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Implicit cognition is impaired and dissociable in a head-injured group with executive deficits

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Running head: Impaired implicit cognition after head injury

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ABSTRACT

Implicit or non-conscious cognition is traditionally assumed to be robust to pathology but Gomez-Beldarrain et al (1999, 2002) recently showed deficits on a single implicit task after head injury. Laboratory research suggests that implicit processes dissociate. This study therefore examined implicit cognition in 20 head-injured patients and age- and I.Q.-matched controls using a battery of four implicit cognition tasks: a Serial Reaction Time task (SRT), mere exposure effect task, automatic stereotype activation and hidden co-variation detection. Patients were assessed on an extensive neuropsychological battery, and MRI scanned. Inclusion criteria included impairment on at least one measure of executive function. The patient group was impaired relative to the control group on all the implicit cognition tasks except automatic stereotype activation. Effect size analyses using the control mean and standard deviation for reference showed further dissociations across patients and across implicit tasks. Patients impaired on implicit tasks had more cognitive deficits overall than those unimpaired, and a larger Dysexecutive Self/Other discrepancy (DEX) score suggesting greater behavioural problems. Performance on the SRT task correlated with a composite measure of executive function. Head-injury thus produced heterogeneous impairments in the implicit acquisition of new information. Implicit activation of existing knowledge structures appeared intact. Impairments in implicit cognition and executive function may interact to produce dysfunctional behaviour after head-injury. Future comparisons of implicit and explicit cognition should use several measures of each function, to ensure that they measure the latent variable of interest.

Keywords: Executive, social cognition, non-conscious processes, fractionated, head injury

INTRODUCTION

Implicit cognition is the acquisition of knowledge that subsequently influences behaviour without explicit awareness of the knowledge acquired (automatic, low-level perceptual processes are not included under this rubric). Historically, implicit cognition has been thought to be robust to neuropathology (Reber, 1989), although Parkinson's disease patients have been shown to be impaired on tasks of implicit cognition (Knowlton, Mangels & Squire, 1996). Recent evidence suggests that frontally injured patients are impaired on a Serial Reaction Time (SRT) task of implicit learning, amongst other cognitive deficits (Gomez-Beldarrain, Grafman, Pascual-Leone & Garcia-Monco, 1999; Gomez-Beldarrain, Grafman, de Valesco, Pascual-Leone & Garcia-Monco, 2002). The current paper presents a comprehensive assessment of implicit cognition in patients with head injury, disordered social behaviour and executive dysfunction and explores the relationship between implicit cognition and executive function indicated by our results.

Head injury may result in an array of cognitive, emotional and behavioural deficits that are often theorised as a result of executive dysfunction particularly where frontal pathology is known or suspected (Baddeley & Wilson, 1988). Executive functions are defined as super-ordinate mechanisms or (top-down) processes that operate on, integrate, inhibit or update lower cognitive processes (Miyake et al, 2000). Gomez-Beldarrain et al's (1999; 2001) findings of diminished implicit performance in a frontal group, indicate that implicit or bottom-up (stimulus driven) processes might also be adversely affected by pathology, not as a result of, but distinct from, executive functions, since implicit cognition makes minimal demands upon controlled attention (Jiménéz, & Méndez, 2001), and can be impaired when executive functions remain intact (Barker, Andrade & Romanowski, 2004). The inverse pattern, impaired executive function with intact implicit cognition has been shown in Parkinson's disease patients (Witt, Nühsman & Deuschl, 2002). Evidence of double dissociation between implicit processes and high level control or executive processes strengthens the assumption that these processes function independently and may be selectively affected by pathology. However, with the exception of our own case study (Barker et al, 2004), previous studies of implicit cognition with neuropathological groups have usually employed only one, and seldom more than two measures of implicit cognition. In the PD literature, implicit tasks usually consist of a Serial Reaction Time task and Pursuit Rotor Tracking task or the Tower of Hanoi with the latter two arguably classified as implicit learning tasks. Consequently, there is a risk that results reflect peculiarities of the chosen tasks that are peripheral to the implicit cognition component, rather than reflecting implicit cognitive ability.

The present study tested the performance of head injured patients and matched controls on a battery of four implicit cognition tasks. Patients presented clinically with frontal type symptoms and negative post-morbid socio-behavioural changes that varied from mild to severe. We measured IQ, executive function, memory and mood state to establish patterns of impairment and sparing on implicit and explicit tasks. Where possible, MRI scans were conducted to establish size and location of pathology.

Implicit tasks were selected according to the framework proposed by Lieberman (2000) that distinguishes between measures of implicit judgment and implicit performance. Seger (1997) similarly distinguished different 'types' of implicit cognition. Lieberman's (2000) distinction is particularly pertinent to head-injured patients with socio-behavioral problems because he proposed that the two types of implicit cognition map onto different aspects of behavior. Implicit judgement underpins ability to detect subtle nonverbal aspects of behaviour (including metalinguistic components of speech) that provide information about others' mood state, personality and intentions, whereas implicit performance enables a nonverbal response to these cues to be orchestrated and behaviourally expressed. Lieberman's (2000) hypothesis provides a catalyst for reframing implicit cognition as comprising important pre-conscious processes that interact with or subserve other cognitive processes to promote adaptive behaviour. This is a new departure for research concerned with implicit processes, which has traditionally focused on isolating implicit processes in the laboratory with most researchers remaining mute as to the 'real world' function of these processes or their interactions with explicit processes.

We chose two tasks of implicit performance, a Serial Reaction Time task (SRT, Nissen & Bullemer, 1987) and an automatic stereotype activation task (ASA, Bargh, Chen & Burrows, 1996), and two of implicit judgement, the mere exposure effect (MEE, Zajonc, 1980) and a hidden co-variation detection (HCD, Lewicki, 1986) task, for the present study. One task in each category manipulated socially meaningful stimuli (elderly stereotype words in the ASA task and female faces in the HCD task) as the crucial variables. This set of tasks enabled us to test the ability of head-injured patients on implicit judgement as well as implicit performance tasks and whether performance is affected by the use of socially-relevant stimuli. As with any measure, these tasks are not process pure, performance may be influenced by explicit as well as implicit processes. Nonetheless, previous research indicates that performance on these tasks is relatively independent of explicit processing: for example, participants with amnesia showed learning on the SRT task despite lack of explicit knowledge of the sequence (Nissen, Willingham & Hartman, 1989). We assessed explicit knowledge contributions to the tasks and included other measures of cognitive function to help delineate the ways in which implicit cognition might contribute to or interact with higher cognitive processes (executive function, IQ, explicit and working memory).

METHOD

All head-injured participants gave informed consent before taking part in the study. Ethical approval was sought from Sheffield South and North and Barnsley and Doncaster NHS Research Committees. Twenty head injured patients (19 male and one female) were matched to twenty controls for age and IQ. Wherever possible spouses or significant others were recruited as controls as we thought it more important to match for demography than gender. Patients were referred (by N. Morton and A. Wasti) on the basis that they presented with varying levels of post-morbid socio-behavioural and emotional problems usually ascribed to frontal injury and executive-type deficits. Inclusion criteria specified that patients showed impaired performance on at least one executive function subtest during neuropsychological testing. Patients were MRI scanned unless there were medical or behavioural contraindications (e.g. metal aneurysm clips, violent behavior). Patients with a history of alcoholism, depression, or drug addiction were not included in the study. Patients were aged between 18 and 65 and at least two years post-injury at time of testing.

All participants completed four tasks of implicit cognition in randomly assigned order with the only caveat that a short task should always follow a longer task. Both groups completed a full assessment of IQ on the Wechsler Adult Intelligence Scale-III (WAIS-III, Wechsler, 1997), Verbal Fluency (Controlled Oral Word Association Test

– FAS version: Benton, 1989) and the Hospital Anxiety and Depression Scale (HAD). The patient group were administered the Wechsler Memory Scale-R (WMS-R, Wechsler, 1987), National Adult Reading Test (NART, Nelson; 1991), and four tests of executive function: Hayling and Brixton (Burgess & Shallice, 1997), Behavioural Assessment of the Dysexecutive Syndrome (BADS, Wilson, Alderman, Burgess, Emslie & Evans, 1996), and the Wisconsin Card Sort Task (WCST, Heaton, 1981).

Implicit cognitive tasks

Serial Reaction Time task

This task was programmed in Psyscope (Cohen, MacWhinney, Flatt & Provost, 1993) and presented on a Macintosh Powerbook 5300. Participants completed a practice session before beginning the task. At acquisition, participants responded as quickly as possible to a target appearing in a predetermined 10 trial sequence, A B C D B C B D B C, by pressing the corresponding key (v, b, n or m). The target was a 1cm diameter closed white circle on a black background, which on any given trial appeared in one of four locations evenly spaced in a row. Participants were randomly assigned to one of two screen assignments (see Seger, 1997), to counterbalance the frequency with which the outer and inner locations were used. Circles disappeared when the appropriate key press was made. The response-stimulus interval was 200 msec.

Stimuli were presented in six acquisition blocks of 50 trials (five sequence repetitions) with rest breaks between each block, followed by a test block of 50 trials. There were also three random blocks, one at the beginning of the acquisition phase to confound any automatic judgement by participants that circles might appear in a pattern, and two flanking the sequence block at test. The test phase, of two random and one sequence block, followed immediately after the acquisition phase and without warning to participants. For the random block trials the target locations were hard wired into the programme in a pseudo-random order to ensure that performance differences between sequence and random blocks at test did not result from mere learning of first order frequency information. The random blocks matched the sequence blocks for frequency of the different locations and the fact that locations were not used twice in succession and consecutively ordered and familiar patterns (4321 and 1234) did not occur.

After the task participants completed an explicit knowledge questionnaire (Seger, 1997). They were informed that circles followed a sequence and rated how certain they were of the presence of a pattern, described any pattern that they had noticed, then rated (overleaf) how sure they were that the sequence consisted of a) ten positions (correct) and b) 12 or more positions.

Task scores

We used Seger's (1997) scoring method for the explicit task and her criterion that a score of sixteen or over showed explicit knowledge of the sequence. Each of the three test blocks (two random and one sequence block) produced 50 reaction time values, divisible as five repeats of ten trials. We calculated the median RTs for each of the five repeats of ten trials. The five medians for each block were combined to produce three means, one sequence mean and one mean for each random block. The two random block means were combined to produce a single mean. The sequence mean was subtracted from the random mean to provide a single learning score for each participant.

Mere exposure effect task

Participants listened to one of two lists of fifteen disyllabic Finnish words, matched for likeability, recorded on compact disc and presented audibly (see Andrade, Englert, Harper and Edwards, 2001). The word list was presented twice, at a rate of one word per 1.5 seconds. Use of word lists as targets or foils was counterbalanced across participants. After the acquisition phase, the C.O.W.A. (Controlled Oral Word Association Test – FAS version - Benton, 1989) was administered for three minutes, serving as a distractor and measure of the executive function of strategy/response initiation. Participants then heard a test list containing all 30 words, targets and foils, recorded in random order with a 4 second inter-stimulus interval. For the preference task, participants were asked to guess whether the words meant something good or something bad on the basis of their sound, rating each word as "very nice/good", "slightly nice/good", "slightly nasty/bad" or "very nasty/bad". The aim of this instruction was to imply that there was a correct answer on each trial to discourage participants from making a global judgement about the sound of Finnish words and consequently rate each word identically (see Murphy & Zajonc, 1993). The mere exposure effect is shown by preference for previously presented words relative to the foils. Participants then rated their recognition for each word as "definitely remember", "seems familiar", "seems unfamiliar", or "definitely do not remember". However, the recognition results are confounded by the preference condition always coming first (as implicit cognition was the main focus) and are not reported further.

Task scores

Response sheets were scored as follows: three points for "very nice", two points for "slightly nice", one point for "slightly nasty", and 0 points for "very nasty".

Individual preference priming scores were calculated by subtracting the sum of preference ratings for foil words from the sum of preference ratings for target words. A score of zero indicated that priming did not take place whilst a positive value indicated that previously exposed words were preferred to new words.

Hidden co-variation detection (HCD) task

This task was programmed in Psyscope (Cohen et al, 1993) and presented on a Macintosh Powerbook 5300. At the beginning of the task, participants were told that stimulus persons were real and were chosen as remarkable, and especially positive in some way. At acquisition they viewed six faces, selected in counter-balanced fashion from a pool of ten. Each face was presented for 15 seconds, with a 2.5 seconds blank interval between presentations. Each face was accompanied by an auditory personality description that lasted for 17 seconds so participants could not observe the faces without hearing the description. The personality descriptions implied, but did not overtly state, that the person was either capable or kind. Personality co-varied with hair length such that long hair=kind personality and short hair=capable personality, or short hair=kind, long hair=capable. The alternate co-variations served as foils at test. Co-variation presentation, order of stimulus faces and order of auditory personality description files were counterbalanced across four groups, to which participants were randomly assigned.

Three of the six stimulus faces had long and three had short hair and they were presented such that hair length alternated. Hair colour was calibrated to the same shade in Adobe Photoshop and graphically manipulated so that each face had both long and short hair (above shoulders) versions. Hair length varied in degree of long or shortness so that the co-variation between hair length and personality trait remained non-salient. Faces were adjusted in Photoshop to be smiling and morphologically similar (softer jaw line, smaller nose, similar hair colour). Adjusted faces did not differ significantly on pilot ratings of attractiveness, capability and kindness. The acquisition phase was followed by a visual distractor task. Participants had to count how many of 36 presented words began with the letter 'S' and select one of three possible answers at the end of the task.

At test, participants saw two presentations of four new faces, accompanied once by the question 'kind?' and once by 'capable?, printed in bold beneath the face. The two presentations of each face were separated by 2-4 presentations of other faces. Presentation of the test stimulus ended when participants pressed either 'Y' (yes) or 'N' (no) on the keypad, and was followed by a blank screen for three seconds. Participants were asked not to think about their response too deeply but to respond on the basis of their first impressions of the stimulus face. Faster responses to the primed associations between personality and hair length indicated implicit detection of that co-variation (Barker & Andrade, in press).

For the explicit measure, participants were asked whether they based their judgements at test on a visual aspect of the person and, if 'yes', which aspect? (Lewicki, 1986).

Task scores

The test phase produced four reaction times to primed hair/trait co-variances and four to non-primed co-variances, for each participant. Reaction time values were combined to provide a single prime and foil mean for each participant.

Automatic stereotype activation task

In Bargh et al's (1996) ASA task, participants exposed to elderly prime words embedded in scrambled sentences walked away from the laboratory more slowly than those exposed to neutral words, despite reporting no awareness of the primes. The present study measured motor speed on a simple paper-and-pencil task in a within-subjects design. Participants began by practising the motor task, an adaptation of the Trails A version of the Trail Making Test (Lezak, 1995). The task had a right/wrong component to prevent participants assuming that they needed to make speedy responses and thereby confounding any effects of the prime. The task comprised 12 sheets of A4 paper containing 20 circles numbered 1-20 distributed randomly over the page. Each sheet was different and the order randomised for each participant. Participants were asked to join up the circles in order from 1-20 and to concentrate on accuracy rather than speed. Participants completed two sheets for the practice, to minimise the amount of speeding up due to practise between the first and second motor tasks.

Next, participants were presented with thirty scrambled sentences consisting of five words each in the prime condition and in the neutral condition. They were instructed to make meaningful and grammatical sentences using only four of the five words. For example, 'flew eagle the plane around' could become 'the eagle flew around'. The prime condition consisted of 28 sentences containing one word each relating to the 'elderly' stereotype (e.g., ancient, wrinkle, bingo, grey) and two neutral sentences. The thirty scrambled sentences in the neutral condition contained no reference to the elderly stereotype.

After completing the first set of sentences, participants attempted five sheets of the motor task. They were surreptitiously timed and told to stop after 60 seconds. Next, they were asked to count backwards from 60 to 0 without making mistakes. The second scrambled sentence condition then began, followed by the last set of five motor task sheets for a time limit of 60 seconds.

The explicit measure consisted of the funnel debriefing approach used by Bargh et al (1996) beginning with general questions ("What do you think the purpose of the experiment was?") and becoming more specific ("Did you notice any particular pattern or theme to the words used in the sentences?").

Task scores

The number of circles conjoined on each motor task (prime and neutral) by each participant constituted the dependent measure.

RESULTS

Controls were well matched with patients for age (control mean 34.1 years, *SD* 12.2, patient mean 32.9 years, *SD* 12.1), years of education (control mean 12.0, *SD* 1.7, patient mean 11.8, *SD* 1.9) and IQ (full scale IQ: control mean 99.9, *SD* 11.7, patient mean 98.2, *SD* 11.9). Estimates of pre-morbid IQ from the NART showed negligible decline in patients' IQ post-injury (mean NART 99.4, *SD* 13.1, $F < 1$).

Brain imaging data

Table 1 presents the imaging data for patients who were MRI scanned or had previous CT scans (one case) that we could access. Lesion data were quantified on the basis of

Brodmann's regions but for ease of comparison are presented here under the general heading of dorsolateral prefrontal cortex (including Brodmann's areas 8, 9, 46), ventromedial prefrontal cortex (including Brodmann's areas 11, 12, 13, 14, 47) and/or additional frontal or other brain regions.

Table 1. Pathology to ventromedial prefrontal cortices (VMPFC), dorsolateral prefrontal cortex (DLPFC) and other brain regions for scanned patients

Case	RIGHT VMPFC	RIGHT DLPFC	LEFT VMPFC	LEFT DLPFC	Additional frontal and other brain regions
Case 1	BA (47)	BA (8)	BA (47)		Bilateral temporal gyrus
Case 2					Middle temporal gyrus Inferior temporal gyrus
Case 3	BA (10), (11), (12), (13), (14). (47)	BA (46), (45)	BA (10), (11), (12), (13), (14). (47)	(BA) 45	Temporal Pole Right and Left
Case 4		BA (8), (9)		BA (8), (9), (46)	
Case 5	BA (10), (11), (12), (13), (47)	BA (8), (9)		BA (8)	Left middle temporal gyri, right temporal lobe BA (44), (45)
Case 6					Focal lesion to Centrum Semiovale
Case 7	Acollosal		Acollosal		
Case 8	Region not specified		Region not specified		
Case 9				BA (8)	Frontal primary motor cortex BA (4)
Case 10			BA (11), (13)		Left temporal lobe
Case 15				BA (8), (9), (46)	
Case 17			BA (47), (11), (13)		Left temporal lobe BA (44), (45)
Case 19					Left frontal lobe lacuna infarcts.
Case 20					Global atrophy and foci of high signal to frontal regions

Table 1 shows the heterogeneous pattern of pathology of the 14 scanned patients. All patients showed clear evidence of pathology to frontal lobes except cases 2 and 6. Seven cases had pathology that encompassed frontal and temporal lobes. Case 8, who had bilateral VMPFC pathology determined by CT scan, did not undergo MRI for the present study.

Serial Reaction Time task

As expected, controls showed speeded responses on sequence blocks and slower responses on the random blocks. Patients showed less of a rebound effect from the sequence block (S) to the last random block (R2) at test and a greater degree of variance in RT latencies overall (Fig. 1)

[insert fig. 1 here]

Two-way ANOVA of RT for the learning blocks (1-6) showed that controls responded more quickly than patients, F (1,38) = 8.74, $p < .01$, and that both groups sped up during this learning phase, F (5,34) = 3.20, $p < .05$. The interaction was not significant, $F < 1$. Patients' sequence learning test scores differed from those of the controls, F (1,39) = 5.47, $p < .05$ with means showing greater learning in the control group (82.4, *SD* 41.1) than in the patient group (15.7, *SD* 120.7). Additional analyses conducted with ratio scores (sequence learning score divided by mean RT for random trials at test x 100%) showed that this group difference persisted even when overall differences in speed were taken into account, F (1,39) = 14.70, $p < .001$ (Table 2).

A final analysis was conducted with data from a sub-group of eleven patients (cases 1, 3-5, 7-10, 15, 17 and 19) with fronto-temporal pathology established by imaging data. One-way ANOVA showed that patients and matched controls had significantly different learning scores. This analysis shows a larger F value than for the total group analysis F (1,21) = 8.26, $p < .01$, consistent with suggestions that fronto-temporal structures mediate aspects of performance on this task (Peigneux et al, 1999).

Controls had higher explicit measure scores than patients, F (1,39) = 4.36, $p = .044$.

This difference may reflect impairments to the explicit system/processing in the patients. Thus patients' impaired performance on the SRT task may be due to impairments in explicit learning 'contamination' rather than impairments in the implicit learning that the task was intended to measure. To establish whether explicit knowledge facilitated learning of the sequence, an ANCOVA was conducted for patient and control sequence learning scores with explicit scores entered as the covariate. Results showed no main effect of explicit scores on the dependent variable ratio scores, $F < 1$ but there was still a main effect of group, F (1,39) = 12.07, $p < .01$. One interpretation of these findings is that the patients are impaired on the explicit and implicit components of this task independently. An alternative explanation is that the apparent explicit deficit in the patient group represents demand effects that led to overestimated explicit knowledge in the control group. Question one informed participants that the circles appeared in a sequence and asked them to rate their awareness of the sequence. Controls might have been more concerned to perform the task 'correctly' than patients and thus rated their awareness more highly.

Table 2: Performance of controls and head-injured patients on the SRT task: Sequence learning scores, combined random mean, ratio and explicit scores.

Group	Sequence learning score	Mean of random blocks at test	Sequence/random ratio	Explicit Score
Controls (*n* = 20)				
Mean	82.4	464.0	17.8 %	11.0
SD	(41.1)	(123.6)	(8.4 %)	(3.1)
Patients (*n* = 20)				
Mean	15.7	787.2	5.6%	8.3
SD	(120.7)	(474.3)	(11.5 %)	(4.7)

Mere exposure effect task

Mean preference priming scores (Table 3) were analysed non-parametrically because the ratings constituted ordinal data and exploratory data analysis showed the data to be somewhat skewed.

Table 3: Preference scores of head-injured patients and controls on the mere exposure effect task.

	Preference Scores		
Group	Target mean	Foil mean	Priming score
Controls (n = 20)			
Mean	26.7	23.2	3.5
SD	(4.2)	(2.6)	(3.2)
Patients (n = 20)			
Mean	24.3	22.6	1.7
SD	(4.0)	(4.7)	(5.0)

Mann-Whitney U showed a significant difference between patient and control priming scores in the preference condition, z = -1.79, $p < .05$, with controls showing a larger priming effect. Separate analysis of target/foil ratings for patients and controls with Wilcoxon Signed Ranks Test showed that ratings for targets and foils were significantly different for controls, z = -3.29, $p < .001$, but not for patients, z = -1.14 *ns,* indicating that controls showed a mere exposure effect but the patient group did not.

Hidden co-variation detection

Data presented in Table 4 show that controls and patients responded more quickly to the primed co-variances (targets) at test than non-primed co-variances (foils).

Table 4: Hidden co-variation detection task: Mean RT values for targets and foils for controls and head-injured patients.

Group	Targets	Foils	Difference
Controls (n = 20)			
Mean	2785.0	2993.7	208.7
SD	(1107.9)	(1227.3)	(616.3)
Patients (n = 20)			
Mean	4493.5	4783.6	290.1
SD	(2029.2)	(2797.0)	(2341.7)

A repeated-measures ANOVA conducted for target and foil mean RT responses (within-subjects factor) and group and condition (between-subjects factors) showed a main effect of stimulus (targets or foils) on RT responses, F (1,36) = 9.50, p < .01. There was no main effect of co-variation type (long-kind / short-capable or short-kind / long-capable presentations), F < 1 and no interaction for stimulus and co-variation type, F <1 suggesting that the observed priming reflected detection of the co-variation and not simply priming of stereotypes (e.g. capable people have short hair). There was no main effect of group, F (1,36) = 3.22, p = .08 but there was an interaction between group and stimulus, F (1,36) = 5.30, p < .05. To investigate the interaction for stimulus and group, patient and control data were analysed separately. A repeated-measures ANOVA showed that reaction time responses to targets and foils were significantly different for controls, F (1,19) = 14.87, p < .001 but not for the patient group, $F < 1$. These results suggest that patients were not primed on this task. On the explicit measure, no participant reported that they had used hair length to guide their responses but instead reported that they focussed on ‘eyes and expression’.

Automatic stereotype activation task

Nineteen head-injured patients (one patient left the rehabilitation unit) and twenty controls completed the task. Controls completed fewer circles overall in the prime condition (M = 63.4, SD 16.5) than the neutral condition (M = 66.9, SD 16.5) regardless of order. Patients also completed fewer circles overall in the prime condition (*M* = 41.3 *SD* 14.8) compared to the neutral condition (*M* = 46.8, *SD* 19.1). ANOVA confirmed the main effect of condition (prime or neutral) on speed (number of circles joined; F (1,35) = 7.63, $p < .01$) and a main effect of group (F (1,35) = 17.75, $p < .001$), as controls were faster overall. There were significant interactions between condition and order F (1,35) = 24.99, $p < .001$ and condition x order x group F (1,35) = 4.69, $p < .05$. There was no significant interaction between condition and group ($F < 1$). Because of interaction effects and the control group being faster overall, we computed number of circles completed in each condition by order to establish whether patients showed an effect of the elderly prime (Table 5). Data showed that when the neutral condition came second, both groups sped up on the second circles task. When the prime condition came second, controls showed a (smaller) increase but the patient group did not speed up at all.

Table 5: Mean scores of head-injured patients and controls on the motor task component of the ASA task by condition and order showing the mean increase in circles completed from first to second task.

Group	Prime 1st	Neutral 2nd	Increase 1st –2nd	Neutral 1st	Prime 2nd	Increase 1st – 2nd
Patients (*n* = 19)						
Mean	39.7	49.5	9.8	43.7	43.0	-0.7
SD	16.6	21.6	7.7	16.5	13.5	6.7
Controls (*n* = 20)						
Mean	61.2	76.1	14.9	57.7	65.6	7.9
SD	17.9	16.9	14.7	10.0	15.7	7.9

Analysis of the difference between number of circles completed in the neutral and prime conditions when the prime condition came second showed a significant group effect, t (1, 17) = –2.56, $p < .05$. This finding indicates that the elderly prime had a greater effect on motor speed of patients, who failed to increase in speed as a result of practise when the prime circles task came second.

Responses for the funnelled debriefing questionnaire showed both groups had no explicit awareness of the elderly stereotype consistent with Bargh at al's (1996) results.

Effect size analysis

Task data were analysed further to investigate whether performance dissociated across tasks dissociated and was associated with psychometric task scores. Patient data were transformed into standardised (z) scores for the three implicit tasks on which they showed impairments (SRT, MEE and HCD). Control group means and standard deviations served as the normative data (SRT learning score mean = 82.4, *SD* = 41.2; MEE preference priming mean = 3.5, *SD* = 3.2; HCD target-foil RT difference mean = 208.7, *SD* = 616.3). One-tailed significance was set to .05, with a z score lower than -1.64 constituting impaired performance on each implicit task. This analysis is likely to provide a conservative estimate of impaired performance because the large standard deviations of the control group made it *less* likely that patient scores would fall into the tail end of the distribution (Figure Two).

[fig 2 about here].

We computed a measure of social function from the dysexecutive questionnaire (DEX) of the BADS (Wilson et al, 1996). DEX scores for Self and Other represent the patient's ratings of their behavioural, cognitive and emotional problems and those of a significant other (spouse, sibling, carer). We subtracted Self from Other scores on the social and emotional questions alone to establish a DEX discrepancy score: the greater the value, the greater the difference between Self and Other ratings reflecting impaired awareness of socio-emotional problems and an increased likelihood of exhibiting socially aberrant behaviour.

We made several hypotheses based on existing findings and the conceptual framework adopted for the study: H_1 – implicit judgement and implicit performance are distinct and dissociable types of implicit cognition (Lieberman, 2000; Seger, 1997); H_2 – executive function is dissociable from implicit cognition (Barker et al, 2004); H_3 – executive function ability contributes to social behaviour; H_4 - implicit cognition mediates non-verbal social cognition (Lieberman, 2000).

Figure Two shows that performance across the three tasks dissociated at the level of individual cases. Some patients were impaired on the SRT (cases five and 11), MEE (cases six and 20) or HCD (cases 13 and 15) tasks alone, others were impaired on a combination of two tasks (cases four, eight, ten and 18), and one case was impaired on all three tasks (case 17). Based on Lieberman's (2000) conceptualisation, we predicted that performance on the implicit judgment tasks would cluster together, however the data did not follow this pattern and only case 4 showed impaired performance on the MEE and HCD tasks and not the SRT task. Cases 8 and 10 showed impaired MEE and SRT and case 18 impaired HCD and SRT. Thus our results do not support H_1 that implicit performance and implicit judgement are distinct types of implicit cognition,

On the basis of z scores, 11 patients showed impaired performance on the implicit cognitive tasks despite all patients showing impaired performance on at least one test of executive function. Thus, consistent with H_2, implicit cognition appears to dissociate from executive function. However, this finding might reflect the lack of sensitivity of the particular implicit cognition tasks in detecting individual differences and the greater range of variability when comparing a patient score to the mean of the whole control group rather than matched age and IQ samples (although patients were matched to their own specific control for age and IQ for the group analyses), rather than a genuine dissociation.

We compared individual scores on the psychometric measures with performance on the implicit tasks to establish whether there were any consistent patterns of deficits and sparing across the tasks for the two subgroups (as determined by effect-size analysis) 'Impaired Implicit' (II- Table 6) and 'Non-Impaired Implicit' (NII-Table 7).

Table 6: Range of scores on DEX, Implicit tasks, WAIS III, WMS-R, BADS, Hayling & Brixton, WCST for head-injured patients impaired on implicit tasks

	Social Measure	Implicit tasks	WAIS III	WMS-R				BADS						Hayling & Brixton		WCST
Patient	DEX	Task	Full-scale	Visual Memory	Attention	Verbal Memory	General Memory	Rule Shift	Action Program	Zoo Map	Key Search	Temp Judgement	Mod6 Elements	Hayling	Brixton	Total score
11	30	SRT	*Ave	**Border	High ave	Ave	Ave	Ave	Impaired	Impaired	Impaired	High ave	Impaired	Impaired	High ave	No data
5	11	SRT	Low ave	Impaired	Ave	Low ave	Border	Impaired	High ave	Impaired	Impaired	Impaired	High ave	Mod ave	Ave	Low ave
8	23	SRT MEE	Ave	Impaired	Low ave	Low ave	Impaired	Impaired	Ave	Impaired	Impaired	Impaired	Impaired	Mod ave	Ave	Ave
10	13	SRT MEE	Low ave	Ave	Ave	Impaired	Impaired	Impaired	Impaired	Ave	Impaired	Impaired	Impaired	Mod ave	Impaired	Low ave
18	-8	SRT HCD	Low ave	Impaired	Ave	Low ave	Impaired	High ave	Impaired	Impaired	Impaired	Impaired	Impaired	Impaired	Impaired	Border
17	-8	ALL	Low ave	Impaired	Ave	Impaired	Impaired	Impaired	Impaired	Impaired	High ave	Impaired	Impaired	Impaired	Impaired	Low ave
6	17	MEE	High ave	High ave	Ave	Ave	Ave	High ave	High ave	High ave	High ave	High ave	Impaired	Ave	High ave	High ave
20	1	MEE	Ave	Low ave	Low ave	Low ave	Low ave	High ave	Ave	Impaired	Ave	High ave	High ave	Poor	Poor	Ave
4	2	MEE HCD	Ave	Low ave	Low ave	Low ave	Low ave	Ave	High ave	Impaired	Ave	Impaired	Ave	Poor	Ave	Ave
13	2	HCD	Ave	Ave	Low ave	Ave	Ave	High ave	High ave	High ave	Impaired	Impaired	High ave	High ave	High ave	Border
15	-7	HCD	Low ave	Ave	Impaired	Ave	Ave	Impaired	High ave	Impaired	Impaired	High ave	High ave	Low ave	Impaired	Border

* Average
**Borderline

Table 7: Range of scores on DEX, Implicit tasks, WAIS III, WMS-R, BADS, Hayling & Brixton, WCST for head-injured patients not impaired on implicit task

	Social Measure	WAIS III	WMS-R				BADS						Hayling & Brixton		WCST
Patient	DEX	Full-scale	Visual Memory	Attention	Verbal Memory	General Memory	Rule Shift	Action Program	Zoo Map	Key Search	Temp Judgement	Mod6 Elements	Hayling	Brixton	Total score
1	6	Ave	Low Ave	Ave	Low Ave	Low Ave	High Ave	High Ave	Impaired	Ave	Impaired	High Ave	Ave	Mod Ave	Ave
2	-8	Ave	Impaired	Border	Low Ave	Border	Ave	High Ave	Impaired	High Ave	Impaired	Ave	Impaired	Ave	Superior
3	28	Superior	Ave	Superior	Ave	Ave	Ave	High Ave	Ave	Ave	Impaired	High Ave	Mod Ave	High Ave	Low Ave
7	7	Ave	Impaired	Low Ave	Ave	Low Ave	Impaired	Ave	Impaired	Ave	Impaired	High Ave	Ave	Mod Ave	Border
[1]9	0	Ave	Superior	Superior	High Ave	Superior	Ave	High Ave	Ave	Ave	Impaired	Impaired	Ave	Ave	Low Ave
12	-13	Ave	Ave	Superior	Ave	Ave	High Ave	Ave	Impaired	High Ave	Impaired	Impaired	Ave	Superior	Superior
14	2	Ave	Ave	Ave	Ave	Ave	Ave	High Ave	Impaired	Impaired	Impaired	High Ave	Mod Ave	Low Ave	Ave
16	4	Low Ave	Low Ave	Border	Low Ave	Low Ave	High Ave	Ave	Impaired	Impaired	Impaired	High Ave	Impaired	Ave	Ave
19	6	Ave	Ave	Ave	Ave	Ave	High Ave	High Ave	Impaired	Impaired	Ave	Ave	Ave	Low Ave	Impaired

* Average
**Borderline

[1]Case nine had experienced repeated testing as a result of a compensation claim that might explain his high memory scores

The II group had greater deficits overall on the psychometric measures than the NII group, specifically regarding performance on Visual Memory and General Memory tests of the WMS-R and across the range of executive function tests with the exception of case 9 (see footnote 1, Table 7). However, scores for the two groups were not significantly different at the two-tailed level for Visual Memory, t (1,18) = 1.65, p .11, and General Memory, t (1,18) = 1.60, p .12. In both groups, cases with high DEX discrepancy scores showed a greater degree of executive impairment than those with low DEX discrepancy scores. There were exceptions to this general trend: patients 16 (NII group) and 13 (II group) had a high number of impaired executive function scores with low DEX scores and inversely case three showed impairment on only one executive subtest but had a DEX discrepancy score of 28. In relation to H_3, this pattern suggests that level of executive function impairment is often, but not necessarily, associated with social deficits as measured by the DEX discrepancy score. In the same way deficits on the implicit tasks were only partly associated with high DEX discrepancy scores. There was a non-significant tendency for higher DEX discrepancy scores in the II group (M = 6.91, SD = 12.9) than the NII group (M = 3.5, SD = 11.4; t(17) = 1.40, p = 0.09 one-tailed, (with case 3 omitted as explained in footnote 2). Thus the data provided only tentative support for H_4 that implicit cognition mediates social function.

To test whether executive function performance was associated with performance on the implicit cognitive tasks (H_2) a correlation was conducted with BADS total score (the most comprehensive of our executive measures) and SRT z scores. We used scores on the SRT because this implicit measure seemed the most sensitive of all the implicit tasks and has been most widely used in the literature. The correlation between BADS and SRT was significant, r (20) = .66, p < .01 one-tailed. This apparent relationship between the process(es) that facilitated performance on both measures is not fully explained by extent of lesion, because SRT performance dissociated from other implicit tasks, so results are not easily interpreted as more extensive or severe pathology leading to greater implicit deficits. Thus, although the presence of executive function deficits in the NII group suggests that executive and implicit processes can dissociate, there is also evidence that implicit cognition and executive function are correlated across the whole group.

DISCUSSION

Head-injured patients were impaired on three of four implicit cognitive tasks at the group level, but performed at least as well as controls on the elderly stereotype activation task. Additional analyses of individual scores on the mere exposure effect, hidden co-variation detection and SRT tasks showed dissociation across tasks, both within and between participants.

Evidence of impaired implicit cognition, particularly in our fronto-temporal sub-group, supports findings reported by Gomez-Beldarrain et al (1999; 2002) of impaired SRT task learning in their frontally injured group. The finding of fractionated performance on implicit tasks partially supports the notion, proposed by Seger (1997), that implicit cognition comprises dissociable systems. However the dissociable patterns of performance shown in the present study cut across Seger (1997) and Lieberman's (2000) conceptual distinction of the different 'types' of implicit task.

Present findings also contrast with studies showing intact implicit cognition in patients with head injury (Doyon et al, 1997). Despite evidence to the contrary, particularly from the Parkinson's disease literature (Jackson et al, 1995), and more recently brain-injured patients (Gomez-Beldarrain et al, 1999; 2002), the notion that implicit processes are robust to pathology remains widely accepted. Reber (2002) recently commented that,

"…the neurologically impaired show these [implicit learning] effects" (2002; pg. xiv).

The findings of the present study challenge these assumptions and mandate the use of several implicit tasks before firm conclusions can be drawn about the implicit cognitive ability of particular populations. The results of each task are discussed separately below due to the dissociable performance across tasks.

SRT task

The patient group was impaired on the SRT task relative to controls, even with baseline speed partialled out. This impairment could reflect visuo-spatial memory deficits (failure to remember the location of preceding stimuli would make it harder to acquire the temporo-spatial associations between stimuli), temporal ordering deficits, or impairments in general attentional or executive processes (for example, error monitoring deficits). Impaired performance is unlikely to reflect impaired explicit learning of key/location contingencies since all participants completed a practice session on a ‘random’ block prior to the task proper, and training continued until they were comfortably familiar with key /location contingencies. Visual memory and a composite executive function score were the only cognitive functions associated with impaired SRT performance across an extensive range of psychometric measures.

Five of the six patients with impaired SRT had visual memory impairments, falling within the very impaired range for four cases. However, cases two and seven had severe visual memory deficits yet intact SRT learning (Table 7). Impaired visual memory (as measured here) therefore might impact upon SRT task performance but is insufficient to fully explain performance deficits on this task.

There is also little evidence that impaired ability to temporally code information provides an alternative explanation for the current findings. Recent research has shown that temporal representations are grounded in specific action systems and events (Shin and Ivry, 2002). Therefore encoding of temporal information of stimulus circles should have proceeded concurrently with sequence learning and the acquisition of key-location contingencies.

Impaired higher level ‘executive’ processes such as attention, monitoring or control processes may have contributed to the patient group’s diminished sequence learning, either directly or by impairing explicit learning of the sequence. One possible interpretation of the current findings is that the patient group had explicit learning deficits and implicit cognition was intact allowing residual performance on this task. Explicit learning can aid performance on the SRT task (Boyd & Winstein, 2001). However this conclusion conflicts with studies showing no effect of dual tasks on SRT learning and intact learning in amnesics (Jiménéz & Méndez, (2001; Nissen et al, 1989). We found little evidence that explicit knowledge contributed to performance in our sample – controls had higher explicit scores than patients but explicit knowledge was not a significant covariate of sequence learning.

All the patients had executive deficits, and BADS total score correlated with SRT performance. However, current findings and frameworks provide little explanation for this relationship. The SRT task is generally considered to be relatively robust to attentional manipulations (Jiménéz & Méndez, 2001) and Willingham, Salidis and Gabrieli (2002) concluded that,

“ SRTT learning is minimally affected by cognitive load” (2001, pg. 1458).

Although there is some evidence that dual task conditions reduce learning on the SRT task (Curran & Keele, 1993), Keele, Ivry, Mahr, Hazeltine and Heuer (2003) argue that such conditions only affect performance when they trigger the operation of a multidimensional learning system. Multidimensional learning happens when the secondary task conflicts with the sequence learning task, for example when participants are responding to auditory tones and a visual sequence. If the secondary task maps closely onto the sequence learning task then a unidimensional learning system can encompass both tasks and there is no dual task decrement. According to this framework, pathological reductions in attention will not affect sequence learning because unidimensional learning systems are sufficient for completing the SRT task. This framework attenuates assumptions that SRT learning makes demand on control processes. Accordingly it is possible that some lower level process needed for SRT learning contributed to performance on the executive function tasks encompassed by the BADS, particularly since executive functions operate across other functions meaning that executive tasks, like implicit learning tasks, are seldom process pure.

The Mere Exposure Effect task (MEE)

In contrast to the control group, the patient group did not show a mere exposure effect. The effect size analysis revealed no notable similarities in performance across the psychometric measures for the two patients who were impaired on the MEE task alone (see Table 6).

Two interpretations of the mere exposure effect may provide clues as to why the head-injured group failed to show a preference effect on this task. Whittlesea and

Price (2001) proposed that the standard methods for eliciting mere exposure effects work because they induce a 'global' processing style where stimuli are encoded holistically. This global processing style facilitates holistic judgements such as preference ratings, but may hinder explicit recognition compared with a feature-based processing style. It is conceivable that patients failed to initiate a global processing style when requested to merely listen to the Finnish words. Unfortunately, because participants always completed the preference rating task before the recognition test, we do not have accurate recognition data to see whether poor performance on the preference condition accompanied better performance on the recognition condition, suggestive of the adoption of a feature-analysis strategy rather than global processing. We have no other evidence that patients approached this task with a different processing style to controls. It is worth noting that a global processing account has also been offered for hidden co-variation detection (Roßnagel, 2001), but there was no association in our data between impairments on the MEE task and impairments on the HCD task.

One problem with the processing style account of the mere exposure effect is that it decouples affect from the phenomenon of conceptual fluency, reconfiguring the mere exposure effect as a purely cognitive phenomenon. In contrast, several researchers have emphasised the role of emotion to this task, attributing the mere exposure effect to an increase in processing fluency that *always* has a positive affective component (e.g., Zajonc, 1980). Given that our patient group varied in the degree of emotional change post-morbidly, the 'affective' hypothesis may have some explanatory power. However, the present study gives little insight into whether patients' deficits on the mere exposure effect task reflect changes in processing style or in automatic affective evaluation. These are possible areas for future research.

HCD task

The control group responded significantly faster to primed co-variances than non-primed co-variances at test; the patient group did not acquire the hidden co-variances. As with the MEE task, global processing has been proposed as conducive to hidden co-variation detection (Roßnagel, 2001). However, the dissociation observed here between MEE and HCD performance is not wholly compatible with a global processing account of both tasks. Attentional deficits may have contributed to poor performance on the HCD task. The two cases (13 and 15) impaired solely on the HCD task had impaired Attention scores and borderline impaired WCST scores. In contrast, cases 3, 9 and 12 of the non-impaired implicit group (Table 7) had superior Attention scores and good HCD scores; case 12 had a WCST scores in the Very Superior range. It is therefore plausible that some attentional and/or executive function processes contributed to HCD performance on the present task, although it must be borne in mind that patients with satisfactory HCD scores also showed impaired Attention scores. None of the participants showed explicit knowledge of the co-variances, so it is possible that attentional or executive processes contributed directly to implicit knowledge acquisition when participants were required to attend to the faces and auditory descriptions.

Automatic stereotype activation task

Both groups completed fewer circles after prime compared to neutral sentences, replicating Bargh et al's (1996) finding of a general slowing effect in response to the elderly prime. In contrast to their performance on the other implicit tasks, the patient group responded 'normally' on this task and showed a significantly stronger priming effect than the controls. Preserved performance on this task may be due to the task priming 'chronic' social knowledge structures, i.e. the elderly stereotype, rather than new information. At face value, it suggests that different measures of implicit cognition dissociate. Alternatively, the apparent preservation may be pathological, reflecting an inability in patients to inhibit automatically triggered responses or a greater susceptibility to the prime and its associate of 'slowness' that offset a general implicit cognitive deficit (Dijksterhuis, Aarts, Bargh, & van Knippenberg, 2000). Many of the head-injured patients commented during testing on the neuropsychological battery that they felt 'slowed down' at cognitive and physical levels since their head injury. The patient groups performance therefore, might indicate a greater affinity with the behavioural construct of 'slowness' primed by the stereotype rather than with the stereotype generally. Their performance also provides evidence of the capacity to acquire information presented explicitly even though the associated behavioural trait is activated implicitly. Of the four implicit tasks in this study, the ASA task is arguably the most prone to contamination by explicit processing. It is the only task in which the study phase is self-paced, giving participants more opportunity to become aware of the critical information. The finding that patients showed ‘normal’ priming on this task, and no awareness of the prime, stands against a general interpretation that diminished ability across the other implicit tasks is due to impaired explicit processing.

Future research might investigate whether priming effects are still seen after head injury with tasks that activate other constructs (e.g. speediness rather than slowness).

Executive function, implicit cognition and behaviour

Whilst the current study has little conclusive to offer in response to the question posed by French and Cleeremans (2002, pg. 1) “What is implicit learning for?,” our findings suggest possible areas for consideration. They are broadly consistent with Lieberman’s (2000) suggestion that implicit cognition underpins social behaviour, in that the patient group as a whole showed impaired implicit cognition and socio-behavioural problems that varied in extent and severity. Those patients impaired on implicit cognitive tasks showed higher DEX discrepancy ratings than the non-impaired implicit group, but there were exceptions in both groups that suggest no firm relationship between social deficits and implicit cognition. However, social and emotional behaviour were not comprehensively assessed in the present study, so the weakness of the observed relationship might reflect the limitations of the DEX discrepancy score in capturing social behavioural problems. It is also worth noting that patients with impaired implicit cognition and high DEX discrepancy scores also tended to have relatively poor executive function scores, although social behavioural problems and implicit cognitive deficits can co-occur without associated executive dysfunction (Barker et al, 2004) and vice versa as the non-impaired implicit group show (Table 7). Despite these inconsistencies our findings indicate, in general terms, that impaired social behaviour and executive and implicit deficits co-occur. The correlation between SRT task performance and the BADS total score suggests that implicit sequence learning and executive function tasks share some processing demands. There may be some mileage in Lieberman's (2000) suggestion that some elements of social behaviour are dependent on implicit processes.

The co-occurrence of social, implicit and executive problems, and particularly the correlation between the SRT task and BADS, raises the question of whether implicit processes contribute directly to social behaviour, do so via a contribution to executive functions, or whether executive function is the key variable in social behaviour and implicit cognition. Another possibility is that performance deficits shown by the patient group on the implicit tasks represent impaired explicit processes. However when considered together our data are not supportive of this assumption. Both groups showed scant explicit knowledge of crucial stimuli across tasks even where the groups differed in this respect and patients performed comparable to controls on the ASA task where critical stimuli were explicitly presented and acquisition was self paced. The relationship shown here between composite score on an executive function measure and SRT learning score is not easily explained. Executive function research has focussed primarily on the function and capacity of these top-down processes and given little consideration to the possibility that disruption to lower level processes (the emphasis here is on underlying processes rather than measures - which are unlikely to be wholly process pure) could also impact upon performance on higher cognitive tasks (although see Miyake et al, 2000). Within the cognitive literature there has been a general focus on distinguishing between explicit and implicit processes, rather than asking, 'how much of each?' (Jacoby, 1991). Future research might examine the possible contribution of implicit cognition to social functioning by measuring specific elements of behaviour (reading of nonverbal signals, orchestrating of responses etc.) to test whether implicit processes contribute to these functions independently of an executive contribution, which might be limited to the monitoring and control of these elements.

CONCLUSION

Our findings challenge two common assumptions, that implicit cognition is resistant to head injury and that different tests of implicit cognition measure the same underlying variable. If there is indeed a general ‘implicit cognition’ component to performance on these tests, it may be only selectively recruited depending on task demands. Future studies should use several tests to ensure they capture it.

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Footnote 2

Case 3 was excluded from the comparison of the group with impaired implicit cognition versus the non-impaired group as his data have been presented elsewhere and showed impaired SRT task learning and lack of preference effect on the MEE when compared with age and IQ matched controls (Barker et al, 2004). In the current analysis, however, his data did not reach criterion for impairment although his SRT z score of -1.50 approached the impaired level. This is likely to reflect the greater variability in scores in this control group compared with the controls tested for his case study.

Figure 1: Serial Reaction Time task: Group means and mean standard errors at acquisition and test for head-injured patients and controls.

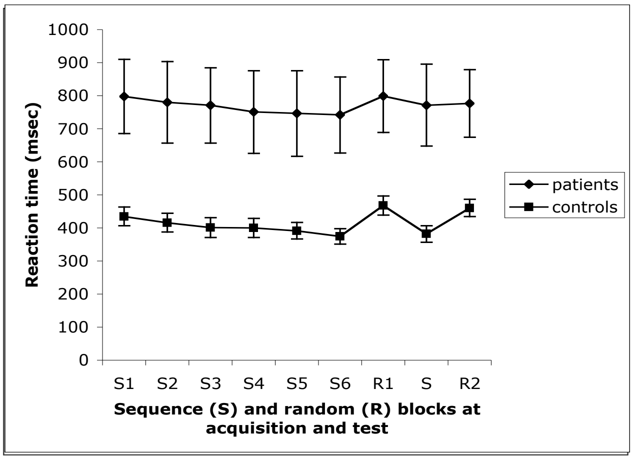

Fig. 2: Z scores of head-injured patients on the serial reaction time, mere exposure effect and hidden co-variation tasks (patients with no impairment, i.e., z scores ≥ -1.64 on all three tasks, are shown in grey)