Available online at www.sciencedirect.com
ScienceDirect
Brain and Cognition 66 (2008) 83–90
Brain and Cognition
www.elsevier.com/locate/b&c

Working memory involved in predicting future outcomes based on past experiences

Michael N. Dretsch [a,*], Jason Tipples [b]

[a] Department of Psychology, University of Wisconsin, 1202 West Johnson Street, Madison, WI 53706-1696, USA
[b] Department of Psychology, University of Hull, UK

Accepted 28 May 2007
Available online 12 July 2007

Abstract

Deficits in working memory have been shown to contribute to poor performance on the Iowa Gambling Task [IGT: Bechara, A., & Martin, E.M. (2004). Impaired decision making related to working memory deficits in individuals with substance addictions. *Neuropsychology, 18*, 152–162]. Similarly, a secondary memory load task has been shown to impair task performance [Hinson, J., Jameson, T. & Whitney, P. (2002). Somatic markers, working memory, and decision making. *Cognitive, Affective, & Behavioural Neuroscience, 2*, 341–353]. In the present study, we investigate whether the latter findings were due to increased random responding [Franco-Watkins, A. M., Pashler, H., & Rickard, T. C. (2006). Does working memory load lead to greater impulsivity? Commentary on Hinson, Jameson, and Whitney's (2003). *Journal of Experimental Psychology: Learning, Memory & Cognition, 32*, 443–447]. Participants were tested under Low Working Memory (LWM; $n = 18$) or High Working Memory (HWM; $n = 17$) conditions while performing the Reversed IGT in which punishment was immediate and reward delayed [Bechara, A., Dolan, S., & Hindes, A. (2002). Decision making and addiction (part II): Myopia for the future or hypersensitivity to reward? *Neuropsychologia, 40*, 1690–1705]. In support of a role for working memory in emotional decision making, compared to the LWM condition, participants in the HWM condition made significantly greater number of disadvantageous selections than that predicted by chance. Performance by the HWM group could not be fully explained by random responding.

Keywords: Decision making; Working memory; Gambling task; Cognition; Emotion; Reward; Punishment

1. Introduction

Impaired decision making is a classic feature of many neuropsychological disorders. The Iowa Gambling Task (IGT: Bechara, Damasio, Damasio, & Anderson, 1994) was originally developed to assess decision making impairments in patients with damage to the ventromedial prefrontal cortex (VMPFC). The Somatic Marker Hypothesis (Bechara et al., 1994) was developed to explain human decision making by contending that affective states termed somatic markers can implicitly bias the decision processes. These somatic markers have been referred to as a "hunch" or "gut-feeling", and allow choices to be made without heavy cognitive deliberation and conscious awareness (Bechara, Tranel, Damasio, & Damasio, 1996).

Since the development of the somatic marker hypothesis, a myriad of research studies have used the IGT to examine decision making in both clinical and non-clinical populations (Dunn, Dalgleish, & Lawrence, 2005). The task has revealed a common pattern of poor performance not only in ventromedial prefrontal patients (Bechara et al., 1994), but also in individuals with drug abuse disorders (Bechara, Dolan, & Hindes, 2002; Rotheram-Fuller, Shoptaw, Berman, & London, 2004), OCD (Cavendini et al., 2002), and psychopathy (Schmitt, Brinkley, & Newman, 1999). A number of explanations have been put forward to explain impaired performance at the IGT

* Corresponding author.
E-mail address: dretsch@wisc.edu (M.N. Dretsch).

0278-2626/$ - see front matter © 2007 Elsevier Inc. All rights reserved.
doi:10.1016/j.bandc.2007.05.006

(for a review; see Dunn et al., 2005) including, but not limited to deficits in reversal-learning (Fellows & Farah, 2005a), risk-taking (Sanfey, Hastie, Colvin, & Grafman, 2003), and apathy (Fellows & Farah, 2005b). Although performance on the task was predicted to rely on the development of implicit or affective information and not explicit awareness of contingencies (Bechara, Damasio, Tranel, & Damasio, 1997), this has been a continuous area of debate (Maia & McClelland, 2004; for rebuttal see; Bechara, Damasio, Tranel, & Damasio, 2005). In addition to the reliance on implicit knowledge for IGT performance, Bechara, Damasio, Tranel, and Anderson (1998) postulated that the necessary affective states develop independently of certain cognitive functions, namely working memory. This previous study revealed that working memory and decision making where doubly dissociated in that VMPFC patients showed normal working memory but impaired IGT performance, whereas patients with dorsolateral prefrontal cortex (DLPFC) damage showed impaired working memory but normal IGT performance. However, more recent lesion studies have provided evidence that damage to the DLPFC contributes to impaired IGT performance (Fellows & Farah, 2005a; Manes et al., 2002). The aim of the present study is to follow recent research (Hinson, Jameson, & Whitney, 2002; Jameson, Hinson, & Whitney, 2004) by attempting to assess the contribution of working memory to performance on this task. Specifically, we ask "Does increased working memory load lead to a similar 'myopic' pattern of poor performance on the IGT as observed in patients with damage to the ventromedial prefrontal cortex (VMPFC)?"

Participants play the IGT with the aim of earning as much play money as possible while avoiding losses. This is accomplished by choosing cards from four decks that contain a complex schedule of monetary penalty and rewards. Participants must learn through trial and error which decks contain the better future payoffs. Advantageous performance on the IGT is characterized by a progressive increase in choices from decks providing small immediate rewards but higher future earnings for an overall net gain. In contrast, disadvantageous performance is associated with a continued high rate of choices from decks providing high immediate rewards but even larger losses for an overall net loss. The first study that used the IGT (Bechara et al., 1994) showed that individuals with damage to the VMPFC failed to learn to choose advantageously. Their performance appeared "myopic" in the sense that choices were based off immediate outcomes rather than overall past experiences; i.e., they showed a preference for cards from the disadvantageous decks that offered immediate gains but larger future losses. Individuals who learned to make advantageous deck selections, but not individuals with damage to the VMPFC, developed anticipatory Skin Conductance Responses (SCRs) when preparing to select cards.

One problem for the interpretation of findings from the standard IGT is that the advantageous and disadvantageous decks differ, not only with respect to future reward gained, but also with respect to magnitude of initial wins (lower for the advantageous decks) and future losses (higher for the disadvantageous decks). Selections from the disadvantageous decks could represent either hypersensitivity to reward or hyposensitivity to punishment, rather than myopia for future outcomes. To test this possibility, Bechara, Tranel, and Damasio (2000) developed a "reversed" version of the IGT. On the reversed version, the rewards and losses are reversed so that the disadvantageous decks offer small immediate losses (a loss of £50 on average) but even smaller future earnings (a loss of £250 per 10 trials), and the advantageous decks offer high immediate losses (£100 on average) but even larger future earnings (a gain of £250 per 10 trials). The results showed that VMPFC patients were impaired at both versions of the IGT and failed to develop anticipatory SCRs. The SCRs when receiving rewards and punishments were not different from those generated by the healthy control group, which implies that the impairment was best explained by myopia for both positive and negative outcomes, and not hypersensitivity to reward or hyposensitivity to punishment.

At first glance, myopia for future outcomes appears to be a cogent explanation for the decision making impairment observed in patients with damage to the VMPFC (Bechara et al., 2000). On the standard version of the IGT, VMPFC patients typically choose more cards from the disadvantageous decks than the advantageous decks. However, impairments by VMPFC patients on the reversed IGT appear to be less extensive in that scores in the last 40 trials were marginally advantageous in that they approached "chance" (50% for both advantageous and disadvantageous deck types). Random sampling has been observed in the presence of an amnesic syndrome in amygdala/hippocampus damaged patients (Bechara, Damasio, Damasio, & Lee, 1999). A more convincing index of myopia for future outcomes would be the development of a consistent preference for the disadvantageous decks on not only the standard IGT, but also the reversed version.

2. Involvement of working memory in emotional decision making

Findings suggest that regions associated with working memory function, such as the dorsolateral prefrontal cortex (DLPFC), aid in the maintenance of information by directing attention to internal representations of sensory stimuli and motor plans that are stored in more posterior regions (Curtis & D'Esposito, 2003). Due to the complex nature of the IGT in that it presents different schedules of reinforcement (i.e., various ratios of rewards and punishments), it is likely that working memory functioning is necessary for performance. For example, normal performance would require that participants maintain the value of overall past choice-outcomes for continued updating of values across trials. However, initial findings (Bechara et al., 1998) suggested that good performance on the IGT did not fully depend on working memory, in that patients with damage to the dorsolateral prefrontal cortex showed working memory deficits but performed similar to controls on the IGT. More recent evidence challenges the postulation that IGT performance is independent of working memory. For example, Bechara and Martin (2004) found that working memory deficits in polysubstance abusers were inversely correlated with performance at the IGT. Furthermore, there is evidence that the experimental manipulation of working memory load impairs performance on a modified version of the IGT (Hinson et al., 2002; Jameson et al., 2004) and other decision making tasks (Hinson, Jameson, & Whitney, 2003). For example, Hinson et al. (2002) used a dual-task experiment to investigate the role of working memory during decision making, specifically the phonological and central executive components. This study used a 3 deck (i.e., good, intermediate, and bad decks) gambling task similar to the IGT (Bechara et al., 2000) by maintaining the original probabilistic nature of gains and losses, but differed in that the overall payoffs were reduced to increase the difficulty in distinguishing the good from the bad decks. The results showed that the high working memory load interfered with developing a preference for the good decks and normal anticipatory SCRs.

Although the data of Hinson et al. (2002) appear convincing, there are a number of reasons why it remains possible that increased working memory does not lead to a myopic style of decision making as observed in VMPFC patients. Firstly, increased working memory load might lead to high rates of random responding (for a similar criticism relating to findings using a Delayed Discounting Procedure see; Franco-Watkins, Pashler, & Rickard, 2006; and also; Hinson & Whitney, 2006). Secondly, as already mentioned, impaired performance on the standard version of the IGT might reflect hyposensitivity to punishment, rather than myopia for future outcomes.

In light of the above comments, the present study was designed to establish whether impaired performance at the IGT under working memory load conditions is the result of (1) increased random responding or (2) an inability to make choices based on past outcomes. In the present study, we address this issue by examining the effects of manipulating working memory load on performance on the reversed IGT. If the effects of high working memory load lead to random responding, then the participants under high memory load will show relative indifference by selecting equally from the advantageous and disadvantageous decks. Statistically, differences in the ratio of selections from advantageous and disadvantageous decks should not differ from zero across blocks nor will there be progression in advantageous choices as indicated by a non-significant linear trend. Finally, if working memory load leads to choices being based on immediate outcomes rather than past experiences, then participants under the high memory load condition will fail to show a progression in advantageous choices in that they are expected to consistently select cards from the disadvantageous decks offering the lowest immediate losses.

3. Method

3.1. Participants

Thirty-five students from the University of Hull (25 women and 10 men; mean age in years $= 22.7$, $SD = 5.07$) volunteered to participant in this study in exchange for course credit. Participants were randomly assigned to perform the IGT under either a low working memory condition (LWM; $n = 18$) or high working memory condition (HWM; $n = 17$).

3.2. Materials and procedure

The reversed version of the Iowa Gambling Task (rIGT) was identical in all aspects to that used in previous studies (Bechara et al., 2000) with the exception of the randomization of the four decks (across 100 trials) within the four predetermined arranged spatial locations. The standard instructions used in previous studies (Bechara et al., 2000) were given to all participants. Decks A and B were advantageous in that they yielded high immediate losses but even larger delayed winnings. For example, the first 10 cards selected from decks A and B yielded a total loss of £1000 (average loss of £100 per card) but wins totalling £1250 resulting in a net gain of £250. Deck A contained a relatively high frequency of wins (e.g., 5 wins totalling £1250 in the first block of 10 trials) and deck B contained a higher magnitude, but less frequent wins (e.g., one win of £1250 in the first block of 10 trials). As the task progressed, the losses associated with decks A and B remained fixed whereas the wins increased in either frequency (deck A) or magnitude (deck B). Decks C and D were disadvantageous in that they yielded small immediate losses but even smaller delayed earnings. For example, the first 10 card selected from decks C and D yielded losses of £500 and wins of £250 resulting in a net loss of £250. Deck C contained a relatively high frequency of wins (e.g., 5 wins totalling £250 in the first block of 10 trials) and deck D contained higher magnitude but less frequent wins (e.g., one win of £250 in the first block of 10 trials). Although there was a 5 s inter-trial-interval (ITI) between each card selection, allowing the participant time to attend to the visually presented feedback (e.g., tally bars) and secondary task (e.g., string of numbers and probe response), participants could take as long as wanted before making their next card choice. Participants started the task with £2000 and were told their aim was to maximize profit. After each selection, participants received two messages indicating the amount of money lost and won (e.g., “You lose £100!”; “You win £1250!”). A smiley face was presented next to the amount won and a sad face was presented next to the amount lost after each selection. In addition, a white bar indicated the net winnings for the task. The size of the white and green bars was proportional to the amount won or lost. Participants were allowed to select freely from any of the decks throughout the game. Participants were not informed that the task would end after 100 trials.

For the secondary task, a string of 5 digits (e.g., 1–5) were presented aurally. There were a total of 5 memory sets, each containing 5 memory trials per block of 20 card selections of the card game. Three different scripts were used to counterbalance the memory probes across card selections, with one probe presented every 2–5 card selections. Each participant was instructed to silently retain in memory the digit string during card selections until presented with a probe, whereupon they were required to identify the digit to the right of the probe. The digit string and probe were always presented during an ITI of the IGT. The digits in the high memory set were random (e.g., 31524) whereas the digits in the low memory group were numerically sequential (i.e., 12345). Participants' responses were made verbally and recorded by the experimenter.

4. Results

4.1. Treatment of data

Data from the memory tasks were quantified as the mean number of correct responses from each memory probe block; 25 memory probes reduced to 5 blocks of 5 probes.

Scores on the rIGT were quantified as the number of average choices from each deck over each of the 5 blocks of 20 trials. The number of selections from the advantageous decks (A and B) and disadvantageous decks (C and D) during each block were computed, and a net score for that block was derived using the following formula $[(A + B) - (C + D)]$ as done elsewhere (Bechara et al., 2000). Net scores below zero indicate disadvantageous performance whereas net scores above zero indicate advantageous performance.

4.2. Memory tasks

Analysis of the memory task data did not reveal any outliers in the HWM group. Data were analysed using a mixed factorial ANOVA with Block (5) as the within-subject factor and Group (LWM vs. HWM) as the between-group factor. The results revealed a main effect of Memory Load [$F(1,33) = 27.57$, $p = .001$]; the number of correct responses was significantly greater for participants performing the LWM task ($M = 5$, $SE = .14$) compared to the HWM task ($M = 3.93$, $SE = .15$). The main effect of Block [$F(4,132) = .45$, $p = .774$] and 2-way Group × Block interaction [$F(4,132) = .45$, $p = .774$] were not significant, suggesting that scores on the secondary task did not significantly improve or worsen as the task progressed.

4.3. Reversed IOWA gambling task

To investigate rIGT performance, averaged scores across the 5 blocks were analysed using a mixed factorial ANOVA with Group (LWM vs. HWM) as the between-subject factor and Block (5) as the within-subject factor. Overall, there was a significant difference in overall performance (averaged over 100 trials) between groups [$F(1,33) = 11.09$, $p = .002$], with the LWM group scoring higher ($M = 2.43$, $SE = 1.68$) than the HWM group ($M = -5.58$, $SE = 1.73$). Interestingly, neither the main effect of Block [$F(4,132) = .60$, $p = .662$] nor the 2-way Group × Block interaction [$F(4,132) = 1.63$, $p = .172$] were significant. The linear effect of Block was not significant for the LWM group [$F(1,17) = .09$, $p = .769$] or the HWM group [$F(1,16) = .21$, $p = .655$]. As observed in Fig. 1, the LWM group showed a decrement in performance over block 5. When this analysis was re-run, excluding block 5, the effect began to show for the LWM group [$F(1,17) = 3.15$, $p = .094$] but not the HWM group [$F(1,16) = .04$, $p = .850$]. To account for delayed learning in the HWM group, we re-run the analysis excluding block 1. The analysis was unsuccessful in revealing a significant linear trend [$F(1,16) = 1.7$, $p = .211$].

The difference in scores between the LWM group ($M = -.33$, $SD = 8.15$) and HWM group ($M = -4.71$, $SD = 7.74$) was not significant [$t(33) = 1.63$, $p = .114$] at **block 1**. However, the LWM group's scores were significantly higher than the HWM group's at **block 2** ($M = 2.67$, $SD = 11.38$; $M = -7.65$, $SD = 9.6$) [$t(33) = 2.89$, $p = .007$], **block 3** ($M = 4.83$, $SD = 9.12$; $M = -5.76$, $SD = 9.23$) [$t(33) = 3.42$, $p = .002$], **block 4** ($M = 4.89$, $SD = 8.41$; $M = -5.76$, $SD = 11.02$) [$t(33) = 3.23$, $p = .003$], but not **block 5** ($M = .11$, $SD = 10.9$; $M = -4$, $SD = 13.82$) [$t(33) = .25$, $p = .334$]. As seen in Fig. 1, the HWM group's scores in block 5 remained within a disadvantageous range.

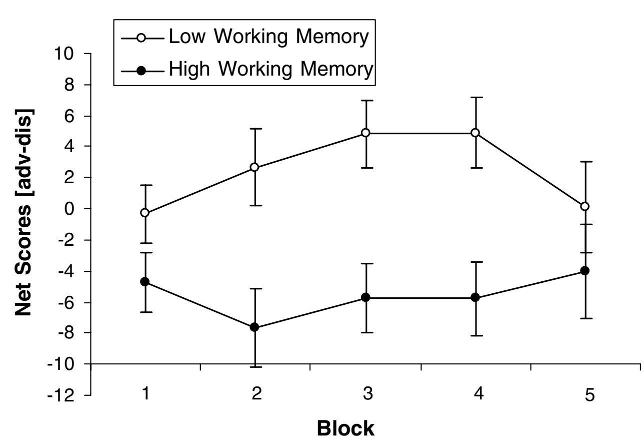

Fig. 1. Net scores (with standard error bars) at the Reversed IGT over 5 blocks as a function of Memory Load. Positive scores indicate advantageous performance whereas negative scores indicate disadvantageous performance.

Although the net gain every 10 cards in both advantageous decks are equal (£250), deck A contains smaller magnitude but more frequent earnings ($P = 0.5$) compared to deck B ($P = 0.1$). For exploratory purposes, we analysed the net choices from both advantageous decks (A vs. B) across blocks (5) using a mixed ANOVA. Results revealed a main effect of Deck [$F(1,33) = 7.38$, $p = .010$], indicating deck A ($M = 29$, $SD = 20.05$) was selected more often than deck B ($M = 16.86$, $SD = 12.86$). The significant main effect of Group [$F(1,33) = 10.85$, $p = .002$] indicated that the LWM group selected more cards from deck A ($M = 37.11$, $SD = 20.4$) than the HWM group ($M = 20.41$, $SD = 16.12$). Both the 2-way Group × Block interaction [$F(4,33) = 1.69$, $p = .156$] and 3-way Group × Block × Deck interaction [$F(4,132) = 1.12$, $p = .350$] were not significant. These findings suggest that the high working memory load interfered with participants' learning that the frequent and moderate-sized delayed earnings outweighed the large immediate losses associated with deck A.

The results of the covariate analysis showed that the high memory digit span task scores did not significantly [$p = .767$] account for scores on the rIGT. Therefore, variance on the rIGT in the HWM group could not be fully explained by the level performance on the secondary memory task. To explore the contribution of gender differences to IGT performance, Gender was used as a covariate to averaged scores across the 5 blocks. The results showed that gender did not significantly influence performance on the IGT [$F(1,33) = .57$, $p = .454$].

4.4. Random responding

To test the hypothesis that high working memory load leads to random responding we compared both groups' scores across blocks with zero. The results revealed that as the task progressed, the LWM group's advantageous scores eventually became significantly different from zero: **Block 1** [$t(17) = -.17$, $p = .864$], **block 2** [$t\ (17) = 60$, $p = .330$], **block 3** [$t(17) = 2.25$, $p = .038$], **block 4** [$t(17) = 2.47$, $p = .025$], **block 5** [$t(17) = .04$, $p = .966$]. In contrast, the disadvantageous scores by the HWM group were significantly different from zero (indicating disadvantageous selection) during **block 1** [$t(16) = -2.51$, $p = .023$], **block 2** [$t(16) = -3.29$, $p = .005$], **block 3** [$t(16) = -2.58$, $p = .020$], **block 4** [$t(16) = -2.16$, $p = .047$], but not **block 5** [$t(16) = -1.19$, $p = .250$]. To test if this slight improvement in performance by the HWM group was due to either exhaustion of one of the disadvantageous decks and subsequent selections from the remaining advantageous decks or delayed learning, participants who depleted any of the disadvantageous decks were eliminated from the analysis. The results showed that the difference between scores in block 5 when compared to zero remained non-significant [$p > .05$], suggesting that the latent improvement by the HWM group could be explained by either delayed learning or a decision to act randomly. Likewise, removing the participants in the LWM group that exhausted one of the advantageous decks could not explain the detriment in performance in the last block of the task [$p > .05$]. Simply put, increased random responding cannot fully account for the poor performance on the rIGT under high memory load conditions.

5. Discussion

The findings from the present study, in combination with earlier reports that working memory load impairs performance on the standard IGT (Pecchinenda, Dretsch, & Chapman, 2006), support the hypothesis that working memory load interferes with making choices based on overall experiences, rather than either hyposensitivity to punishment or increased random responding. The random responding hypothesis did not receive support because both groups made consistent selections, even if (in the case of the HWM group) the selections were from the disadvantageous decks. In short, the findings corroborate the conclusion reached elsewhere (Hinson et al., 2002) that avers that working memory resources are critical for emotional decision making. However, our findings extend this assertion by showing that impaired decision making following increased working memory load cannot be fully explained by random responding. Alternatively, working memory load resulted in what appeared to be choices based on immediate outcomes, and not the accumulation of overall past outcomes.

At first glance, the findings from the present study appear to contradict those reported in Turnbull, Evans, Bunce, Carzolio, and O'Connor (2005) which reported that secondary tasks that load cognitive resources do not interfere with IGT performance. However, differences in secondary tasks used reconcile differences between our findings and those reported in Turnbull et al. The secondary task used in the present study, the digit span task, would have placed more demands on processes necessary for IGT performance, namely the encoding, maintenance, and retrieval of relevant information (e.g., earnings and losses across trials) held in working memory. In contrast, the random number generation and subvocal rehearsal tasks used in Turnbull et al. may not have been taxing enough to interfere with performance. In fact, inconsistencies of the effect of random number generation on decision making has been observed in Hinson et al. (2002) in that they failed to replicate impaired decision making in one of their experiments when using this secondary task. The effect of working memory load on IGT performance has been observed in other studies (Jameson et al., 2004; Pecchinenda et al., 2006), however the present study is the first to test the reversed IGT under working memory conditions.

5.1. Reversal-learning

How did working memory interfere with emotional decision making? One explanation is that the secondary task interfered with reversal-learning. This has been tested with the standard version of the IGT in that they fail to shift away from the disadvantageous decks after continued losses. Fellows and Farah (2005a) modified the IGT to eliminate the reversal-learning component. Patients with VMPFC damage were impaired on the standard but unimpaired on the modified version. In contrast, patients with DLPFC damage were impaired on both versions. Although this is inconsistent with the findings in Bechara et al. (1998) which reported DLPFC patients perform normally on the standard IGT, it does suggest that working memory may be involved in a number of tasks including those that involve reversal-learning.

5.2. Attention to feedback

Other evidence by Hornak and colleagues (Hornak et al., 2004) challenge the reversal-learning interpretation by showing that impairments on a reversal-learning task by DLPFC patients is not due to a deficit in reversal-learning, but is attributed to a failure to use available feedback during the task. Dorsolateral patients were categorized into two subgroups based on normal or impaired performance. The post-test questionnaire revealed that performance in the impaired group was correlated with the failure to pay attention to total earning bars and other information presented on the monitor, rather than an actual reversal-learning deficit. In the present study, a failure to pay attention to visual information in the form of tally bars presented at the top of the screen and the outcome feedback (e.g., "You Lose £100"; "You Win £350") could prevent participants from making associations with certain decks.

Although failure to use visually presented feedback may partially explain the poor reversal-learning performance in patients with DLPFC damage, for the current study it is an unlikely explanation for the primary reason that the HWM group consistently selected cards from the disadvantageous decks. It seems more likely that failure to use available information would be characterized by an increased random responding and not consistent selections from disadvantageous decks. The fact that a preference for the disadvantageous decks was formed suggests that attentional focus on available feedback was maintained for at least some of the time. Rather, it is more likely that the HWM load interfered with participants' ability to fully integrate earnings and losses experienced over the course of the task.

5.3. Apathy

Dunn et al. (2005) raises the question of impaired IGT performance being attributed to apathy in VMPFC patients. Fellows and Farah (2005b) reported diminished prospective thinking in ventromedial prefrontal patients. The results revealed an inverse relationship between apathy scores and personal future time perspective for VMPFC patients. To the extent that apathy contributes to the decision making impairment observed in VMPFC patients has yet to be thoroughly investigated. The findings in the present study could be attributed to the HWM load interfering with participants' willingness to exert effort on the rIGT. To the extent that lack of motivation occurred during high memory load conditions cannot be ascertained in the present study. Yet there is no a priori reason to assume that two separate groups of healthy individuals would differ in apathy levels, so this is unlikely to explain the differences in performance. Future studies using clinical populations should consider measuring apathy levels.

5.4. Risk-taking

An alternative interpretation could be that the HWM load increased risk-taking. However, the present study used the reversed IGT and not the standard. In the reversed IGT, the disadvantageous decks are the least risky in that each choice outcome has smaller magnitude losses, but even smaller overall future gains in comparison to the advantageous decks. Furthermore, in a previous study (Pecchinenda et al., 2006), we showed that working memory load interfered with performance on the standard IGT, therefore ruling-out increased risk-taking as an explanation. Another way of interpreting our data from the rIGT is that HWM conditions interfere with a normal level of risk-taking necessary (i.e., risk aversive) for advantageous performance on the reversed version of the IGT.

The most convincing explanation is that working memory is involved in the continuous updating of competing information (i.e., wins vs. losses; immediate vs. future outcomes) and maintenance for the appraisal of the future goodness or badness associated with individual decks. Indeed, our results show that under HWM load conditions, the ability to effectively learn to choose the good decks over the bad decks is adversely affected as observed by participants' tendency to choose from the disadvantageous decks.

5.5. Limitations

The present study has several limitations. Firstly, we did not focus on individual differences but were solely concerned with the effects of working memory load in general. Although IQ level does not appear to influence task performance (Lösel & Schmucker, 2004), other research has shown that individual motivational trait differences do influence performance on the standard IGT (Franken & Muris, 2005). Other studies (Overman, 2004) have revealed gender differences on the IGT, with females typically showing slightly poorer performance compared to males. Although our analyses failed to show a relationship between gender and task performance, our sample consisted of only 25% male participants. Since the reversed version has only recently begun to receive a high degree of attention, future studies should continue to assess the contribution of individual differences in addition to working memory.

Secondly, the failure of our analyses to find a significant main effect of Block and/or Group × Block interaction may have been due to our small sample size; LWM ($n = 18$), HWM ($n = 17$). However, testing for the main effects and interactions are underpowered because they do not capture the pattern of data. There is a clear learning effect, but this occurs from Block 1 to Block 4 in the LWM group and then decreases. The data from the LWM group is consistent with other studies using the reversed IGT (see; Windmann et al., 2006). This detriment in performance in the last block of the task might best be explained by participants becoming bored and consequently exploring the other decks.

Lastly, there has been an on-going debate regarding the role of awareness needed for IGT performance. This was initially proposed in Bechara et al. (1997) after showing that VMPFC patients develop explicit awareness of task contingencies in the last block of the task, but still fail to perform advantageously. In addition to a failure to develop anticipatory SCRs, the results suggested that the impaired performance by VMPFC patients was associated with the failure to subjectively report implicit knowledge or a gut-feeling of goodness or badness of individual decks. Maia and McClelland (2004) challenged the impenetrability of the IGT by providing evidence that the questionnaires used by Bechara et al. were too general to detect explicit awareness. In fact, using more specific questionnaires they showed that explicit awareness can occur in the first block of the task. While some evidence suggests that a secondary working memory load interferes with the development of explicit knowledge (Brunstrom & Higgs, 2002), the present study did not incorporate subjective reports of contingency awareness. Consequently, we cannot report on the level of contingent awareness our participants' experience. However, as observed in real-life scenarios, many people make poor choices even when they are aware of the potentially negative consequences.

The findings in the present study provide evidence that working memory is critical for good decision making and that loading working memory does not simply lead to random responding. More specifically, the poor performance appears to be due to a preference for the disadvantageous options. In other words, high working memory conditions can contribute to a "myopic" decision making style characterized by choices being guided by immediate outcomes rather than overall past experiences.

References

Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition, 50*, 7–15.

Bechara, A., Damasio, H., Damasio, A. R., & Lee, G. P. (1999). Different contributions of the human amygdala and ventromedial prefrontal cortex to decision making. *The Journal of Neuroscience, 19*, 5473–5481.

Bechara, A., Damasio, H., Tranel, D., & Anderson, S. (1998). Dissociation of working memory from decision making within the human prefrontal cortex. *Journal of Neuroscience, 18*, 428–437.

Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (1997). Deciding advantageously before knowing the advantageous strategy. *Science, 275*, 1293–1295.

Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (2005). The IGT and the somatic marker hypothesis: Some questions and answers. *Trends in Cognitive Sciences, 9*, 159–162.

Bechara, A., Dolan, S., & Hindes, A. (2002). Decision making and addiction (part II): Myopia for the future or hypersensitivity to reward? *Neuropsychologia, 40*, 1690–1705.

Bechara, A., & Martin, E. M. (2004). Impaired decision making related to working memory deficits in individuals with substance addictions. *Neuropsychology, 18*, 152–162.

Bechara, A., Tranel, D., & Damasio, H. (2000). Characterization of the decision making deficit of patients with ventromedial prefrontal cortex lesions. *Brain, 123*, 2189–2202.

Bechara, A., Tranel, D., Damasio, H., & Damasio, A. (1996). Failure to respond autonomically to anticipated future outcomes following damage to prefrontal cortex. *Cerebral Cortex, 6*, 215–225.

Brunstrom, J. M., & Higgs, S. (2002). Exploring evaluative conditioning using a working memory task. *Learning and Motivation, 22*, 433–455.

Cavendini, P., Riboldi, G., D'Annucci, A., Belotti, P., Cisima, M., & Bellodi, L. (2002). Decision making heterogeneity in obsessive-compulsive disorder: Ventromedial prefrontal cortex function predicts different treatment outcomes. *Neuropsychologia, 40*, 205–211.

Curtis, C. E., & D'Esposito, M. (2003). Persistent activity in the prefrontal cortex during working memory. *Trends in Cognitive Sciences, 7*, 415–423.

Dunn, B. D., Dalgleish, T., & Lawrence, A. D. (2005). The somatic marker hypothesis: A critical evaluation. *Neuroscience & Biobehavioral Reviews, 30*, 239–271.

Fellows, L. K., & Farah, M. J. (2005a). Different underlying impairments in decision making following ventromedial and dorsolateral frontal lobe damage in humans. *Cerebral Cortex, 15*, 58–63.

Fellows, L. K., & Farah, M. J. (2005b). Dissociable elements of human foresight: A role for the ventromedial frontal lobes in framing the future, but not in discounting future rewards. *Neuropsychologia, 43*, 1214–1221.

Franco-Watkins, A. M., Pashler, H., & Rickard, T. C. (2006). Does working memory load lead to greater impulsivity? Commentary on Hinson, Jameson, and Whitney's (2003). *Journal of Experimental Psychology: Learning, Memory & Cognition, 32*, 443–447.

Franken, I. H. A., & Muris, P. (2005). Individual differences in decision making. *Personality and Individual Differences, 5*, 991–998.

Hinson, J., Jameson, T., & Whitney, P. (2002). Somatic markers, working memory, and decision making. *Cognitive, Affective, & Behavioural Neuroscience, 2*, 341–353.

Hinson, J., Jameson, T., & Whitney, P. (2003). Impulsive decision making and working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*, 298–306.

Hinson, J., & Whitney, P. (2006). Working memory load and decision making: A reply to Franco-Watkins, et al. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*, 448–450.

Hornak, J., O'Doherty, J., Bramham, J., Rolls, E. T., Morris, R. G., Bullock, P. R., et al. (2004). Reward-related reversal learning after surgical excisions in orbito-frontal or dorsolateral prefrontal cortex in humans. *Journal of Cognitive Neuroscience, 16*, 463–478.

Jameson, T. L., Hinson, J. M., & Whitney, P. (2004). Components of working memory and somatic markers in decision making. *Psychonomic Bulletin and Review, 11*, 515–520.

Lösel, F., & Schmucker, M. (2004). Psychopathy, risk taking, and attention: A differential test of the somatic marker hypothesis. *Journal of Abnormal Psychology, 113*, 522–529.

Manes, F., Sahakian, B., Clark, L., Rogers, R., Antoun, N., Aitken, M., et al. (2002). Decision making processes following damage to the prefrontal cortex. *Brain, 125*, 624–639.

Maia, T. V., & McClelland, J. L. (2004). A re-examination of the evidence for the somatic marker hypothesis: What participants really know in the IGT. *Proceedings from the National Academy of Sciences, 101*, 16075–16080.

Overman, W. H. (2004). Sex differences in early childhood, adolescence, and adulthood on cognitive tasks that rely on orbital prefrontal cortex. *Brain and Cognition, 55*, 134–147.

Pecchinenda, A., Dretsch, M., & Chapman, P. (2006). Working memory involvement in emotion-based processes underlying choosing advantageously. *Experimental Psychology, 53*, 191–197.

Rotheram-Fuller, E., Shoptaw, S., Berman, S. M., & London, E. D. (2004). Impaired performance in a test of decision making by opiate-dependent tobacco smokers. *Drug and Alcohol Dependency, 73*, 79–86.

Sanfey, A. G., Hastie, R., Colvin, M. K., & Grafman, J. (2003). Phineas gauged: Decision making and the prefrontal cortex. *Neuropsychologia, 41*, 1218–1229.

Schmitt, W., Brinkley, C., & Newman, J. (1999). Testing Damasio's somatic marker hypothesis with psychopathic individuals: Risk takers or risk aversive?. *Journal of Abnormal Psychology, 108*, 538–543.

Turnbull, O. H., Evans, C. E. Y., Bunce, A., Carzolio, B., & O'Connor, J. (2005). Emotion-based learning and central executive resources: An investigation of intuition and the IGT. *Brain and Cognition, 57*, 244–247.

Windmann, S., Kirsch, P., Mier, D., Stark, R., Walter, B., Güntürkün, O., et al. (2006). On framing effects in decision making: Linking lateral versus medial orbitofrontal cortex activation to choice outcome processing. *Journal of Cognitive Neuroscience, 18*, 1198–1211.