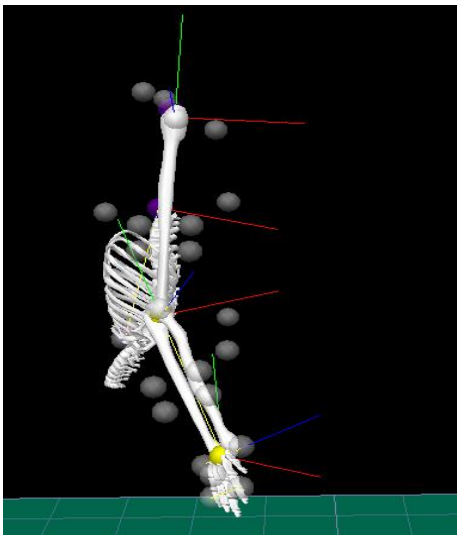
X-axis (Red) – Anterior-Posterior

Y-axis (Green) – Vertical

Z-axis (Blue) – Medial-Lateral

Joint Coordination System





Frontal View

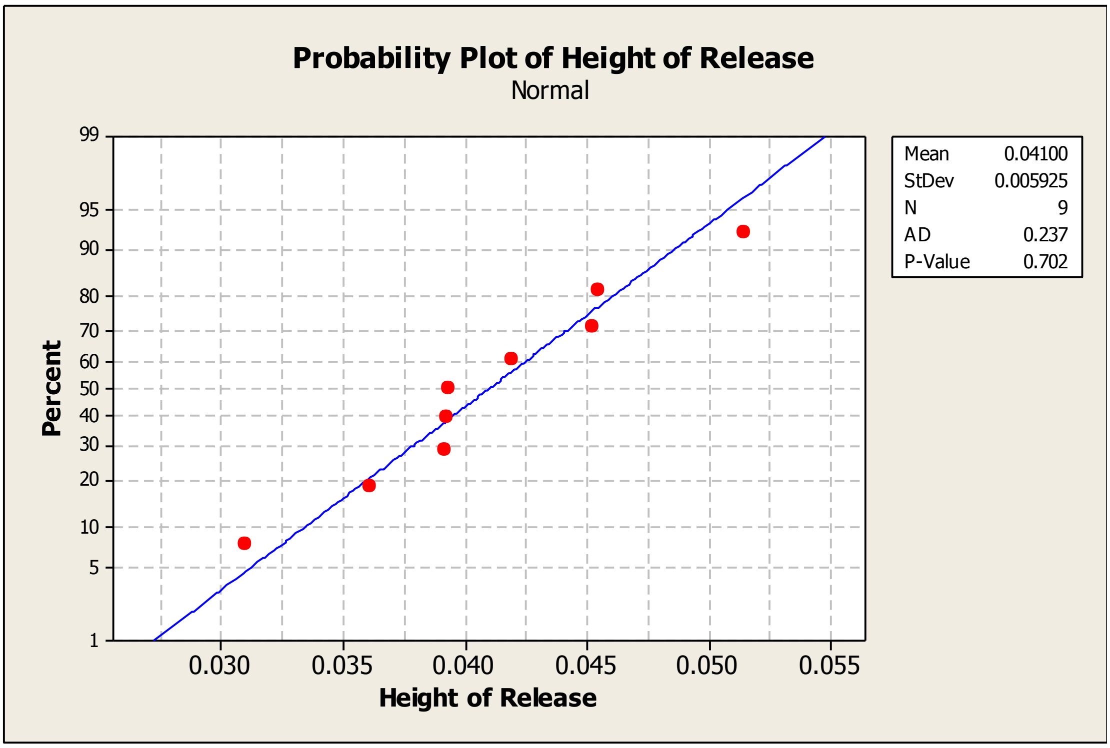
Lateral View

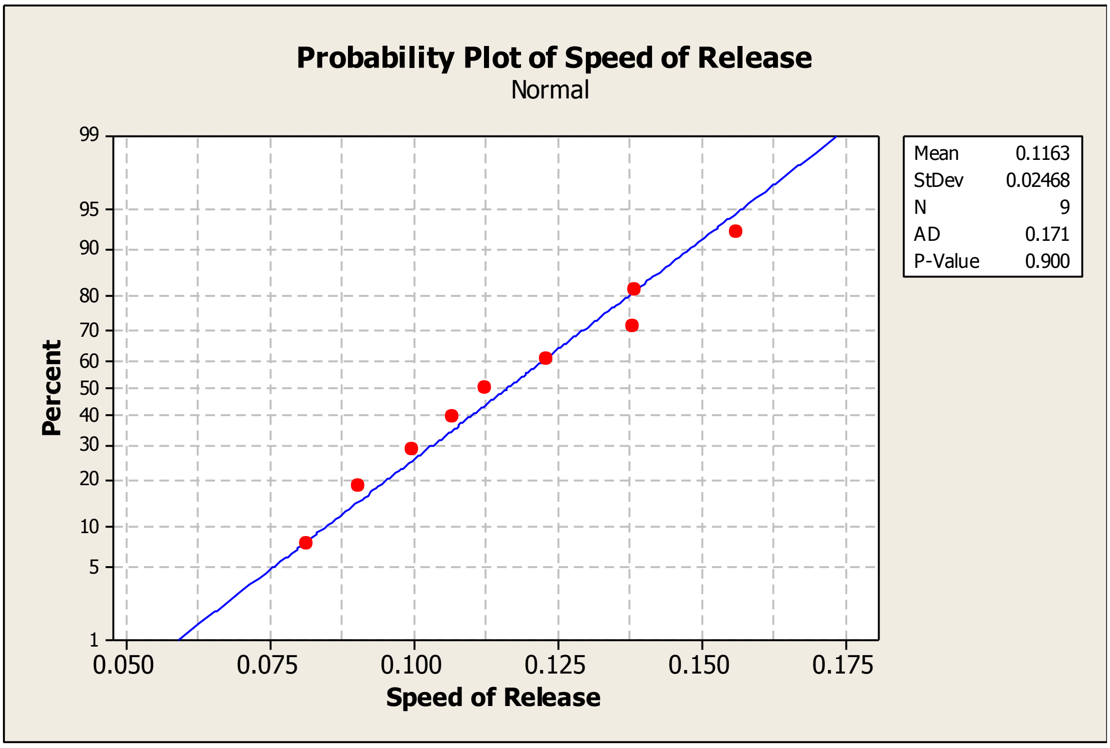
Model-Based Computation of Wrist, Elbow and Shoulder Angles

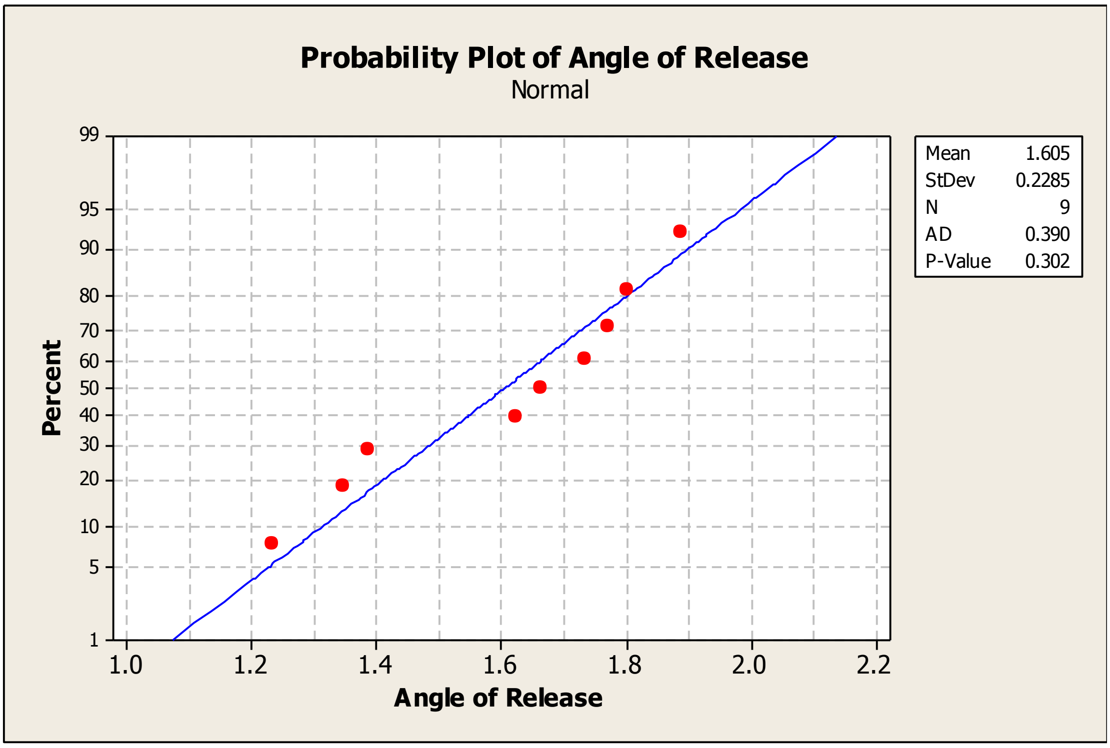
Joint Angle	Segment	Reference Segment	Cardan Angle Sequence
Wrist	Right Hand	Right Forearm	Y-X-Z
Elbow	Right Forearm	Right Upper Arm	Z-X-Y
Shoulder	Right Upper Arm	Thorax / Abdomen	Z-X-Y

VERIFICATION OF ASSUMPTIONS UNDERPINNING STATISTICAL TESTS

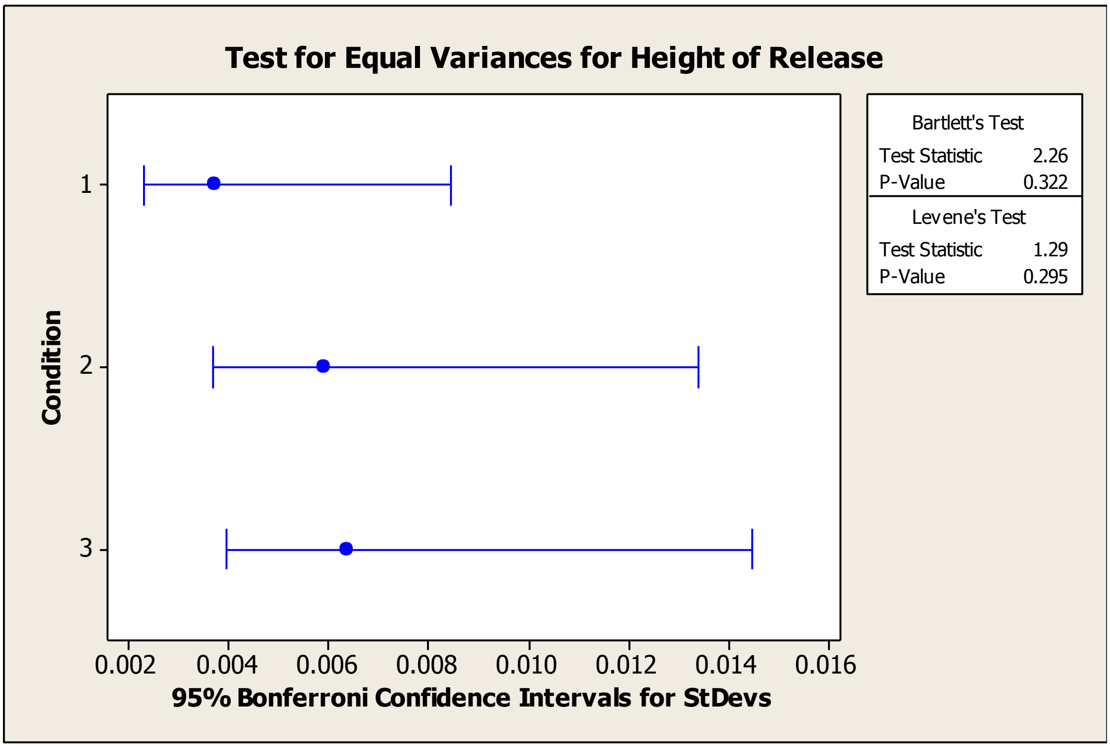
TEST OF NORMALITY

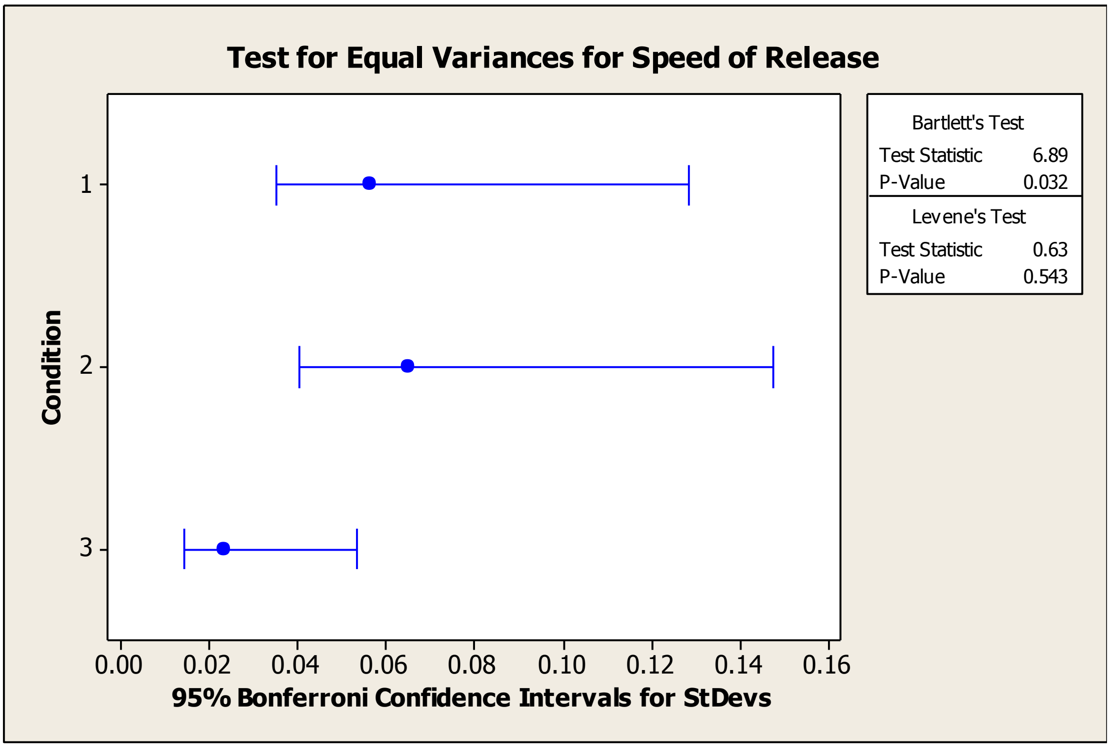


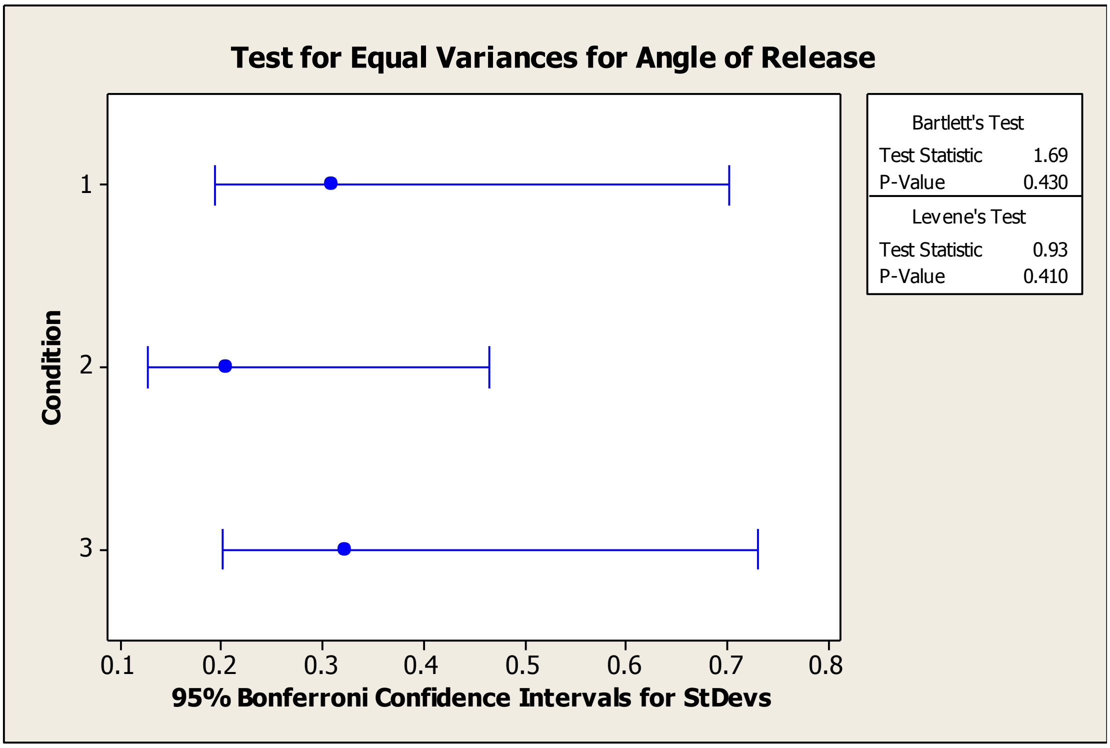




TEST FOR HOMOGENEITY OF VARIANCE




Test for Equal Variances for Speed of Release
Bartlett's Test
Test Statistic 6.89
P-Value 0.032
Levene's Test
Test Statistic 0.63
P-Value 0.543
Condition
1
2
3
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
95% Bonferroni Confidence Intervals for StDevs


Test for Equal Variances for Angle of Release
Bartlett's Test
Test Statistic 1.69
P-Value 0.430
Levene's Test
Test Statistic 0.93
P-Value 0.410
Condition
1
2
3
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
95% Bonferroni Confidence Intervals for StDevs

BASKETBALL SHOOTING PERFORMANCE

Within-Subjects Factors

Measure:MEASURE_1

dist	Dependent Variable
1	Shooting_1
2	Shooting_2
3	Shooting_3

Between-Subjects Factors

		Value Label	N
Skill	1	Novice	9
	2	Intermediate	9
	3	Expert	9

Descriptive Statistics

	Skill	Mean	Std. Deviation	N
Shooting_1	Novice	127.6667	10.29563	9
	Intermediate	151.4444	18.95462	9
	Expert	186.6667	17.44276	9
	Total	155.2593	29.10008	27
Shooting_2	Novice	117.6667	13.71131	9
	Intermediate	141.5556	17.36456	9
	Expert	180.8889	13.69712	9
	Total	146.7037	30.23093	27
Shooting_3	Novice	102.8889	27.40641	9
	Intermediate	125.1111	12.68310	9
	Expert	164.3333	7.59934	9
	Total	130.7778	31.12053	27

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
dist	Sphericity Assumed	8335.580	2	4167.790	23.934	.000	.499
	Greenhouse-Geisser	8335.580	1.591	5239.250	23.934	.000	.499
	Huynh-Feldt	8335.580	1.828	4560.727	23.934	.000	.499
	Lower-bound	8335.580	1.000	8335.580	23.934	.000	.499
dist * Skill	Sphericity Assumed	65.086	4	16.272	.093	.984	.008
	Greenhouse-Geisser	65.086	3.182	20.455	.093	.968	.008
	Huynh-Feldt	65.086	3.655	17.806	.093	.979	.008
	Lower-bound	65.086	2.000	32.543	.093	.911	.008
Error(dist)	Sphericity Assumed	8358.667	48	174.139			
	Greenhouse-Geisser	8358.667	38.184	218.907			
	Huynh-Feldt	8358.667	43.864	190.557			
	Lower-bound	8358.667	24.000	348.278			

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1685380.938	1	1685380.938	3686.429	.000	.994
Skill	51563.284	2	25781.642	56.392	.000	.825
Error	10972.444	24	457.185			

Pairwise Comparisons

Measure:MEASURE_1

(I) Skill	(J) Skill	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Novice	Intermediate	-23.296*	5.819	.002	-38.273	-8.319
	Expert	-61.222*	5.819	.000	-76.199	-46.245
Intermediate	Novice	23.296*	5.819	.002	8.319	38.273
	Expert	-37.926*	5.819	.000	-52.903	-22.949
Expert	Novice	61.222*	5.819	.000	46.245	76.199
	Intermediate	37.926*	5.819	.000	22.949	52.903

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Pairwise Comparisons

Measure:MEASURE_1

(I) dist	(J) dist	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	8.556*	2.863	.019	1.187	15.925
	3	24.481*	4.380	.000	13.208	35.755
2	1	-8.556*	2.863	.019	-15.925	-1.187
	3	15.926*	3.363	.000	7.270	24.582
3	1	-24.481*	4.380	.000	-35.755	-13.208
	2	-15.926*	3.363	.000	-24.582	-7.270

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

JOINT ANGLE VARIABILITY AT RELEASE

Within-Subjects Factors

Measure:MEASURE_1

distance	Dependent Variable
1	Wrist_Var_1
2	Wrist_Var_2
3	Wrist_Var_3

Between-Subjects Factors

		Value Label	N
Expertise	1	Novice	9
	2	Intermediate	9
	3	Expert	9

Descriptive Statistics

	Expertise	Mean	Std. Deviation	N
Wrist_Var_1	Novice	8.4118	2.28540	9
	Intermediate	8.7659	3.37379	9
	Expert	12.3066	4.10932	9
	Total	9.8281	3.67649	27
Wrist_Var_2	Novice	8.8938	3.53553	9
	Intermediate	11.8554	4.41477	9
	Expert	9.4917	2.37749	9
	Total	10.0803	3.64421	27
Wrist_Var_3	Novice	9.1586	3.24955	9
	Intermediate	9.1341	2.12806	9
	Expert	10.1087	1.02585	9
	Total	9.4671	2.27599	27

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
distance	Sphericity Assumed	5.129	2	2.564	.489	.616	.020
	Greenhouse-Geisser	5.129	1.424	3.602	.489	.554	.020
	Huynh-Feldt	5.129	1.614	3.177	.489	.577	.020
	Lower-bound	5.129	1.000	5.129	.489	.491	.020
distance * Expertise	Sphericity Assumed	88.115	4	22.029	4.203	.005	.259
	Greenhouse-Geisser	88.115	2.848	30.941	4.203	.014	.259
	Huynh-Feldt	88.115	3.229	27.291	4.203	.010	.259
	Lower-bound	88.115	2.000	44.057	4.203	.027	.259
Error(distance)	Sphericity Assumed	251.555	48	5.241			
	Greenhouse-Geisser	251.555	34.174	7.361			
	Huynh-Feldt	251.555	38.745	6.493			
	Lower-bound	251.555	24.000	10.481			

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	7766.280	1	7766.280	417.311	.000	.946
Expertise	45.085	2	22.542	1.211	.315	.092
Error	446.647	24	18.610			

Pairwise Comparisons

Measure:MEASURE_1

(I) Expertise	(J) Expertise	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Novice	Intermediate	-1.097	1.174	1.000	-4.119	1.925
	Expert	-1.814	1.174	.406	-4.836	1.207
Intermediate	Novice	1.097	1.174	1.000	-1.925	4.119
	Expert	-.717	1.174	1.000	-3.739	2.305
Expert	Novice	1.814	1.174	.406	-1.207	4.836
	Intermediate	.717	1.174	1.000	-2.305	3.739

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Pairwise Comparisons

Measure:MEASURE_1

(I) distance	(J) distance	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.252	.774	1.000	-2.244	1.740
	3	.361	.628	1.000	-1.255	1.977
2	1	.252	.774	1.000	-1.740	2.244
	3	.613	.414	.455	-.453	1.679
3	1	-.361	.628	1.000	-1.977	1.255
	2	-.613	.414	.455	-1.679	.453

Based on estimated marginal means

a.Adjustment for multiple comparisons: Bonferroni.

JOINT ANGLE VARIABILITY AT RELEASE

Within-Subjects Factors

Measure:MEASURE_1

distance	Dependent Variable
1	Wrist_Var_1
2	Wrist_Var_2
3	Wrist_Var_3

Between-Subjects Factors

		Value Label	N
Expertise	1	Novice	9
	2	Intermediate	9
	3	Expert	9

Descriptive Statistics

	Expertise	Mean	Std. Deviation	N
Wrist_Var_1	Novice	8.4118	2.28540	9
	Intermediate	8.7659	3.37379	9
	Expert	12.3066	4.10932	9
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	Intermediate	11.8554	4.41477	9
	Expert	9.4917	2.37749	9
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Wrist_Var_3	Novice	9.1586	3.24955	9
	Intermediate	9.1341	2.12806	9
	Expert	10.1087	1.02585	9
	Total	9.4671	2.27599	27

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
distance	Sphericity Assumed	5.129	2	2.564	.489	.616	.020
	Greenhouse-Geisser	5.129	1.424	3.602	.489	.554	.020
	Huynh-Feldt	5.129	1.614	3.177	.489	.577	.020
	Lower-bound	5.129	1.000	5.129	.489	.491	.020
distance * Expertise	Sphericity Assumed	88.115	4	22.029	4.203	.005	.259
	Greenhouse-Geisser	88.115	2.848	30.941	4.203	.014	.259
	Huynh-Feldt	88.115	3.229	27.291	4.203	.010	.259
	Lower-bound	88.115	2.000	44.057	4.203	.027	.259
Error(distance)	Sphericity Assumed	251.555	48	5.241			
	Greenhouse-Geisser	251.555	34.174	7.361			
	Huynh-Feldt	251.555	38.745	6.493			
	Lower-bound	251.555	24.000	10.481			

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	7766.280	1	7766.280	417.311	.000	.946
Expertise	45.085	2	22.542	1.211	.315	.092
Error	446.647	24	18.610			

Pairwise Comparisons

Measure:MEASURE_1

(I) Expertise	(J) Expertise	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
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	Expert	-1.814	1.174	.406	-4.836	1.207
Intermediate	Novice	1.097	1.174	1.000	-1.925	4.119
	Expert	-.717	1.174	1.000	-3.739	2.305
Expert	Novice	1.814	1.174	.406	-1.207	4.836
	Intermediate	.717	1.174	1.000	-2.305	3.739

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Pairwise Comparisons

Measure:MEASURE_1

(I) distance	(J) distance	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	-.252	.774	1.000	-2.244	1.740
	3	.361	.628	1.000	-1.255	1.977
2	1	.252	.774	1.000	-1.740	2.244
	3	.613	.414	.455	-.453	1.679
3	1	-.361	.628	1.000	-1.977	1.255
	2	-.613	.414	.455	-1.679	.453

Based on estimated marginal means

a.Adjustment for multiple comparisons: Bonferroni.

NORMALISED ROOT MEAN SQUARED DIFFERENCE (ELBOW-SHOULDER JOINT COUPLING)

Within-Subjects Factors

Measure:MEASURE_1

dist	Dependent Variable
1	NoRMS_e_s_1
2	NoRMS_e_s_2
3	NoRMS_e_s_3

Between-Subjects Factors

		Value Label	N
Skill	1	Novice	9
	2	Intermediate	9
	3	Expert	9

Descriptive Statistics

	Skill	Mean	Std. Deviation	N
NoRMS_e_s_1	Novice	10.5467	3.73791	9
	Intermediate	6.4456	2.43859	9
	Expert	4.5367	1.19048	9
	Total	7.1763	3.61853	27
NoRMS_e_s_2	Novice	10.6578	3.15405	9
	Intermediate	6.2622	1.60818	9
	Expert	4.5967	.85626	9
	Total	7.1722	3.29706	27
NoRMS_e_s_3	Novice	9.8956	3.04113	9
	Intermediate	5.8878	1.25185	9
	Expert	5.0622	1.37281	9
	Total	6.9485	2.92151	27

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
dist	Sphericity Assumed	.917	2	.459	.239	.789	.010
	Greenhouse-Geisser	.917	1.894	.484	.239	.777	.010
	Huynh-Feldt	.917	2.000	.459	.239	.789	.010
	Lower-bound	.917	1.000	.917	.239	.630	.010
dist * Skill	Sphericity Assumed	5.079	4	1.270	.661	.622	.052
	Greenhouse-Geisser	5.079	3.789	1.341	.661	.614	.052
	Huynh-Feldt	5.079	4.000	1.270	.661	.622	.052
	Lower-bound	5.079	2.000	2.539	.661	.526	.052
Error(dist)	Sphericity Assumed	92.220	48	1.921			
	Greenhouse-Geisser	92.220	45.463	2.028			
	Huynh-Feldt	92.220	48.000	1.921			
	Lower-bound	92.220	24.000	3.843			

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	4082.074	1	4082.074	342.302	.000	.934
Skill	461.481	2	230.741	19.349	.000	.617
Error	286.209	24	11.925			

Pairwise Comparisons

Measure:MEASURE_1

(I) Skill	(J) Skill	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Novice	Intermediate	4.168*	.940	.001	1.749	6.587
	Expert	5.635*	.940	.000	3.216	8.054
Intermediate	Novice	-4.168*	.940	.001	-6.587	-1.749
	Expert	1.467	.940	.395	-.952	3.886
Expert	Novice	-5.635*	.940	.000	-8.054	-3.216
	Intermediate	-1.467	.940	.395	-3.886	.952

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Pairwise Comparisons

Measure:MEASURE_1

(I) dist	(J) dist	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.004	.382	1.000	-.978	.986
	3	.228	.412	1.000	-.832	1.288
2	1	-.004	.382	1.000	-.986	.978
	3	.224	.334	1.000	-.636	1.084
3	1	-.228	.412	1.000	-1.288	.832
	2	-.224	.334	1.000	-1.084	.636

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Sheffield Hallam University

School of Sport and Leisure Management
Research Ethics Committee

VOLUNTARY INFORMED CONSENT FORM (STUDY 2)

TITLE OF PROJECT: DIOPTRIC BLUR AS A PERFORMANCE PERTURBATION DURING A DISCRETE MULTI-ARTICULAR ACTION

The participant should complete the whole of this sheet himself/herself

Have you read the Participant Information Sheet?	YES/NO
Have you had an opportunity to ask questions and discuss this study?	YES/NO
Have you received satisfactory answers to all of your questions?	YES/NO
Have you received enough information about the study?	YES/NO
To whom have you spoken? .... Do you understand that you are free to withdraw from the study: • at any time • without having to give a reason for withdrawing • and without affecting your future medical care	YES/NO
Have you had sufficient time to consider the nature of this project?	YES/NO
Do you agree to take part in this study?	YES/NO

Signed .... Date ....……………

(NAME IN BLOCK LETTERS)..……………………

Signature of Parent / Guardian in the case of a minor

....

FOR USE WHEN STILL OR MOVING IMAGES WILL BE RECORDED

Consent to scientific illustration
I hereby confirm that I give consent for photographic and/or videotape and sound recordings (the 'material') to be made of me. I confirm that the purpose for which the material would be used has been explained to me in terms which I have understood and I agree to the use of the material in such circumstances. I understand that if the material is required for use in any other way than that explained to me then my consent to this will be specifically sought.
1. I understand that the material will form part of my confidential records and has value in scientific assessment and I agree to this use of the material. Signed.. Date....................................... Signature of Parent / Guardian in the case of a minor ....
2. I understand the material has value in teaching and I consent to the material being shown to appropriate professional staff for the purpose of education, staff training and professional development. Signed.. Date....................................... Signature of Parent / Guardian in the case of a minor ....
I hereby give consent for the photographic recording made of me on...................... to be published in an appropriate journal or textbook. It is understood that I have the right to withdraw consent at any time prior to publication but that once the images are in the public domain there may be no opportunity for the effective withdrawal of consent. Signed .... Date .... Signature of Parent / Guardian in the case of a minor ....

Sheffield Hallam University

School of Sport and Leisure Management

Research Ethics Committee

Risk Assessment Pro Forma (STUDY 2)

Procedure	DIOPTRIC BLUR AS A PERFORMANCE PERTURBATION DURING A DISCRETE MULTI-ARTICULAR ACTION

Assessment Number	

Date Assessed	09/2005

Assessed By	Neil Donovan

Signed	**Position**
	Head Technician

Hazards	**Risks and Specific Control Measures**
Muscle injury to participants	Stretching and warm up to be undertaken prior to data collection
Tripping over camera cabling	Cables to be taped to the floor
Damage to equipment within the laboratory from basketball rebounding off ring	A screen will be situated to protect the desktop computers on trolleys. The retractable net will also be used to protect the cameras and equipment behind the basketball ring. A data collection assistant will also be used to obtain rebounds.
Falling off ladder adjusting cameras	Ladder training conducted by university. Ladders only climbed if supported by another individual.
Mild distress and discomfot caused from blurred vision	Participants will be permitted to remove trial frames between trials and conditions if needed to alleviate discomfort. There will be no lasting psychological effects. Participants will be monitored through data collection for nausea or discomfort.

Risk Evaluation (Overall)
Very low level of risk associated with the procedures. Furthermore, specific control measures will be in situ to avoid injury and/or damage to participants and university property.
General Control Measures
All cabling will be tidied and extraneous equipment removed from the lab and/or relocated into the corner, away from the data collection area. Restricted access to the laboratory and access only granted to permitted individuals. Data collection to be undertaken in the middle of the laboratory at an appropriate location with respect to fixed equipment.

Emergency Procedures
To notify the technicians and contact a first aider in the event of any accident or injury to myself and/or the participant. Maintain a record of contact numbers of emergency staff personnel in the event of accident. In the case of a fire, leave all possessions and all individuals exit via the fire exit to the designated meeting point.

Monitoring Procedures
Regular checks will be done before and after each individual data collection session i.e. per participant.

Review Period	N/A

Reviewed By	Date
N/A	N/A

CONFIDENTIAL

Sheffield Hallam University **School of Sport and Leisure Management** **Research Ethics Committee** **APPLICATION FOR APPROVAL OF RESEARCH (STUDY 2)**	

In designing research involving humans, principal investigators should be able to demonstrate a clear intention of benefit to society and the research should be based on sound principles. These criteria will be considered by the Ethics Committee before approving a project. ALL of the following details must be provided, either typewritten or word-processed preferably at least in 11 point font.

Please either tick the appropriate box or provide the information required.

1. Date of Application	03/10/2005

2. Anticipated Date of Completion	31/12/2005

3. Title of Investigation	The effect of visual acuity on movement variability and shooting performance in basketball

4. Subject Area	Biomechanics / Motor Control

5. Principal Investigator **Email address** **Telephone/mobile number**	Matthew Robins matthewtrobins@hotmail.com matthew.robins@student.shu.ac.uk 0114 2252262 / 07976851531

6. Is this		
6.1 a research project? [✓]		
6.2 an undergraduate project? [ ]	**Unit Name**	**Unit Number**

8. Intended duration and timing of project	3 years (Full-Time)

6.3 a postgraduate project? [ ]		

7. Director of Studies/ Supervisor/Tutor	Professor Ian Maynard
8. Director of Studies/ Supervisor/Tutor	Professor Keith Davids Associate Professor Roger Bartlett Dr. Jonathan Wheat

9. Location of project (If parts are external to SHU, provide evidence in support in section 19)	SHU

10. Is this study	
10.1 Collaborative? [ ]	**If yes please include appropriate agreements in section 19**
10.2.1 Replication [ ] of 10.2.2 New [✓]	Please see: Applegate *et al.* (1992). Set shot shooting performance and visual acuity in basketball. *Optometry and Vision Science*. **69** (10), 765-8.

11. Participants	
11.1 Number	10
11.2 Rationale for this number: (eg calculations of sample size)	Using a dynamical systems framework, it is important to analyse the data using both a multiple single-subject design. This research design accounts for the self-organisation processes specific to each individual whereby performers "search" for unique solutions to the task. However, if trends are common within ability groups the data will be collapsed accordingly. Collapsing the data will allow statistical comparisons to be run as a function of the experimental manipulation e.g. vision. To maintain the continuity between experiments (see Study

	1, and Button et al., 2003), 30 trials will be performed by each participant for each condition, and each ability group will comprise of 10 individuals.
11.3 Criteria for inclusion and exclusion:	Both novice and advanced basketball players are required, as this allows a comparative analysis to be performed upon the dependant variables of interest e.g. scores for movement variability. Specifically, it enables the identification of potential differences that are evident as a function of ability group. For instance, can advanced participants adapt to the changing constraints on performance, and use movement variability to successfully accomplish the task e.g. exploration of phase-space Alternatively, do novices exhibit as much or more variability that is not functional owing to a weak adaptation to the constraints?
11.4 Does the study have *minors or ‡vulnerable adults as participants?	Yes [ ] No [✓]
11.5 Is CRB disclosure required for the Principal Investigator? *(To be determined by risk assessment)*	Yes [ ] No [✓] If yes, is standard [ ] or enhanced [ ] disclosure required?
*Minors are participants under the age of 18 years. ‡Vulnerable adults are participants over the age of 16 years who are likely to exhibit: a) learning difficulties b) physical illness/impairment c) mental illness/impairment d) advanced age e) any other condition that might render them vulnerable	

12. Purpose and benefit of investigation

Statement of the research problem with any necessary background information.

(No more than 1 side of A4)

Although there has been a substantial quantity of literature identifying the effects of task constraints upon motor performance (McDonald *et al.*, 1995, Bennett and Davids, 1997, Fayt *et al.*, 1997, Delignieres *et al.*, 1999, Heijink *et al.*, 2002, Post *et al.*, 2003), the influence of environmental constraints has not received as much attention (Nougier *et al.*, 1993, Savelsburgh and van der Kamp, 2000). One of the key environmental constraints that is manipulated in the research literature is vision. The importance of vision in terms of the regulation and coordination of movement has been stated repeatedly (Bennett and Davids, 1997, Cullen et al., 2001, and Oudejans *et al.*, 2002, 2003). However, vision is usually occluded during segments of the movement i.e. either during the preparation or execution phase of the action, and the effect of blurring vision is rarely addressed (Applegate *et al.*, 1992, and Derriman, 2004). For instance, Applegate *et al.* (1992) found no significant difference in shooting performance of a basketball free-throw when visual acuity was degraded. Derriman (2004) echoed similar results, with batsmen performing equally well with blurred vision as they did with normal / corrected to normal vision.

The findings of both Applegate *et al.* (1992) and Derriman (2004) could be interpreted using the concepts of stochastic resonance and prospective movement control. Stochastic resonance is a nonlinear, statistical dynamic, whereby information flow in a multi-state system is enhanced by the presence of optimized, random noise (see Douglass *et al.*, 1993). Although within a linear system noise can be detrimental to the signal to noise ratio (SNR), intermediate levels of noise can reduce the extent of SNR degradation and thus enhance the ability of non-linear systems to detect particular stimuli (Dykman and McClintock, 1998). This phenomenon has been reported within several biological systems, which include sharks (Braun *et al.*, 1994), paddlefish (Russell *et al.*, 1999), and crayfish (Douglass *et al.*, 1993), and more recently tactile sensation (Cordo *et al.*, 1996, Collins *et al.*, 1996, Waddington and Adams, 2003) and postural control (Priplata *et al.*, 2002) in humans. Stochastic resonance may facilitate enhanced visual control and regulation of the shooting arm in basketball. Chardenon *et al.* (2005) argue that the performer relies continuously on "current action-related information", so that the movement is essentially prospective in nature. This idea emphasises the importance of the perception-action link, one of the seminal concepts of dynamical systems theory. Another important consideration is derived from the findings of Williams and Elliott (1999) who reported that experts were more adept at picking up perceptual information, thereby facilitating performance.

Consequently, the purpose of the study is two-fold:

Firstly, to address whether blurring vision has a cooperative, beneficial effect on movement control. It is hypothesised that the novice participants may not have the capacity to use the available perceptual information to visually regulate the shooting arm successfully. However, blurring vision may assist with this process through the principles of stochastic resonance.

Secondly, to identify the impact of blurring vision on coordination and coordination variability. Another area of interest is how both advanced and novice performers adapt to the changing constraints of the task i.e. visual acuity. It is postulated that advanced performers use the movement variability inherent within the motor system in a functional manner by exploring the available phase-space in search of new solutions to the task.

13. Details of the research design and protocol(s)	
13.1 Provide details. Participants will be asked to perform multiple trials (see Section 11.2) from a distance of 4.25 metres, a distance of 4.25 m equating to the free-throw line. Empirical data suggests that shots are frequently taken from this position during competition (Elliott, 1992), thereby increasing the external validity of the study. Joint kinematics will be collected via an on-line motion analysis system (MAC). 25 retro-reflective markers will be used to define four segments of the body e.g. the hand, lower arm, upper arm and trunk. 30 trials will be performed under 5 vision conditions. A base-line measure will be taken followed by visual acuities of 6/24, 6/48 and 6/75 (see Applegate *et al.*, 1992). Each trial will be rated on a scale from 1-8 (as performed in Study 1). The kinematic data collected will then be used to profile intra-limb coordination of the shooting arm and subsequent movement variability. Coordination will be assessed by means of three joint couplings: wrist-elbow, elbow-shoulder and wrist-shoulder. Movement variability will be measured by the normalised root mean squared difference method (Sidaway *et al.*, 1995) and continuous relative phase using circular statistics (see Batschelet, 1981,and Mardia, 1971). Temporal variables will also be calculated to provide an index of temporal movement control e.g. time to peak flexion / extension, peak velocity / acceleration at release etc? Coordination profiles will also be split into deciles and the magnitude of variability within each identified? Performance outcome (max. 240) can then be related to the key dependant measures of interest.	
13.2 Are these "minor" procedures as defined in Appendix I of the ethics guidelines?	Yes [ ] No [✓]

14. Indicative methods of analysis

14.1 Provide details of the quantitative and qualitative analysis to be used.

It is recommended that single-subject analyses are conducted for studies investigating variability so that subtle nuances are not disguised when collapsing across groups. Therefore, a multiple single-subject design will be implemented. If common trends are exhibited within each ability group, then the data will be collapsed accordingly. The differences for both the spatial and temporal variables of interest will be assessed using a 2 (ability group) * 4 (vision conditions) Mixed ANOVA with repeated measures on vision. An alpha level of $p < 0.05$ will be selected as a sensible compromise between committing a type I and II error. Levels of significance will be supplemented by both effect size and statistical power. A Bonferroni correction will be used to prevent the family-wise error rate by conducting multiple comparisons.

15. Substances to be administered (Refer to Appendix V of the ethics guidelines)

15.1 The protocol does not involve the administration of pharmacologically active substances or nutritional supplements. *(Please tick the box if this statement applies and go to section 16)* [✓]

15.2 Name and state the risk category for each substance. If a COSHH assessment is required state how the risks are to be managed.

16. Degree of discomfort that participants might experience

16.1 To consider the degree of physical or psychological discomfort that will be experienced by the participants. State the details which must be included in the participant information sheet to ensure that the participants are fully informed about any discomfort that they may experience.

The experiment involves multiple repetitions (30 trials), which may predispose the participants to physiological fatigue. The shooting action is also a dynamic throwing task, so the potential for muscle injury should be noted. However, it must be stressed that due to the nature of the task i.e. shooting, the procedure is not *maximal* and does not involve anything which extends beyond regular competition performance. Therefore, the level of fatigue and the likelihood for injury would arguably be negligible. Nonetheless, it should also be stated that there may be a difference with regards to the level of discomfort experienced by each ability group because novices may be more susceptible because they are unaccustomed to the task. Sufficient rest intervals will, therefore, be allowed in order to minimise any intervening effects of fatigue. The main source of discomfort is from altering the quality of optical focus. However, the participants are only subjected to each visual acuity condition for a brief duration. Therefore, no prolonged or detrimental effects will be incurred as a result of the testing protocol.

17. Outcomes of Risk Assessment	

17.1 Provide details of the control measures arising out of the assessment of risk including the nature of supervision and support required during the experimental phase of the project.

During the entire data collection process is it imperative that full supervision and support are provided. Due to the potential risks outlined above (section 16.1), all participants will be continually monitored to ensure they are happy to proceed with the investigation. Appropriate rest intervals will be given to minimise the risk of fatigue and associated injury. It is important to note that longer rest intervals may be appropriate for the novice group. Due to the dynamic nature of the task, the beginning of each session will be dedicated to a thorough warm-up. This ensures that the participants are fully prepared for the task and again minimises the likelihood of injury. Prior to data collection all instructions and guidelines will be given so that the participants are made fully aware of the procedure, and that they understand they are able to withdraw at any time during the experiment.

18. Safe System of Work	

18.1 Indicate how the control measures outlined in section 17.1 will be implemented to minimise the risks in undertaking the research protocol (refer to 13.1). State the technical skills needed by the Principal Investigator to ensure safe working.

It is important that the testing environment (Biomechanics Laboratory) is tidy and all cable / wiring is taped down. Sufficient time will be allowed during data collection to both warm-up and clarify any questions and ensure that the participants are happy to continue with the investigation.

19. Attachments *(Place a tick in the appropriate description)*	
19.1 Risk Assessment(s) (Include CRB risk assessment)	[ ]
19.2 COSHH Assessment	[ ]
19.2 Participant Information Sheet	[ ]
19.3 Informed Consent Form	[ ]
19.4 Pre-Test Medical Questionnaire	[ ]
19.5 Collaboration evidence/support (see 10)	[ ]
19.6 Collaboration facilities (see 9)	[ ]
19.7 Clinical Trials Form (FIN 12)	[ ]

20. Signature Principal Investigator	**Once this application is approved, I will undertake the study as approved. If circumstances necessitate that changes are made to the approved protocol, I will discuss these with my Project Supervisor. If the supervisor advises that there should be a resubmission to the Ethics Committee, I agree that no work will be carried out using the changed protocol until approval has been sought and formally received.** **M. Robins .... Principal Investigator**
21. Approval Project Supervisor to sign off **EITHER** box A **OR** box B as applicable. *(refer to Appendix I and the flowchart in appendix VI of the ethics guidelines)*	**Box A:** **I confirm that the experimental protocol contained in this proposal is based solely on 'minor' procedures, as outlined in Appendix 1 of the School's Ethics Procedures for the Use of Humans in Research document, and therefore does not need to be submitted to the SLMREC.** **In terms of ethics approval, I agree the 'minor' procedures proposed here and confirm that the Principal Investigator may proceed with the study as designed.** **Project Supervisor ………………………………………..........Date ………….....**
	Box B: **I confirm that the experimental protocol contained in this proposal is not based solely on 'minor' procedures, as outlined in Appendix 1 of the School's Ethics Procedures for the Use of Humans in Research document, and therefore must be submitted to the SLMREC for approval.** **I confirm that the appropriate preparatory work has been undertaken and that this document is in a fit state for submission to SLMREC.** **Project Supervisor……………………………………………… Date …………....**

Sheffield Hallam University

School of Sport and Leisure Management

Research Ethics Committee

Participant Information Sheet (STUDY 2)

Project Title	The effect of visual acuity on movement variability ar shooting performance in basketball

Name of Participant	

Supervisor/Director of Studies	Dr. Jonathan Wheat

Principal Investigator	Matthew Robins

Purpose of Study and Brief Description of Procedures
(Not a legal explanation but a simple statement)

The purpose of the study is to identify how movement variability (specifically continuous coordination variability and segment end-point variability), changes with both visual acuity and ability level. This will provide an insight into how participants of differing ability respond to changes in vision, caused by introducing myopic blur. Myopic blur will be introduced by wearing a pair of trial frames that allow spherical lenses to be inserted in front of the eyes. The procedure involves using the on-line motion analysis system and attaching reflective markers to the torso and shooting arm. Twenty shots will then be performed for each of the four visual conditions: Baseline (Plano), +1.00 D, +2.00 D and +3.00 D. The +3.00 D condition is equivalent to the legal blindness limit. Sufficient rest will be allowed during data collection to prevent any intervening effects of fatigue. You may also remove the glasses in between trials to alleviate any discomfort caused by changes in vision quality.

If necessary continue overleaf

It has been made clear to me that, should I feel that these Regulations are being infringed or that my interests are otherwise being ignored, neglected or denied, I should inform Professor Edward Winter, Chair of the School of Sport and Leisure Management Research Ethics Committee (Tel: 0114 225 4333) who will undertake to investigate my complaint.

CSAI-2

The effects of highly competitive sports can be powerful and very different among athletes. The inventory you are about to complete measures how you generally feel about competition. Please complete the inventory as honestly as you can. Sometimes athletes feel that they should not admit to any nervousness, anxiety or worry they experience before competition because this is undesirable. Actually, these feelings are quite common, and to help me understand them I want you to share your feelings with me openly. If you worry about competition or have butterflies or other feelings that you know are signs of anxiety, please indicate these feelings accurately on the inventory. Equally, if you feel calm and relaxed, indicate those feelings as accurately as you can. Your answers will not be shared with anyone. I will be looking only at group responses. Please remember that you are responding to how you generally feel about competition.

Instructions : A number of statements which athletes have used to describe their feelings before competition are given below. The questionnaire is divided into 2 sections. Read each statement and then circle the appropriate number, in each of the two sections, to the right statement to indicate how you generally feel.. There are no right or wrong answers. Do not spend too much time on any one statement, but choose the answer which describes your general feelings / feelings right now.

When you have this thought/ feeling do you normally regard it as negative (debilitative) or positive (facilitative) in relation to your upcoming performance. NB. if you have scored '1' (not at all) on the first scale, then respond in relation to that feeling e.g. If you respond 'not at all' to question 4, then you would respond on this scale as if you had no self-doubts

INTENSITY SCALE **DIRECTION SCALE**

	not at all	somewhat	moderately so	very much so	Very negative (i.e. debilitative)			Unimportant			Very positive (i.e. facilitative)
1. I am concerned about this competition	1	2	3	4	-3	-2	-1	0	+1	+2	+3
2. I feel nervous	1	2	3	4	-3	-2	-1	0	+1	+2	+3
3. I feel at ease	1	2	3	4	-3	-2	-1	0	+1	+2	+3
4. I have self doubts	1	2	3	4	-3	-2	-1	0	+1	+2	+3
5. I feel jittery	1	2	3	4	-3	-2	-1	0	+1	+2	+3
6. I feel comfortable	1	2	3	4	-3	-2	-1	0	+1	+2	+3
7. I am concerned that I may not do as											

well in this competition as I could	1	2	3	4	-3	-2	-1	0	+1	+2	+3
8. My body feels tense	1	2	3	4	-3	-2	-1	0	+1	+2	+3
9. I feel self-confident	1	2	3	4	-3	-2	-1	0	+1	+2	+3

	not at all	**somewhat**	**moderately so**	**very much so**	**Very negative (i.e. debilitative)**		**Unimportant**			**Very positive (i.e. facilitative)**	
10. I am concerned about losing	1	2	3	4	-3	-2	-1	0	+1	+2	+3
11. I feel tense in my stomach	1	2	3	4	-3	-2	-1	0	+1	+2	+3
12. I feel secure	1	2	3	4	-3	-2	-1	0	+1	+2	+3
13. I am concerned about choking under pressure	1	2	3	4	-3	-2	-1	0	+1	+2	+3
14. My body feels relaxed	1	2	3	4	-3	-2	-1	0	+1	+2	+3
15. I am confident I can meet the challenge	1	2	3	4	-3	-2	-1	0	+1	+2	+3
16. I am concerned about performing poorly	1	2	3	4	-3	-2	-1	0	+1	+2	+3
17. My heart is racing	1	2	3	4	-3	-2	-1	0	+1	+2	+3
18. I'm confident about performing well	1	2	3	4	-3	-2	-1	0	+1	+2	+3
19. I'm worried about reaching my goal	1	2	3	4	-3	-2	-1	0	+1	+2	+3
20. I feel my stomach sinking	1	2	3	4	-3	-2	-1	0	+1	+2	+3
21. I feel mentally relaxed	1	2	3	4	-3	-2	-1	0	+1	+2	+3
22. I'm concerned that others will be disappointed with my performance	1	2	3	4	-3	-2	-1	0	+1	+2	+3
23. My hands are clammy	1	2	3	4	-3	-2	-1	0	+1	+2	+3

24. I'm confident because I mentally picture myself reaching my goal	1	2	3	4	-3	-2	-1	0	+1	+2	+3
25. I'm concerned I won't be able to concentrate	1	2	3	4	-3	-2	-1	0	+1	+2	+3
26. My body feels tight	1	2	3	4	-3	-2	-1	0	+1	+2	+3
27. I'm confident at coming through under pressure	1	2	3	4	-3	-2	-1	0	+1	+2	+3

Sheffield Hallam University

School of Sport and Leisure Management
Research Ethics Committee

VOLUNTARY INFORMED CONSENT FORM (STUDY 3)

TITLE OF PROJECT: EFFECTS OF EXPERTISE AND ANXIETY ON ATTENTIONAL STRATEGIES AND JOINT KINEMATICS DURING A DISCRETE MULTI-ARTICULAR ACTION

The participant should complete the whole of this sheet himself/herself

Have you read the Participant Information Sheet?	YES/NO
Have you had an opportunity to ask questions and discuss this study?	YES/NO
Have you received satisfactory answers to all of your questions?	YES/NO
Have you received enough information about the study?	YES/NO
To whom have you spoken? .... Do you understand that you are free to withdraw from the study: • at any time • without having to give a reason for withdrawing • and without affecting your future medical care	YES/NO
Have you had sufficient time to consider the nature of this project?	YES/NO
Do you agree to take part in this study?	YES/NO

Signed .... Date ....

(NAME IN BLOCK LETTERS)...

Signature of Parent / Guardian in the case of a minor

....

FOR USE WHEN STILL OR MOVING IMAGES WILL BE RECORDED

Consent to scientific illustration
I hereby confirm that I give consent for photographic and/or videotape and sound recordings (the 'material') to be made of me. I confirm that the purpose for which the material would be used has been explained to me in terms which I have understood and I agree to the use of the material in such circumstances. I understand that if the material is required for use in any other way than that explained to me then my consent to this will be specifically sought.
1. I understand that the material will form part of my confidential records and has value in scientific assessment and I agree to this use of the material. Signed.. Date....................................... Signature of Parent / Guardian in the case of a minor ....
2. I understand the material has value in teaching and I consent to the material being shown to appropriate professional staff for the purpose of education, staff training and professional development. Signed.. Date....................................... Signature of Parent / Guardian in the case of a minor ....
I hereby give consent for the photographic recording made of me on...................... to be published in an appropriate journal or textbook. It is understood that I have the right to withdraw consent at any time prior to publication but that once the images are in the public domain there may be no opportunity for the effective withdrawal of consent. Signed .... Date .... Signature of Parent / Guardian in the case of a minor ....

Sheffield Hallam University

School of Sport and Leisure Management

Research Ethics Committee

Risk Assessment Pro Forma (STUDY 3)

Procedure	EFFECTS OF EXPERTISE AND ANXIETY ON ATTENTIONAL STRATEGIES AND JOINT KINEMATICS DURING DISCRETE MULTI-ARTICULAR ACTION

Assessment Number	

Date Assessed	09/2005

Assessed By	Neil Donovan

Signed	**Position**
	Head Technician

Hazards	**Risks and Specific Control Measures**
Muscle injury to participants	Stretching and warm up to be undertaken prior to data collection
Tripping over camera cabling	Cables to be taped to the floor
Damage to equipment within the laboratory from basketball rebounding off ring	A screen will be situated to protect the desktop computers on trolleys. The retractable net will also be used to protect the cameras and equipment behind the basketball ring. A data collection assistant will also be used to obtain rebounds.
Falling off ladder adjusting cameras	Ladder training conducted by university. Ladders only climbed if supported by another individual.
Elevated anxiety caused by psychological intervention	Anxiety intervention is not considered to be severe and is in line with past research. There will be no lasting psychological effects. Participants will be monitored throughout data collection.

Risk Evaluation (Overall)
Very low level of risk associated with the procedures. Furthermore, specific control measures will be in situ to avoid injury and/or damage to participants and university property.
General Control Measures
All cabling will be tidied and extraneous equipment removed from the lab and/or relocated into the corner, away from the data collection area. Restricted access to the laboratory and access only granted to permitted individuals. Data collection to be undertaken in the middle of the laboratory at an appropriate location with respect to fixed equipment.

Emergency Procedures
To notify the technicians and contact a first aider in the event of any accident or injury to myself and/or the participant. Maintain a record of contact numbers of emergency staff personnel in the event of accident. In the case of a fire, leave all possessions and all individuals exit via the fire exit to the designated meeting point.

Monitoring Procedures
Regular checks will be done before and after each individual data collection session i.e. per participant.

Review Period	N/A

Reviewed By	**Date**
N/A	N/A

Sheffield Hallam University **School of Sport and Leisure Management** **Research Ethics Committee** **APPLICATION FOR APPROVAL OF RESEARCH (STUDY 3)**	

In designing research involving humans, principal investigators should be able to demonstrate a clear intention of benefit to society and the research should be based on sound principles. These criteria will be considered by the Ethics Committee before approving a project. ALL of the following details must be provided, either typewritten or word-processed preferably at least in 11 point font.

Please either tick the appropriate box or provide the information required.

1. Date of Application	03/10/2005
2. Anticipated Date of Completion	30/4/2005
3. Title of Investigation	The influence of anxiety on movement variability and shooting performance in basketball
4. Subject Area	Biomechanics / Motor Control
5. Principal Investigator	Matthew Robins
Email address	matthewtrobins@hotmail.com matthew.robins@student.shu.ac.uk
Telephone/mobile number	0114 2252262 / 07976851531

6. Is this		
6.1 a research project? [✓]		
6.2 an undergraduate project? [ ]	**Unit Name**	**Unit Number**

8. Intended duration and timing of project	3 years (Full-Time)

6.3 a postgraduate project? [ ]		

7. Director of Studies/ Supervisor/Tutor	Professor Ian Maynard Professor Keith Davids Associate Professor Roger Bartlett Dr. Jonathan Wheat

9. Location of project (If parts are external to SHU, provide evidence in support in section 19)	SHU

10. Is this study	
10.1 Collaborative? [ ]	**If yes please include appropriate agreements in section 19**
10.2.1 Replication [ ] of 10.2.2 New [✓]	Please see: Court *et al.* (2005). Anxiety constraints on co-ordination dynamics: Can attentional strategies mediate perturbations to rhythmical task performance. *Neuroscience Letters*. **384**, 17-22.

11. Participants	
11.1 Number	10
11.2 Rationale for this number: (eg calculations of sample size)	Using a dynamical systems framework, it is important to analyse the data using both a multiple single-subject design. This research design accounts for the self-organisation processes specific to each individual whereby performers “search” for unique solutions to the task. However, if trends are common within ability groups the data will be collapsed accordingly. Collapsing the data will allow statistical comparisons to be run as a function of the experimental manipulation e.g. anxiety. To maintain the continuity between experiments (see

	Study 1 & 2, and Button et al., 2003), 30 trials will be performed by each participant for each condition, and each ability group will comprise of 10 individuals.
11.3 Criteria for inclusion and exclusion:	Both novice and advanced basketball players are required, as this allows a comparative analysis to be performed upon the dependant variables of interest e.g. scores for movement variability. Specifically, it enables the identification of potential differences in coping strategy as a function of ability group. For instance, how does anxiety influence joint amplitude and movement variability in novices and advanced performers respectively, and can advanced participants alleviate the detrimental effects of anxiety by increasing the attentional demands of the task?
11.4 Does the study have *minors or ‡vulnerable adults as participants?	Yes [ ] No [✓]
11.5 Is CRB disclosure required for the Principal Investigator? *(To be determined by risk assessment)*	Yes [ ] No [✓] If yes, is standard [ ] or enhanced [ ] disclosure required?
*Minors are participants under the age of 18 years. ‡Vulnerable adults are participants over the age of 16 years who are likely to exhibit: a) learning difficulties b) physical illness/impairment c) mental illness/impairment d) advanced age e) any other condition that might render them vulnerable	

12. Purpose and benefit of investigation
Statement of the research problem with any necessary background information. *(No more than 1 side of A4)*

Despite the extensive research interest into understanding the ramifications of anxiety upon performance, very few researchers have identified the effect of anxiety upon joint kinematics (Beuter and Duda, 1985, Beuter *et al.*, 1989, Williams *et al.*, 2002), movement variability (Higuchi *et al.*, 2002), coordination dynamics (Court *et al.*, 2004) or compared advanced and novice performers (Williams and Elliott, 1999). The findings pertaining to the influence of anxiety on movement kinematics also appear equivocal. Higuchi *et al.* (2002) reported a reduction in joint amplitude and movement variability with psychological stress, whereas, Williams *et al.* (2002) found no significant differences in movement kinematics during the execution of a table-tennis shot when exposed to either low or high anxiety conditions. These opposing findings could have been an artefact of the variables assessed because no coordination profiling or joint angle calculations were performed, and the kinematic analysis was restricted to movement time, mean ball velocity, initial position, arm velocity at contact, and peak arm velocity.

However, the findings could be explained using Eysenck and Calvo's Processing Efficiency Theory (Eysenck and Calvo, 1992) which segregates performance into two "categories": performance effectiveness and performance efficiency. Williams *et al.* (2002) discovered that performance efficiency was impaired to a greater extent than performance effectiveness. Similar findings have also been reported for rhythmic arm movements (Court *et al.*, 2004), reaching movements in rock climbing (Bourdin *et al.*, 1998) and visual search strategies in karate (Williams and Elliott, 1999) and during a racing simulation (Murray and Janelle, 2003). Processing efficiency theory proposes that anxiety impairs the working memory and creates biased attention towards phobic stimuli. Increased anxiety therefore requires increased attentional resources which reduces performance efficiency i.e. the efficiency by which information is processed and acted upon, and subsequently could be detrimental to performance (see Janelle, 2002). However, as highlighted above, performance effectiveness appears to be preserved by elevating the attentional demands of the task. For instance, Court *et al.* (2004) found that when participants performed a flexion-extension exercise of the forearm, the transition to the in-phase mode from the anti-phase pattern of motion occurred later into the trial when participants were significantly anxious. It was suggested that by increasing the attentional demands of the task, the participants were able to suppress the tendency to switch toward the in-phase pattern of coordination.

It would therefore be interesting to discover how coordination, coordination variability and joint amplitude of advanced and novice basketball players change under conditions of low and high anxiety. For instance, advanced basketball players have been found to possess greater movement variability at closer distances, which was suggested to allow flexibility in the movement system and facilitate exploration of the available phase-space (Robins *et al.*, under review). Therefore, can expert performers maintain this movement variability exhibited by the shooting arm under conditions of high anxiety by elevating the attentional demands of the task? Can this strategy be extended from single degree of freedom actions e.g. rhythmic finger movements, to more complex multi-articular movements? Alternatively, do they employ a more constrained pattern of motion as seen by Higuchi *et al.* (2003), which requires less monitoring and correction being directed by cognitive processing?

A secondary question is how do these coping strategies differ between both advanced and novices participants, because Williams and Elliott (1999) observed varying effects of anxiety as a function of ability level, with Janelle (2002) proposing that experts may be capable of mediating the negative effects of anxiety to a greater extent than novices. It is therefore important to identify whether these findings extend to multi-articular, dynamic tasks such as basketball shooting to ascertain whether increasing anxiety alters co-ordination of the shooting arm and subsequent movement variability.

13. Details of the research design and protocol(s)

13.1 Provide details.

This investigation involves comparing the effects of anxiety on processing efficiency, coordination and coordination variability in advanced and novice basketball performers. Participants will be asked to perform multiple trials (see Section 11.2) from a distance of 4.25 metres, this distance equating to the free-throw line. Empirical data suggests that shots are frequently taken from this position during competition (Elliott, 1992), thereby increasing the external validity of the study. Joint kinematics will be collected via an on-line motion analysis system (MAC). 25 retro-reflective markers will be used to define four segments of the body e.g. the hand, lower arm, upper arm and trunk. 30 trials will be performed by each participant under low (control) and high anxiety conditions. Each trial will be rated on a scale from 1-8 (as performed in Study 1). A state of high anxiety will be induced by social mechanisms e.g. "assessor", audience and a financial incentive. Both of these methods have been deemed successful for manipulating anxiety (see Chell, unpublished). A CSAI-2 will be completed prior to undertaking the basketball shooting trials. To calculate processing efficiency, a dual-task paradigm will be used, with the aid of a beeper and microphone being integrated into the MAC system. This secondary task will be a vocal reaction time test performed during the execution phase of the movement. The kinematic data collected will then be used to profile intra-limb coordination of the shooting arm and subsequent movement variability. Therefore, both performance outcome measures (max. of 240) and movement variability scores can be related to processing efficiency e.g. can participants maintain performance by increasing the attentional demands of the task.

13.2 Are these "minor" procedures as defined in Appendix I of the ethics guidelines?	Yes [✓] No [ ]

14. Indicative methods of analysis

14.1 Provide details of the quantitative and qualitative analysis to be used.

It is recommended that single-subject analyses are conducted for studies investigating variability so that subtle nuances are not disguised when collapsing across groups. Therefore, a multiple single-subject design will be implemented. If common trends are exhibited within each ability group, then the data will be collapsed accordingly. The differences for each of the dependant variables e.g. reaction time, performance outcome and movement variability will be assessed using paired t-tests. An alpha level of $p < 0.05$ will be selected as a sensible compromise between committing a type I and II error. Levels of significance will be supplemented by both effect size and statistical power. A Bonferroni correction will be used to prevent the family-wise error rate by conducting multiple comparisons.

15. Substances to be administered (Refer to Appendix V of the ethics guidelines)

15.1 The protocol does not involve the administration of pharmacologically active substances or nutritional supplements. *(Please tick the box if this statement applies and go to section 16)* [ ]

15.2 Name and state the risk category for each substance. If a COSHH assessment is required state how the risks are to be managed.

16. Degree of discomfort that participants might experience

16.1 To consider the degree of physical or psychological discomfort that will be experienced by the participants. State the details which must be included in the participant information sheet to ensure that the participants are fully informed about any discomfort that they may experience.

The experiment involves multiple repetitions (30 trials), which may predispose the participants to physiological fatigue. The shooting action is also a dynamic throwing task, so the potential for muscle injury should be noted. However, it must be stressed that due to the nature of the task i.e. shooting, the procedure is not *maximal* and does not involve anything which extends beyond regular competition performance. Therefore, the level of fatigue and the likelihood for injury would arguably be negligible. Nonetheless, it should also be stated that there may be a difference with regards to the level of discomfort experienced by each ability group because novices may be more susceptible because they are unaccustomed to the task. Sufficient rest intervals will, therefore, be allowed in order to minimise any intervening effects of fatigue. The anxiety manipulation is solely performed by social mechanisms e.g. an assessor and financial incentive, and is commonplace amongst psychological studies. The level of discomfort is deemed negligible.

17. Outcomes of Risk Assessment

17.1 Provide details of the control measures arising out of the assessment of risk including the nature of supervision and support required during the experimental phase of the project.

During the entire data collection process is it imperative that full supervision and support are provided. Due to the potential risks outlined above (section 16.1), all participants will be continually monitored to ensure they are happy to proceed with the investigation. Appropriate rest intervals will be given to minimise the risk of fatigue and associated injury. It is important to note that longer rest intervals may be appropriate for the novice group. Due to the dynamic nature of the task, the beginning of each session will be dedicated to a thorough warm-up. This ensures that the participants are fully prepared for the task and again minimises the likelihood of injury. Prior to data collection all instructions and guidelines will be given so that the participants are made fully aware of the procedure, and that they understand they are able to withdraw at any time during the experiment.

18. Safe System of Work

18.1 Indicate how the control measures outlined in section 17.1 will be implemented to minimise the risks in undertaking the research protocol (refer to 13.1). State the technical skills needed by the Principal Investigator to ensure safe working.

It is important that the testing environment (Biomechanics Laboratory) is tidy and all cable / wiring is taped down. Sufficient time will be allowed during data collection to both warm-up and clarify any questions and ensure that the participants are happy to continue with the investigation.

19. Attachments *(Place a tick in the appropriate description)*	
19.1 Risk Assessment(s) (Include CRB risk assessment)	[ ]
19.2 COSHH Assessment	[ ]
19.2 Participant Information Sheet	[ ]
19.3 Informed Consent Form	[ ]
19.4 Pre-Test Medical Questionnaire	[ ]
19.5 Collaboration evidence/support (see 10)	[ ]
19.6 Collaboration facilities (see 9)	[ ]
19.7 Clinical Trials Form (FIN 12)	[ ]

20. Signature Principal Investigator	**Once this application is approved, I will undertake the study as approved. If circumstances necessitate that changes are made to the approved protocol, I will discuss these with my Project Supervisor. If the supervisor advises that there should be a resubmission to the Ethics Committee, I agree that no work will be carried out using the changed protocol until approval has been sought and formally received.** **M. Robins .... Principal Investigator**
21. Approval Project Supervisor to sign off **<u>EITHER</u>** box A **<u>OR</u>** box B as applicable. *(refer to Appendix I and the flowchart in appendix VI of the ethics guidelines)*	**Box A:** **I confirm that the experimental protocol contained in this proposal is based solely on 'minor' procedures, as outlined in Appendix 1 of the School's Ethics Procedures for the Use of Humans in Research document, and therefore does not need to be submitted to the SLMREC.** **In terms of ethics approval, I agree the 'minor' procedures proposed here and confirm that the Principal Investigator may proceed with the study as designed.** **Project Supervisor …………………………………………...........Date …………....**
	Box B: **I confirm that the experimental protocol contained in this proposal is <u>not</u> based solely on 'minor' procedures, as outlined in Appendix 1 of the School's Ethics Procedures for the Use of Humans in Research document, and therefore <u>must</u> be submitted to the SLMREC for approval.** **I confirm that the appropriate preparatory work has been undertaken and that this document is in a fit state for submission to SLMREC.** **Project Supervisor……………………………………………… Date ……………....**

Sheffield Hallam University

School of Sport and Leisure Management

Research Ethics Committee

Participant Information Sheet (STUDY 3)

Project Title	The influence of anxiety on movement variability and shooting performance in basketball.

Name of Participant	

Supervisor/Director of Studies	Dr. Jonathan Wheat

Principal Investigator	Matthew Robins

Purpose of Study and Brief Description of Procedures
(Not a legal explanation but a simple statement)

The purpose of the study is to assess the impact of anxiety and task expertise on shooting performance and movement variability during a basketball free throw. Moreover, the study aims to ascertain whether individuals differing in expertise respond and adapt to anxiety differently. This will provide an insight not only into the effects of anxiety on joint kinematics and movement variability, but into how attentional resources are allocated as a function of skill. The procedure involves using the on-line motion analysis system and attaching 25 reflective markers to the torso and shooting arm. Thirty shots will then be performed from a distance of 4.25 metres (free-throw line), under a control and anxiety condition. The outcome of each shot will be rated using an objective assessment scale (modified from Landin *et al.*, 1993). Sufficient rest will be allowed during data collection to prevent any intervening effects of fatigue. To measure the allocation of attentional resources, a dual-task paradigm will be used, whereby players respond vocally ("Shot") to an auditory stimulus whilst executing each performance trial.

If necessary continue overleaf

It has been made clear to me that, should I feel that these Regulations are being infringed or that my interests are otherwise being ignored, neglected or denied, I should inform Professor Edward Winter, Chair of the School of Sport and Leisure Management Research Ethics Committee (Tel: 0114 225 4333) who will undertake to investigate my complaint.

Sheffield Hallam University

School of Sport and Leisure Management
Research Ethics Committee

VOLUNTARY INFORMED CONSENT FORM (STUDY 4)

TITLE OF PROJECT: FOCUS OF ATTENTION AND DISCRETE ACTION PERFORMANCE: A PROCESS-ORIENTED APPROACH

The participant should complete the whole of this sheet himself/herself

Have you read the Participant Information Sheet?	YES/NO
Have you had an opportunity to ask questions and discuss this study?	YES/NO
Have you received satisfactory answers to all of your questions?	YES/NO
Have you received enough information about the study?	YES/NO
To whom have you spoken? .... Do you understand that you are free to withdraw from the study: • at any time • without having to give a reason for withdrawing • and without affecting your future medical care	YES/NO
Have you had sufficient time to consider the nature of this project?	YES/NO
Do you agree to take part in this study?	YES/NO

Signed .... Date ....

(NAME IN BLOCK LETTERS)..

Signature of Parent / Guardian in the case of a minor

....

FOR USE WHEN STILL OR MOVING IMAGES WILL BE RECORDED

Consent to scientific illustration
I hereby confirm that I give consent for photographic and/or videotape and sound recordings (the 'material') to be made of me. I confirm that the purpose for which the material would be used has been explained to me in terms which I have understood and I agree to the use of the material in such circumstances. I understand that if the material is required for use in any other way than that explained to me then my consent to this will be specifically sought.
1. I understand that the material will form part of my confidential records and has value in scientific assessment and I agree to this use of the material. Signed.. Date.. Signature of Parent / Guardian in the case of a minor ....
2. I understand the material has value in teaching and I consent to the material being shown to appropriate professional staff for the purpose of education, staff training and professional development. Signed.. Date.. Signature of Parent / Guardian in the case of a minor ....
I hereby give consent for the photographic recording made of me on...................... to be published in an appropriate journal or textbook. It is understood that I have the right to withdraw consent at any time prior to publication but that once the images are in the public domain there may be no opportunity for the effective withdrawal of consent. Signed .... Date .... Signature of Parent / Guardian in the case of a minor ....

Sheffield Hallam University

School of Sport and Leisure Management

Research Ethics Committee

Risk Assessment Pro Forma (STUDY 4)

Procedure	FOCUS OF ATTENTION AND DISCRETE ACTIO PERFORMANCE: A PROCESS-ORIENTED APPROACH

Assessment Number	

Date Assessed	10/2006

Assessed By	Neil Donovan

Signed	**Position**
	Head Technician

Hazards	**Risks and Specific Control Measures**
Muscle injury to participants	Stretching and warm up to be undertaken prior to data collection
Tripping over camera cabling	Cables to be taped to the floor
Damage to equipment within the laboratory from basketball rebounding off ring	A screen will be situated to protect the desktop computers on trolleys. The retractable net will also be used to protect the cameras and equipment behind the basketball ring. A data collection assistant will also be used to obtain rebounds.
Falling off ladder adjusting cameras	Ladder training conducted by university. Ladders only climbed if supported by another individual.

Risk Evaluation (Overall)
Very low level of risk associated with the procedures. Furthermore, specific control measures will be in situ to avoid injury and/or damage to participants and university property.
General Control Measures
All cabling will be tidied and extraneous equipment removed from the lab and/or relocated into the corner, away from the data collection area. Restricted access to the laboratory and access only granted to permitted individuals. Data collection to be undertaken in the middle of the laboratory at an appropriate location with respect to fixed equipment.

Emergency Procedures
To notify the technicians and contact a first aider in the event of any accident or injury to myself and/or the participant. Maintain a record of contact numbers of emergency staff personnel in the event of accident. In the case of a fire, leave all possessions and all individuals exit via the fire exit to the designated meeting point.

Monitoring Procedures
Regular checks will be done before and after each individual data collection session i.e. per participant.

Review Period	N/A

Reviewed By	Date
N/A	N/A

CONFIDENTIAL

Sheffield Hallam University **School of Sport and Leisure Management** **Research Ethics Committee** **APPLICATION FOR APPROVAL OF RESEARCH (STUDY 4)**	

In designing research involving humans, principal investigators should be able to demonstrate a clear intention of benefit to society and the research should be based on sound principles. These criteria will be considered by the Ethics Committee before approving a project. ALL of the following details must be provided, either typewritten or word-processed preferably at least in 11 point font.

Please either tick the appropriate box or provide the information required.

1. Date of Application	10/2006

2. Anticipated Date of Completion	3/2007

3. Title of Investigation	FOCUS OF ATTENTION AND DISCRETE ACTION PERFORMANCE: A PROCESS-ORIENTED APPROACH

4. Subject Area	Biomechanics

5. Principal Investigator	Matthew Robins
Email address	matthewtrobins@hotmail.com
Telephone/mobile number	0114 2252262 / 07941034571

6. Is this		
6.1 a research project? [✓]		
6.2 an undergraduate project? [ ]	**Unit Name**	**Unit Number**

8. Intended duration and timing of project	3 years (Full-Time)

6.3 a postgraduate project? [ ]		

7. Director of Studies/ Supervisor/Tutor	Professor Ian Maynard

9. Location of project (If parts are external to SHU, provide evidence in support in section 19)	SHU

10. Is this study	
10.1 Collaborative? [ ]	**If yes please include appropriate agreements in section 19**
10.2.1 Replication [ ] of	
10.2.2 New [✓]	

11. Participants	
11.1 Number	15
11.2 Rationale for this number: (eg calculations of sample size)	Due to longitudinal nature of the learning intervention, 15 participants was deemed to be a sensible compromise between convenience sampling, bearing in mind the logistical challenges afforded by this study, and gaining sufficient statistical power to detect differences between treatment groups.
11.3 Criteria for inclusion and exclusion:	Novice participants are required for this study. Participants are deemed to be novice based on performance pre-test scores as well as information gleaned from a participant pro-forma, outlining previous basketball playing experience and highest level of competition etc. These stringent measures are commensurate with those used within other studies forming part of this PhD programme of work.

11.4 Does the study have *minors or ‡vulnerable adults as participants?	Yes [ ] No [✓]
11.5 Is CRB disclosure required for the Principal Investigator? *(To be determined by risk assessment)*	Yes [ ] No [✓] If yes, is standard [ ] or enhanced [ ] disclosure required?
*Minors are participants under the age of 18 years. ‡Vulnerable adults are participants over the age of 16 years who are likely to exhibit: a) learning difficulties b) physical illness/impairment c) mental illness/impairment d) advanced age e) any other condition that might render them vulnerable	

12. Purpose and benefit of investigation
Statement of the research problem with any necessary background information.
(No more than 1 side of A4)

Following the initial, seminal work by Wulf *et al.* (1998a), there has been much research proposing the beneficial effects of an external focus of attention. An external focus has been suggested to improve motor performance (Zachry *et al.*, 2005; Wulf *et al.*, 2007; Wulf, 2008; Wulf and Dufek, 2009), motor skill retention (Shea and Wulf, 1999; Wulf *et al.*, 1999; Wulf *et al.*, 2002; Wulf and Su, 2007; Chiviacowsky *et al.*, 2010), and motor skill transfer (Totsika and Wulf, 2003; Lohse, 2012). The benefits associated with external focus of attention have been explained using the constrained action hypothesis (Wulf *et al.*, 2001b; McNevin *et al.*, 2003). The constrained action hypothesis formed a logical extension to the common coding principle and advocates that an external focus of attention permits unconscious or automatic processes to control movement. An internal focus of attention, conversely, causes participants to consciously intervene in these control processes and inadvertently disrupt the coordination of reflexive and self-organising processes (McNevin *et al.*, 2003). This theoretical explanation is congruent with existing empirical data pertaining to focus dependent changes in postural control (McNevin and Wulf, 2002; Wulf *et al.*, 2003; Chiviacowsky *et al.*, 2010), attentional cost (Wulf *et al.*, 2001a), and movement economy (Vance *et al.*, 2004; Zachry *et al.*, 2005; Marchant *et al.*, 2009; Wulf *et al.*, 2010). However, from a methodological perspective, one of the challenges for experimentation on focus of attention is the exploration of potential internal focus benefits. The practical implications derived from the attentional focus research appear to signify that coaches should refrain from giving instructions relating to body movements, and instead, encourage participants to focus on the effects of their movements (see James, 2012). However, there is still a lack of clarity as to whether an external focus of attention is *universally* advantageous irrespective of task expertise. This is because the existing programme of attentional focus research routinely uses rather vague internal focus statements, such as focus on the swinging motion of the arms (Wulf and Su, 2007), or on the 'snapping' motion of the wrist (Zachry *et al.*, 2005). Therefore, it is debateable whether such instruction provides sufficient task-specific guidance to instigate re-organisation of the perceptual-motor system, consequently inhibiting task performance and learning. This opinion is supported by James (2012) who argues that the focus of attention research has not utilised instructions relating to proper body movement, and that, importantly, the verbal instructions given must be offered in terms of specific optimisation criteria defined by the constraints of the task. This challenge is further exacerbated by the distinct lack of research examining focus-dependent changes in movement kinematics (Zentgrag and Munzert, 2009; Lohse *et al.*, 2010; Southard, 2011), and the complete absence of research relating to coordination or coordination variability. As a result, the present study emerged because of the apparent discrepancies in attentional focus findings in relation to task expertise and the inherent gaps within the attentional focus literature. The latter include limited practice duration, provision of insufficient task-relevant internal focus instruction, and lack of data pertaining to focus dependent changes in movement kinematics. Therefore, the study had two aims. The first was to examine the interactive effects of practice and focus of attention on both performance and learning of a discrete multi-articular action. The second was to identify potential focus-dependent changes on the emergence of the basketball shooting action through examination of joint kinematics, intra-limb coordination and coordination variability.

Key References

Lohse, K.R. (2012). The influence of attention on learning and performance: pre-movement time and accuracy in an isometric force production task. *Human Movement Science*, *31*, 12-25.

Lohse, K.R., Sherwood, D.E. and Healy, A.F. (2010). How changing the focus of attention affects performance, kinematics, and electromyography in dart throwing. *Human Movement Science*, *29*, 542-555.

Wulf, G. (2007a). *Attention and Motor Skill Learning*. Human Kinetics: Champaign, Illinois.

Wulf, G., Hob, M. and Prinz, W. (1998a). Instructions for motor learning: differential effects of internal versus external focus of attention. *Journal of Motor Behavior*, *30* (2), 169-179.

13. Details of the research design and protocol(s)	
13.1 Provide details. Participant will be randomly assigned into either a control, internal-external or external-external group. Participants within both the internal-external and external-external groups will perform a total of 840 practice trials of a basketball free-throw from a regulation distance of 4.25 m. The 840 practice trials will be divided into twelve equal sessions of 70 free-throws. The 70 practice trials are to be undertaken in seven blocks of 10 trials with adequate rest permitted between blocks to minimise confounding fatigue effects. Moreover, two sessions will be completed in each week with the total practice duration therefore spanning a six week period. The control group will not undertake any basketball free-throw practice throughout the intervention. During each of the first six practice sessions (i.e. Weeks 2-4 inclusive), the internal-external group were provided with task-relevant information. Specifically, participants were instructed to focus on: extending the shoulder, extending the shooting arm completely at the elbow, and flexing the wrist and fingers forward and down (see Wissel, 2004). During the final six remaining practice sessions (Weeks 6-8 inclusive), the internal-external group were given an external focus of attention, and instructed to concentrate solely on the basketball ring and achieving a successful outcome. The external-external group, conversely, were instructed to focus on the basketball ring and scoring a successful shot during all 12 practice sessions. Joint kinematics will be collected via an on-line motion analysis system (MAC). 25 retro-reflective markers will be used to define four segments of the body e.g. the hand, lower arm, upper arm and trunk. 30 trials will be performed under 5 vision conditions. The kinematic data collected will then be used to profile intra-limb coordination of the shooting arm and subsequent movement variability. Coordination will be assessed by means of three joint couplings: wrist-elbow, elbow-shoulder and wrist-shoulder. Movement variability will be measured by the normalised root mean squared difference method (Sidaway *et al.*, 1995).	
13.2 Are these "minor" procedures as defined in Appendix I of the ethics guidelines?	Yes [✓] No [ ]

14. Indicative methods of analysis
14.1 Provide details of the quantitative and qualitative analysis to be used. Kinematic data will be derived from the methods outlined in Section 13.1. Group inferential statistics will be conducted, subject to conforming to the assumptions underpinning parametric statistics. Specifically, 3*4 ANOVA will be conducted with group as the between-subjects and time as the within subjects factor.

15. Substances to be administered (Refer to Appendix V of the ethics guidelines)
15.1 The protocol does not involve the administration of pharmacologically active substances or nutritional supplements. *(Please tick the box if this statement applies and go to section 16)* [✓] 15.2 Name and state the risk category for each substance. If a COSHH assessment is required state how the risks are to be managed.

16.1 To consider the degree of physical or psychological discomfort that will be experienced by the participants. State the details which must be included in the participant information sheet to ensure that the participants are fully informed about any discomfort that they may experience.

The experiment involves multiple repetitions, which may predispose the participants to physiological fatigue. The shooting action is also a dynamic throwing task, so the potential for muscle injury should be noted. However, it must be stressed that due to the nature of the task i.e. shooting, the procedure is not *maximal* and does not involve anything which extends beyond regular competition performance. Therefore, the level of fatigue and the likelihood for injury would arguably be negligible. Nonetheless, it should also be stated that there may be a difference with regards to the level of discomfort experienced by each ability group because novices may be more susceptible because they are unaccustomed to the task.

17. Outcomes of Risk Assessment

17.1 Provide details of the control measures arising out of the assessment of risk including the nature of supervision and support required during the experimental phase of the project.

During the entire data collection process is it imperative that full supervision and support are provided. Due to the potential risks outlined above (section 16.1), all participants will be continually monitored to ensure they are happy to proceed with the investigation. Appropriate rest intervals will be given to minimise the risk of fatigue and associated injury. It is important to note that longer rest intervals may be appropriate for the novice group. Due to the dynamic nature of the task, the beginning of each session will be dedicated to a thorough warm-up. This ensures that the participants are fully prepared for the task and again minimises the likelihood of injury. Prior to data collection all instructions and guidelines will be given so that the participants are made fully aware of the procedure, and that they understand they are able to withdraw at any time during the experiment.

18. Safe System of Work

18.1 Indicate how the control measures outlined in section 17.1 will be implemented to minimise the risks in undertaking the research protocol (refer to 13.1). State the technical skills needed by the Principal Investigator to ensure safe working.

The principal investigator will undertake/instruct a thorough warm-up procedure prior to data collection to ensure the participants are fully prepared to undertake testing. The principal investigator will also allow appropriate time for rest to allow the participant to recover in between bouts of shooting performance. However, it should be noted that this is purely a precautionary measure, and does not infer that the testing procedure is ‘dangerous’. The technical skills needed would be a competent knowledge of the on-line motion capture system. In terms of ‘participant preparation’, this involves a good knowledge of marker placements, and to ensure that the participant is comfortable with the data collection attire.

19. Attachments *(Place a tick in the appropriate description)*	
19.1 Risk Assessment(s) (Include CRB risk assessment)	[ ]
19.2 COSHH Assessment	[ ]
19.2 Participant Information Sheet	[ ]
19.3 Informed Consent Form	[ ]
19.4 Pre-Test Medical Questionnaire	[ ]
19.5 Collaboration evidence/support (see 10)	[ ]
19.6 Collaboration facilities (see 9)	[ ]
19.7 Clinical Trials Form (FIN 12)	[ ]

20. Signature Principal Investigator	**Once this application is approved, I will undertake the study as approved. If circumstances necessitate that changes are made to the approved protocol, I will discuss these with my Project Supervisor. If the supervisor advises that there should be a resubmission to the Ethics Committee, I agree that no work will be carried out using the changed protocol until approval has been sought and formally received.** **..................Matthew Robins..Principal Investigator**
21. Approval Project Supervisor to sign off **EITHER** box A **OR** box B as applicable. *(refer to Appendix I and the flowchart in appendix VI of the ethics guidelines)*	**Box A:** **I confirm that the experimental protocol contained in this proposal is based solely on 'minor' procedures, as outlined in Appendix 1 of the School's Ethics Procedures for the Use of Humans in Research document, and therefore does not need to be submitted to the SLMREC.** **In terms of ethics approval, I agree the 'minor' procedures proposed here and confirm that the Principal Investigator may proceed with the study as designed.** **Project Supervisor ……………………………………..............Date …………....** **Box B:** **I confirm that the experimental protocol contained in this proposal is not based solely on 'minor' procedures, as outlined in Appendix 1 of the School's Ethics Procedures for the Use of Humans in Research document, and therefore must be submitted to the SLMREC for approval.** **I confirm that the appropriate preparatory work has been undertaken and that this document is in a fit state for submission to SLMREC.** **Project Supervisor…………………………………………… Date ……………...**

Sheffield Hallam University

School of Sport and Leisure Management

Research Ethics Committee

Participant Information Sheet (STUDY 4)

Project Title	FOCUS OF ATTENTION AND DISCRETE ACTION PERFORMANCE: A PROCESS-ORIENTED APPROACH

Name of Participant	

Supervisor/Director of Studies	Dr. Jonathan Wheat

Principal Investigator	Matthew Robins

Purpose of Study and Brief Description of Procedures
(Not a legal explanation but a simple statement)

The purpose of the study is to examine the effects of attentional focus strategy on the acquisition and retention of basketball shooting performance. In addition, aims to quantify any changes in the movement pattern and movement consistency. You will be randomly assigned into either a control, internal-external or external-external group. Participants within both the internal-external and external-external groups will perform a total of 840 practice trials of a basketball free-throw from a regulation distance of 4.25 m. The 840 practice trials will be divided into twelve equal sessions of 70 free-throws. The 70 practice trials are to be undertaken in seven blocks of 10 trials with adequate rest permitted between blocks to minimise confounding fatigue effects. Moreover, two sessions will be completed in each week with the total practice duration therefore spanning a six week period. The sessions will be arranged at a convenient time in discussion with the Principal Investigator (Matt Robins). The control group will not undertake any basketball free-throw practice throughout the intervention. They will only be required at set times to conduct a pre-test, mid test and post test. During each of the first six practice sessions (i.e. Weeks 2-4 inclusive), the internal-external group will be provided with task-relevant information. Specifically, participants will be instructed to focus on: extending the shoulder, extending the shooting arm completely at the elbow, and flexing the wrist and fingers forward and down. During the final six remaining practice sessions (Weeks 6-8 inclusive), the internal-external group were given an external focus of attention, and instructed to concentrate solely on the basketball ring and achieving a successful outcome. The external-external group, conversely, were instructed to focus on the basketball ring and scoring a successful shot during all 12 practice sessions. Joint kinematics will be collected via an on-line motion analysis system (MAC). 25 retro-reflective markers will be used to define four segments of the body e.g. the hand, lower arm, upper arm and trunk. 30 trials will be performed under 5 vision conditions. The data will then be used to examine underlying movement patterns, coordination, as well as movement consistency.

If necessary continue overleaf

It has been made clear to me that, should I feel that these Regulations are being infringed or that my interests are otherwise being ignored, neglected or denied, I should inform Professor Edward Winter, Chair of the School of Sport and Leisure Management Research Ethics Committee (Tel: 0114 225 4333) who will undertake to investigate my complaint.