Pupil Dilation and Cognitive Reflection as Predictors of Performance on the Iowa Gambling Task

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Abstract

Risky decisions involve cognitive and emotional factors. As the primary test for the Somatic Marker Hypothesis (SMH), the Iowa Gambling Task (IGT) examines these factors. Skin conductance shows anticipatory physiological responses on the IGT supporting SMH. Pupil dilation offers an alternative physiological marker. Predictive effects of anticipatory pupillary responses to positive and negative decks on IGT performance were examined in an extended IGT. The extended Cognitive Reflection Test (CRT) examined the relationship between reflective thinking and IGT performance. Data demonstrated correlations between reflective thinking and performance from the second block onwards and that task learning continued into the additional blocks - performance was not optimized even in the final block. Regression analysis showed both anticipatory pupil dilation for disadvantageous and advantageous decks, and reflective thinking were strong predictors of IGT performance. While both emotional and reflective processes are implicated in IGT performance, analytic cognition is more important than traditionally acknowledged.

Keywords: Pupil dilation; Iowa Gambling Task; Cognitive Refection; Somatic Marker Hypothesis; Dual-process Theory.

Introduction

Learning and decision making in uncertain situations is an important activity, and it can be challenging to find an optimal decision even for simple choices. Decisions can be driven by the desire to maximize expected utility (Quartz, 2009), but information management regarding reward utility is frequently uncertain. Cognitive and emotional influences on risky decision making were traditionally regarded as separate in nature, with emotional factors typically seen as a hindrance. However, more recent evidence indicates that there is an interplay between the two, such that cognitive functions may serve as moderators for emotion-based learning (e.g. Brevers, Bechara, Cleeremans, & Noel, 2013; Simonovic, Stupple, Gale & Sheffield, 2016).

Damasio (1994) developed Somatic Marker Hypothesis (SMH) arguing that emotional processes play a central role in risky decision-making. SMH postulates that decisions are guided by subjective ‘gut feelings’ (e.g. bodily representations) about the inherent goodness or badness of future choices. These somatic markers direct individuals towards alternatives that have been positive previously or guide them away from the negative options. Particularly in uncertain conditions, response options are marked with an emotional signal, and only those options that are marked as favorable are cognitively processed (Damasio, 1994; Bechara & Damasio 2005). Somatic markers operate covertly, indicate arousal anticipation and are regarded as physiological markers of emotion-based learning (Bechara & Damasio, 2005; Critchley et al., 2001).

A further theoretical framework for investigating risky decision making is Dual Process which proposes that there are two types of cognitive process: unconscious, emotional gut-feelings (Type 1) that contrast with explicit, effortful, analytic processes (Type 2) (e.g. Kahneman. 2003). This proposal has been linked with SMH; for example Type 1 processes include a range of intuitive processes such as emotional responses or gut feelings (Glockner & Witteman 2010) that can be measured through physiological techniques. There is also evidence of a role for cool reflective processing (Brevers, Bechara, Cleeremans, & Noel, 2013; Simonovic et al., 2016) which maps onto Type 2 processing.

The primary paradigm in evaluation of emotion-based learning is the Iowa Gambling Task (IGT, Bechara, Damasio, Damasio, & Anderson, 1994). The IGT offers a means of testing decision preferences and performance and has become an important experimental tool in evaluation of emotion-based learning and decision making. It has been argued that IGT resembles real life decision making as it involves uncertainty and monitoring of rewards and punishments (Bechara & Damasio, 2005). Participants are required to choose cards from four decks (A, B, C, and D), all of which differ in frequencies of financial rewards and punishments. Advantageous decks (C and D) offer moderate rewards and small punishments whereas disadvantageous decks (A and B) offer larger rewards but substantial penalties, which result in an overall loss.

During the IGT, participants need to learn from experience about the 'goodness' or 'badness' of decks based on the feedback of learned contingencies. Thus, while participants experience deck reward properties they also assign affective values to the decks which implicitly influence decision making. The standard IGT consists of five blocks of 20 trials and healthy participants are considered to reach ceiling performance in the final block as the disadvantageous selections have been extinguished. Optimal IGT performance rests therefore on monitoring emotional responses and impulse inhibition related to the rewards and punishments (e.g., Bechara & Damasio, 2005).

An important finding for SMH is that anticipatory somatic markers of emotions occur before decisions are made, indicating that covert anticipatory emotions can guide decision making (e.g. Bechara, Damasio, Tranel & Damasio, 1997). Indeed, there is evidence demonstrating anticipatory Skin Conductance Responses (aSCR) to rewards and punishments under uncertain conditions (e.g. Bechara et al., 1997; Wagar & Dixon 2006). Furthermore, interpretation of these aSCR's highlight the primary role of emotions in guiding decision making performance (e.g. Bechara & Damasio, 2005).

In contrast, there is also evidence that reflective evaluation of affective choices guides future decision-making and occurs relatively early in the decision-making processes (e.g. Bowman, Evans, & Turnbull, 2005 Brevers et al., 2013; Simonovic et al., 2016). This evidence is consistent with an interplay between Type 1 and Type 2 processes in determining the outcome of the decision making process (cf. Kahneman, 2003). Indeed, Brevers et al. (2013) argued that anticipation of long-term consequences in uncertain condition rely on two neural systems: a 'cool' and a 'hot' systems. The 'hot' system is impulsive, laden with affective 'gut feelings' akin to intuition, while the 'cool' system is reflective and includes analytic aspects. Learning and optimal decisions depend on the integration of both systems whereby, a 'cool' reflective process can be critical in monitoring or inhibiting 'hot' processes. It has also been argued that cool reflective processes should not play a role until the deck contingencies become explicit and so there should not be a role for Type 2 processing in the early blocks. Simonovic et al., (2016), however, demonstrated that reflective processes play a role earlier than previously predicted (cf. Schiebener, Zamarian, Delazer and Brand 2011).

Evidence suggest that aSCRs represent a good example of anticipatory somatic markers or 'hot processing'. They are, however, imperfectly represented because the SCR is not sufficiently sensitive in discriminating between negative and positive valence (Dunn et al., 2006). Faster measures of emotion feedback (e.g. heart rate and blood pressure with an electrocardiogram or pupil dilation using eye trackers) are warranted (e.g. Bradley, Codispoti, Cuthbert & Lang, 2001). Indeed, studies that use faster physiological measurement, (e.g. eye-tracking methodology) can better capture surprised responses to unexpected stimuli (e.g. Lavin, San Martin, & Jubal, 2014).

Recent studies have also shown pupil dilation can measure surprise such as when feedback does not meet expectation (Preuschoff, Hart, & Einhauser, 2011), when negative feedback occurs during the gambling task (Satterthwaite et al., 2007), and as evidence of learning (Lavin et al., 2014). Moreover, there is evidence linking pupillary responses to Locus Coeruleus (LC) - norepinephrine (NE) activity in the brain stem in anticipation of a reward, suggesting memory enhancement (Tully & Bolshakov, 2010), and consolidation of behavioural decisions (Bouret & Sara, 2005). Some evidence indicates greater pupillary responses before selecting negative options (e.g. Bierman, 2004), or after experiencing unexpected losses (Satterthwaite et al., 2007), thus indicating that anticipatory pupillary responses can be related to negative outcomes. However, Lavin et al. (2014) argue that pupillary responses are associated with positive feedback. Thus, although anticipatory pupillary responses serve as affective physiological markers and may offer a measure of the somatic markers that moderate learning in uncertain conditions their interpretation is also not necessarily straightforward.

To our knowledge, only one study has utilised eye-tracking methodology during the IGT performance in a healthy population. Lavin et al. (2014) tested IGT performance and measured pupil dilation in a sample of 10 participants and demonstrated changes in pupil dilation due to learned uncertainty. Their results suggest that changes in pupil dilation reflect learned uncertainty about future feedback conditions, thus indicating differential processing of unexpected feedback. However, a non-standard version of the IGT was used and did not differentiate between disadvantageous and advantageous deck selection. In the present study, we extend Lavin et al.'s (2014) findings, with a larger sample and an alternative approach to measuring anticipatory pupil dilation.

Our focus was on the period during the IGT where participants had hypothetically developed somatic markers but that these were not yet sufficient to extinguish particular card selection. On this basis we measured pupil dilation in the 500ms prior to the final selection from each deck and hypothesized that there should be somatic markers indicating negative anticipation for disadvantageous decks and positive anticipation for advantageous decks. We measured anticipatory pupillary responses for the advantageous (C + D) and the disadvantageous (A + B) final options. If anticipatory somatic markers play a role in IGT performance then these should be evident prior to the final selection of each type of card.

Moreover, we included a direct measure of deliberative thinking to replicate previous findings demonstrating that the CRT was highly predictive of IGT performance (Simonovic et al., 2016). We used the extended seven-item Cognitive Reflection Test (CRT[1]), developed to measure the ability to resist and override intuitive responses by engaging analytic ability (Toplak, West, & Stanovich, 2014), this is a more comprehensive measure than the original three item CRT used in the Simonovic et al. (2016) study.

It was predicted that the CRT and last anticipatory pupillary responses for advantageous and disadvantageous deck picks would predict IGT performance. It was also predicted that the correlations observed by the Simonovic et al., (2016) between CRT score and disadvantageous card selections across blocks would be replicated (such that strong correlations would be found in blocks 2 – 4, but no correlation would be observed in the early trials and the correlation would be reduced in the final blocks). Finally, the standard analysis of IGT performance across blocks was extended to test whether performance reached ceiling levels in the fifth block (the final block in the standard IGT) or whether performance continued to improve.

Method

Design

Predictor variables were: the seven-item CRT (Toplak et al., 2014) and pupillary responses averaged across the 500ms prior to the final selection for both advantageous (C + D) and disadvantageous (A + B) decks. The CRT was used as a measure of analytic thinking. The dependent variable was the IGT score. Performance across blocks was also examined for completeness with (C+D) – (A + B) as the dependent variable for performance in each block

Participants

Sixty-nine[2], healthy students from the University of Derby, aged 19-29 years, received course credit for participation. Research was conducted in accordance with stipulations of the local ethics committee. Participants had normal or corrected to normal vision.

Materials and Procedure

Participants completed Bechara et al.'s (1994) computerised version of IGT[3]. Scoring was derived by deducting 'good' card picks (C + D) from total 'bad' picks (A + B). A positive score indicates a more optimal decision-making strategy.

The seven-item CRT (Toplak, West & Stanovich, 2014) score was the total number of correct answers. Higher CRT scores indicated higher reflective ability. Cronbach's alpha was $\alpha = .66$.

Eye movements were recorded with the Eye-gaze binocular system Tobii-X2-30 (Inquisit 4 milliseconds plugins), with a remote binocular sampling rate of 30 Hz and an accuracy of about 0.45°. The X2 Eye Tracker is a stand-alone eye tracker, and it was attached to a laptop (Dell, Precision M6700, 2.70Ghz). Participants were seated approximately 70 cm from the laptop monitor. The Tobii measured 184mm (7.2'') in length and enabled tracking at close distances (up to 36° gaze angle). The eye-tracker used both bright and dark pupil illumination setups to calculate the optimal gaze position. Blinking periods were filtered and replaced via linear interpolation (e.g. Siegle, Steinhauer Carter, Ramel, & Thase, 2003). The anticipatory pupil dilation (aPD) diameter was defined as the mean pupillary response generated 500ms before card selection. A 500ms time frame was identified *a priori* as a period where fixation occurs, and direction of the information search can be determined (e.g. Horstmann. Ahlgrimm, & Glockner, 2009).

Analytic Strategy

Initial analyses focused on participants' performance per block by using repeated measures ANOVA. Next, correlations between CRT scores and selection of disadvantageous cards for each block were calculated. Finally, regression analysis was used to examine the independent contributions of CRT scores and pupil dilations on IGT performance. Analysis was conducted using IBM SPSS 24 for Windows.

Results

Performance across blocks was tested using a Greenhouse-Geisser adjusted repeated measures ANOVA. There was a main effect of Block condition, $F(3.86, 239.12) = 25.21$, $p < .001$, $\eta_p^2 = .29$. Bonferroni adjusted post hoc tests demonstrated that performance improved significantly through the blocks of trials (excluding Block 6). Notably the nonstandard additional blocks 6 and 7 continued to show changes in performance relative to earlier blocks such that performance dipped in Block 6 but Block 7 was significantly better than all but Block 5. Means and standard deviations are shown in Table 1.

Table 1: Mean (SD) IGT Performance as a function of Trial Block.

[1] Although there is some disagreement about the aspect of analytic thinking that the CRT measures (e.g. Stupple, Gale, & Richmond, 2013; Toplak, West, & Stanovich, 2011), it is a useful tool in measuring analytic ability and reflective processing.

[2] Six participants were excluded from the analysis due to incomplete pupil dilation data (N=4) or extreme outlier pupil dilation data (N=2)

[3] We extended the original IGT to 140 trials to assess the learning effect (e.g. Bagneux, Font, & Bollon, 2013).

Trial Block	IGT Performance
Block 1	-3.65 (6.29)
Block 2	-.016 (7.71)
Block 3	2.76 (8.79)
Block 4	4.19 (10.45)
Block 5	7.38 (9.75)
Block 6	5.86 (11.24)
Block 7	9.35 (9.63)
Total	26.27 (46.70)

Table 2: Correlations between Disadvantageous card selections and CRT score as a function of Trial Block

Trial Block	Correlation
Block 1	r= -.18, p=.150
Block 2	r= -.41, p=.001
Block 3	r= -.74, p<.001
Block 4	r= -.81, p<.001
Block 5	r= -.70, p<.001
Block 6	r= -.71, p<.001
Block 7	r= -.67, p<.001
Total	r= -.89, p<.001

Correlations between CRT score and selection of disadvantageous cards across blocks were conducted (see Table 2). These demonstrated a significant negative relationship between CRT score and disadvantageous card selections in all but the first block of trials.

A multiple regression (Enter method) tested the relative predictive strength of last anticipatory pupillary responses for disadvantageous (A + B) (mean, SD = 3.02, 0.36mm) and advantageous (C + D) (mean, SD =3.00, 0.38mm) deck picks and CRT scores (mean, SD = 2.13, 1.76) for performance on the IGT. Data indicated that the three predictors combined reliably accounted for 35% of the variability in IGT scores. The standardized beta for disadvantageous cards showed a negative correlation with pupil dilation while the advantageous cards showed a positive correlation. This indicated that increased pupil dilation on the last pick of a disadvantageous card predicted poorer overall performance in contrast with increased pupil dilation for advantageous cards which was associated with better overall performance. The CRT score was the strongest predictor with higher scores on the CRT predicting better card selections.

Table 3: Multiple Regression Analysis of CRT, Final Anticipatory Pupil Dilation for Disadvantageous (AB) Decks, Last Pupil Dilation for Advantageous (CD) decks as predictors (standardized betas) of IGT performance

Predictors	
Model ‘Enter.'	R^2=.38, R^2_{adj}=.35 F(3, 58)= 12.03, p=.001
CRT scores	β=.56, p<.001
Last aPD (A + B)	β= -.46, p=.05
Last aPD (C + D)	β= .52, p=.03

Durbin Watson= 1.93, VIF= 1.042; 4.965; 4.992

Discussion

Consistent with our predictions anticipatory pupillary responses and reflective thinking were reliable independent predictors of IGT performance. Importantly, pupillary responses differ according to the nature of the deck and incrementally predict performance in addition to cognitive reflection. Specifically, increased pupil dilation on the last pick of disadvantageous cards predicted poorer overall performance, whereas increased pupil dilation for the last pick of advantageous cards was associated with better overall performance. This is important because it indicates that differing somatic markers may develop for advantageous and disadvantageous decks and that these predict task performance alongside cognitive reflection.

Correlations between CRT scores and IGT broadly replicated the findings from the control group in Simonovic et al., (2016) but with stronger correlations and evidence that reflective processing is implicated even earlier in the task. Finally, block by performance analysis demonstrated that IGT performance did not reach ceiling at block 5 and significantly improved in block 7 after a (non-significant) dip in block 6, albeit it was not greater than block 5.

While our data indicate that participants' last aPD responses predict IGT performance, these somatic markers require some deciphering. Pupil dilation can be interpreted in various ways with anticipated threat, anticipated reward and general cognitive effort all potentially resulting in dilated pupils. Our data showing increased pupil dilation for advantageous deck is consistent with participants anticipating a positive outcome rather than a threat. However, it is possible that an increased level of cognitive effort may be in play (which would also be consistent with the correlations with cognitive reflection). Irrespective of the precise interpretation these data demonstrate a role for somatic markers in performance on the IGT, but allow for the possibility that these somatic markers are of cognitive effort as well as an indicator of emotional learning.

Pupillary responses data for the IGT contributes to the understanding of SMH and support a role for anticipatory physiological mechanisms in successful performance on risky decision-making tasks. These somatic markers inform explicit knowledge and facilitate learning of deck contingencies (e.g. Bechara & Damasio, 2005). However, our findings are incongruent with the proposition that IGT performance is primarily dependent on the development of somatic markers (Bechara et al., 1997; Wagar & Dixon, 2006) and are instead compatible with the dual-process model where 'cool' reflective processes inhibit impulses that interfere with long-term goals. This is consistent with the proposition that integrating reflective and emotional processes is necessary to explain IGT performance and suggests that the ability to reflect on gut feelings about decisions may improve performance (Schiebener et al., 2011; Simonovic et al., 2016).

The CRT was shown to be a stronger predictor of IGT performance than the pupil dilation measures, with higher scorers clearly outperforming lower scorers. This is clear evidence that Type 2 reflective processing plays a salient role in the task and supports the view of Brevers et el. (2013) that the IGT is best understood within a dual process framework. Toplak et al.'s (2014) extended seven item version of the CRT was used and the more comprehensive nature of this measure along with the greater variability may explain the stronger correlations and greater proportion of variance explained than in Simonovic et al. (2016). The evidence from the correlations between CRT and performance across the blocks replicated findings from Simonovic et al. (2016). These data indicate a consistent role for analytic ability in determining IGT performance from the second block onwards. This is inconsistent with the view that the learning on the task is implicit until the contingencies are well established and is instead indicative of a role for explicit monitoring of deck contingencies even in the early blocks.

These CRT data nonetheless need to be interpreted with caution. There is debate as to whether the CRT is a measure of cognitive miserliness or a more general measure of analytic thinking or numerical ability as it has been correlated with both working memory (e.g., Stupple et al., 2013) and risk neutrality (Oechssler, Roider, & Schmitz, 2009), which could impact on performance or task strategy.

Most of our participants began the task by exploring disadvantageous decks (A + B). Hence it could be argued that a reduced pupillary reaction for disadvantageous cards in relation to IGT performance occur because participants had 'unlearned' the initial preferences for big reward. This is consistent with a suggestion that during the IGT performance reversal learning, needs to be implemented to suppress learned preferences that are no longer beneficial (Dunn, Dalgleish, & Lawrence, 2006). Lavin et al. (2014) suggest that successful performance on IGT depends on positive feedback (based on the money gain) and highlighted pupillary responses to unexpected punishments on positive decks. This proposal is consistent with as both are indicative of anticipatory effects, as both are indicative of anticipatory effects, however, the differing methodologies of the current study and Lavin et al.'s make direct comparisons difficult.

Since the SCR has a relatively slow time course, it is possible that a distinct somatic marker cannot be distinguished by conventional SCR measurements (Newell & Shanks, 2014). The use of an eye-tracker allows a distinction between somatic reactions on different options before a decision has been made. This is particularly important because the anticipatory SCR captured during the IGT performance may represent part of a broader response such as attentional bias, implicit learning and a risk-taking.

Steingroever et al. (2013), called for greater scrutiny of IGT performance in healthy populations to bolster the ecological validity of IGT and demonstrate that IGT scores measure real-life decision making. The validation of IGT performance in healthy population is of great importance for such a widely used clinical tool; our analyses add to this literature on healthy populations. The prominent role of cognitive reflection in IGT performance leads us to urge caution in its application in diagnosing emotional deficits in populations who may lack the working memory capacity to perform well on the CRT and, by implication the IGT.

The measures used in the present study are relatively narrow and further applications of the pupil dilation methodologies are necessary to more fully explore the utility of this measure in investigating the IGT and the SMH more broadly; in particular, extending analysis across the task to examine how pupillary responses relate to IGT performance curves may be illuminating. Moreover, alternative eye-tracking measures such as fixations on particular decks of cards offer strong potential in investigating the locus of explicit attention as learning progresses on the task.

In conclusion, our data demonstrated that a combination of anticipatory pupil dilation and reflective thinking predicted IGT performance, such that both emotional and reflective processes are implicated in IGT performance. That is, anticipatory pupil dilation may serve as learning markers particularly for individuals with higher levels of cognitive reflection. Analytic cognition, moreover, plays a more salient role than traditionally acknowledged.

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