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Examining the Neural Correlates of Choice Behavior in a Gambling Task Using Steady State Topography

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The present study investigated the behavioral and neuropsychological characteristics of decision-making behavior during a gambling task as well as how these characteristics may relate to the Somatic Marker Hypothesis and the Frequency of Gain model. The applicability to intertemporal choice was also discussed. Patterns of card selection during a computerized interpretation of the Iowa Gambling Task were assessed for 10 men and 10 women. Steady State Topography was employed to assess cortical processing throughout this task. Results supported the hypothesis that patterns of card selection were in line with both theories. As hypothesized, these 2 patterns of card selection were also associated with distinct patterns of cortical activity, suggesting that intertemporal choice may involve the recruitment of right dorsolateral prefrontal cortex for somatic labeling, left fusiform gyrus for object representations, and the left dorsolateral prefrontal cortex for an analysis of the associated frequency of gain or loss. It is suggested that processes contributing to intertemporal choice may include inhibition of negatively valenced options, guiding decisions away from those options, as well as computations favoring frequently rewarded options.

Keywords: SSVEP, decision making, intertemporal choice, EEG

Intertemporal choice refers to a type of decision making that involves a trade-off between costs and benefits occurring over time (Kable & Glimcher, 2007). Understanding the neuropsychological mechanisms that influence such decision making may facilitate favorable business and economic choices as well as assist the prediction of consumer behavior. Several decision-making theories have now emerged that may provide insight into the neuropsychological mechanisms influencing intertemporal choice. This study focuses on two such theories that are referred to herein as the Somatic Marker Hypothesis (SMH) and Frequency-of-Gain (FOG) model. Both these theories may provide an avenue for the assessment of neural activity in regards to quantifiable decision-making efforts.

The SMH, proposed by Damasio and colleagues, suggests that decisions are dependant upon the influence of somatic markers, or representations of them, which flag potential options with an emotional valence. Negative somatic markers are thought to guide decisions away from the associated option and toward favorable outcomes (Bechara & Damasio, 2005; Damasio, 1994). Lesion studies have implicated the ventromedial prefrontal cortex as a crucial part of the neural circuitry that links stored somatic information with thoughts or memories internally generated in working memory (Bechara, Damasio, Damasio, & Anderson, 1994; Bechara, Damasio, Damasio, & Lee, 1999). Neuroimaging studies have also implicated the dorsolateral prefrontal cortex (DLPFC) in this decision-making process; however, its precise contribution is still the subject of some debate (Bechara & Damasio, 2005; Bechara, Damasio, Tranel, & Anderson, 1998; Knoch et al., 2006; Manes et al., 2002). The debate centers on whether results from neuroimaging studies involving the IGT have been adequately interpreted in light of the cognitive penetrability of the reward/punishment schedule inherent in the IGT and the relative lack of direct causal evi-

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dence linking peripheral feedback to Iowa Gambling Task (IGT) performance (Dunn, Dalgleish, & Lawrence, 2006). Nevertheless, many reciprocal interconnections have been found to exist between the ventromedial and dorsolateral prefrontal cortices, providing support for the notion that these two areas may function as a neural network (Fukui, Murai, Fukuyama, Hayashi, & Hanakana, 2005; Ongur & Price, 2000).

It has been suggested that activity in the right DLPFC may be associated with risk avoidance (Knoch et al., 2006). This may manifest through the inhibition of thoughts or memories preceding the activation of behavior (Bechara & Damasio, 2005). Furthermore, individuals with greater prefrontal neural activation prior to making disadvantageous decisions also tended to demonstrate better decision-making abilities during the gambling task (Fukui et al., 2005).

The IGT is a common measure used to assess decision-making abilities. An interpretation of the IGT, namely the Decision-Making Task (DMT), was selected for use in the current study to explore decision-making behavior. The IGT involves the selection of cards from either one of four decks (A, B, C, or D). Unbeknownst to the participants, each card is associated with a financial win and occasional loss. Some decks return higher immediate gains (A and B), but due to larger random losses they also result in a net deficit over time and are thus referred to as "risky" decks. The other decks (C and D) return lower immediate gains but due to smaller random losses they result in a net profit over time and are thus referred to as safe decks (Bechara et al., 1994). Individuals are instructed to attempt to win as much play money as possible. The IGT incorporates realistic decision-making factors, such as uncertainty, reward, punishment, and a trade-off between long-term costs and short-term benefits occurring over time; in this way, it may be seen as representative of aspects of intertemporal decision-making behaviors observable in the realms of business and economics. Strictly speaking, the IGT is not generally characterized as a measure of intertemporal choice as the literal payoffs do not have intertemporal implications. Nevertheless, performance on this task is likely to be mediated by similar neurocognitive mechanisms, since the participant is in an iterated choice situation whereby a temporal dynamic is implied through the small likelihood of immediate consequences in any single trial, balanced by the inevitability of negative consequences in the long term.

According to the SMH, individuals are guided away from risky decisions due to the negative valance associated with them, leading to more advantageous choices during the IGT (Bechara & Damasio, 2005; Bechara et al., 1994). An alternative explanatory framework, the FOG model suggests that computational cognitive processes rather than "gut feelings" may account for healthy individual's performance during the IGT (Chiu & Lin, 2007; Chiu et al., 2008; Lin, Chiu, Lee, & Hsieh, 2007).

Applied to the IGT, the FOG model refers to an analysis of the number of wins associated with each deck relative to the number of losses for that same deck. During the IGT, individuals choose more cards that frequently return gains despite their long-term outcome. For example, Deck B and D are considered high FOG decks as only one random loss is incurred every 10 card sections and, according to the FOG model, would thus be selected most often. Conversely, Decks A and C incur losses 50% of the time and are therefore considered low FOG decks. Numerous studies have observed the frequency effect under the gambling condition (Fernie & Tunney, 2006; Ritter, Meador-Woodruff, & Dalack, 2004; Wilder, Weinberger, & Goldberg, 1998); however, Chiu et al. (2008) and Ahn, Busemeyer, Wagenmakers, and Stout (2008) may be the first to empirically evaluate the SMH and FOG models directly in a gamble structure. Therefore, research has indicated that individuals pattern of card selection may be in line with both the SMH and the FOG model.

Brand, Labudda, and Markowitsch (2006) suggested that individuals pattern of card selection may reflect multiple decision-making theories, because in the early stages of the IGT when the rules are ambiguous and decisions are based largely on "hunches" the SMH may explain the process of decision making. However, as the task progresses and the participants start to learn the gist of the game, choices may resemble other decision-making theories. Computations regarding the frequency of gains and losses may influence decision making at this later stage of the IGT.

Although behavioral measures of decision making provide valuable information with regards to the predictability of an individual's actions, identifying related brain activity can offer additional insight into the cognitive mechanisms that facilitate that behavior. Steady State Topography (SST) is an electroencephalogram (EEG) technique that can record cortical processing over continuous periods of hundreds of milliseconds to hours. SST involves the presentation of an external probe stimulus, commonly a 13 Hz sinusoidal light flicker to the visual field (stimulation at this frequency has been most widely used in the literature since it robustly entrains oscillatory activity in most healthy adults; Silberstein & Cadusch, 1992). This elicits Steady State Visually Evoked Potentials (SSVEP) that are superimposed onto background ongoing EEG. The SSVEP can be extracted from the background EEG using Fourier techniques and assessed for changes in cortical processing in the amplitude and phase domain (Gray, Kemp, Silberstein, & Nathan, 2003; Silberstein, Ciorciari, & Pipingas, 1995; Silberstein et al., 1990). As SST is insensitive to artifact and sensitive to cognitive processes, SSVEP analysis is thus an ideal technique for investigating cortical processing occurring in the seconds preceding decision making (Gray et al., 2003; Silberstein et al., 1995). This study therefore utilized SST to examine brain activity associated with intertemporal choice thus providing a neural based measure of decision making on an idiosyncratic basis.

The current study aims to investigate the behavioral and cortical processes associated with decision making as well as their applicability to the SMH and the FOG model. It was hypothesized that participants will demonstrate a pattern of card selection favoring both the “safe” decks as well as the “high FOG” decks during the DMT. Based on Knoch and colleagues (2006), it was hypothesized that differences in activity in the right DLPFC would be observed prior to making risky decisions. Furthermore, in line with Fukui and colleagues (2005), it was also expected that the magnitude of cortical processing would be associated with decision-making abilities. It was also hypothesized that differences in cortical processing would be evident prior to making decisions associated with high relative to low FOG decks. In line with Brand and colleagues (2006) findings, it was also hypothesized that differences in cortical processes associated with safe and risky options would be most evident in the first rather than the second half of the DMT. Additionally, differences in cortical processing between high and low FOG options would be evident in the second, rather than the first half of the DMT.

Method

Participants

Twenty right-handed individuals with no known history of psychological illness or neurological disorders (e.g., epilepsy) participated in this study. This included 10 men (M = 26.20 years, SD = 4.16 years) and 10 women (M = 23.40 years, SD = 2.01 years), aged between 18 and 35. Informed consent was provided by all participants as approved by the Swinburne University Human Research Ethics Committee.

Measures

The decision-making task. The DMT is a shortened and computerized interpretation of the IGT originally developed by Bechara and colleagues (1994) and based on the E-prime script by Patterson (2008). The DMT requires individuals to try and win as much play money as they can by selecting 80 cards, one at a time from either four decks (A, B, C, or D). Eighty rather than the 100 trials administered during the IGT were presented as the pattern of card selection in healthy individuals tends to stabilize by this time (Manes et al., 2002; Suzuki, Hirota, Takasawa, & Shigemasu, 2003). Each deck has different predetermined financial gains and losses associated with it. Unbeknownst to the participants, Decks A and B yielded small financial rewards and incurred random smaller losses so that the end result would be an accumulated net profit. In contrast, Decks C and D yielded large financial rewards as well as random larger financial losses, resulting in an accumulated net deficit. Unlike the IGT, Decks A and B are therefore considered safe, and Decks C and D risky (See Table 1). Furthermore, Decks A and D are also considered high FOG decks as the ratio of wins to losses was 10:1. In contrast, Decks B and C are considered low FOG decks as the ratio of wins to losses was 2:1.

Prior to pressing spacebar and beginning the DMT, instructions were first presented on the

Table 1
Predetermined Matrix of Wins and Losses

	Deck A	Deck B	Deck C	Deck D
Win each card selection	$50	$50	$100	$100
Amount randomly lost/10 card selections	$250	$50	$150	$1,250
	$0	$50	$200	$0
	$0	$50	$250	$0
	$0	$25	$300	$0
	$0	$75	$350	$0
	$0	$0	$0	$0
	$0	$0	$0	$0
	$0	$0	$0	$0
	$0	$0	$0	$0
	$0	$0	$0	$0

monitor. A 3-s countdown was then presented above the cards before participants made each card selection, allowing time to consider their next choice. Participants started with a $2,000 loan. A card was then selected from either four decks (A, B, C, or D) by pressing the corresponding spatially congruent button on the keyboard. All participants used their left hand to control for any confounding influences. The deck chosen turned red and a screen with the financial win and occasional random loss appeared along with the accumulated total (see Figure 1).

From a fixed distance of 1.3 m, the entire display of the DMT subtended a horizontal angle of 10.6° and a vertical angle of 6.8°. To allow participants a break from the simultaneously presented 13 Hz light flicker necessary to elicit SSVEP, the DMT was divided into two blocks of 40 trials. A total DMT score is obtained by subtracting the number of risky choices from the number of safe choices. Scores can thus range from −80 to +80. A higher value indicates that more cards have been selected from the safe decks (A and B) and participants' task performance is considered more advantageous. DMT results are also calculated for each of the four blocks of 20 trials to assess the progression of decision-making abilities. For each block of 20 trials (Block 1, Block 2, Block 3, and Block 4), scores could range from −20 to +20 with higher values indicating better performance during the DMT. The number of times each deck was selected was also calculated for each participant. Therefore, each deck could be chosen from zero to 80 times. To get a total FOG score, the total number of low FOG decks selected was subtracted from the total number of high FOG decks selected.

Steady state topography and steady state visually evoked potentials. SST is a paradigm designed to assess changes in cortical processing (Nield, 2004; Silberstein et al., 1995; Silberstein et al., 1990). The current study involved the continuous presentation of an external probe stimulus in the form of a 13 Hz spatially uniform sinusoidal visual light flicker. The task-irrelevant 13 Hz stimulus was presented via a set of goggles comprising of two light emitting diode (LED) arrays viewed through half-silvered mirrors subtending horizontal and vertical angles of 160° and 90°, respectively. The modulation depth of the stimulus when viewed against the background was 45%. The diffuse 13 Hz stimulus was superimposed onto the visual field using in-house proprietary hardware, providing an external reference signal necessary to elicit and analyze SSVEP. The average potential between linked earlobes was used to reference electrodes and the nose served as ground. Cortical activity was recorded at a sampling frequency of 500 Hz using a 64-channel amplifier (in-house hardware developed to typical EEG recording standards). EEG data was collected from 64 scalp locations based on the International 10/20 system, with additional electrodes located midway between.

Procedures

The methodology used to extract the SSVEP is detailed elsewhere (see Silberstein et al., 1995; Silberstein et al., 1990) and thus only the major steps are described here (see Figure 1). Brain activity was amplified and band pass filtered (0.1 to 70 Hz) prior to digitization to 16-bit accuracy at a sampling rate of 500 Hz. SSVEP data was analyzed using the propriety software BrainSci. SSVEP were determined from 13 Hz Fourier Coefficients (FC) over 10 stimulus cycles. FC were then shifted one stimulus cycle and recalculated. Overlapping blocks of 10 FC were averaged to smooth the time series, yielding a temporal resolution of 0.77 s. This process was continued for each 300-s period (approximate) of recording across all card selections. This process was repeated for all 64 electrode sites. All data from each electrode

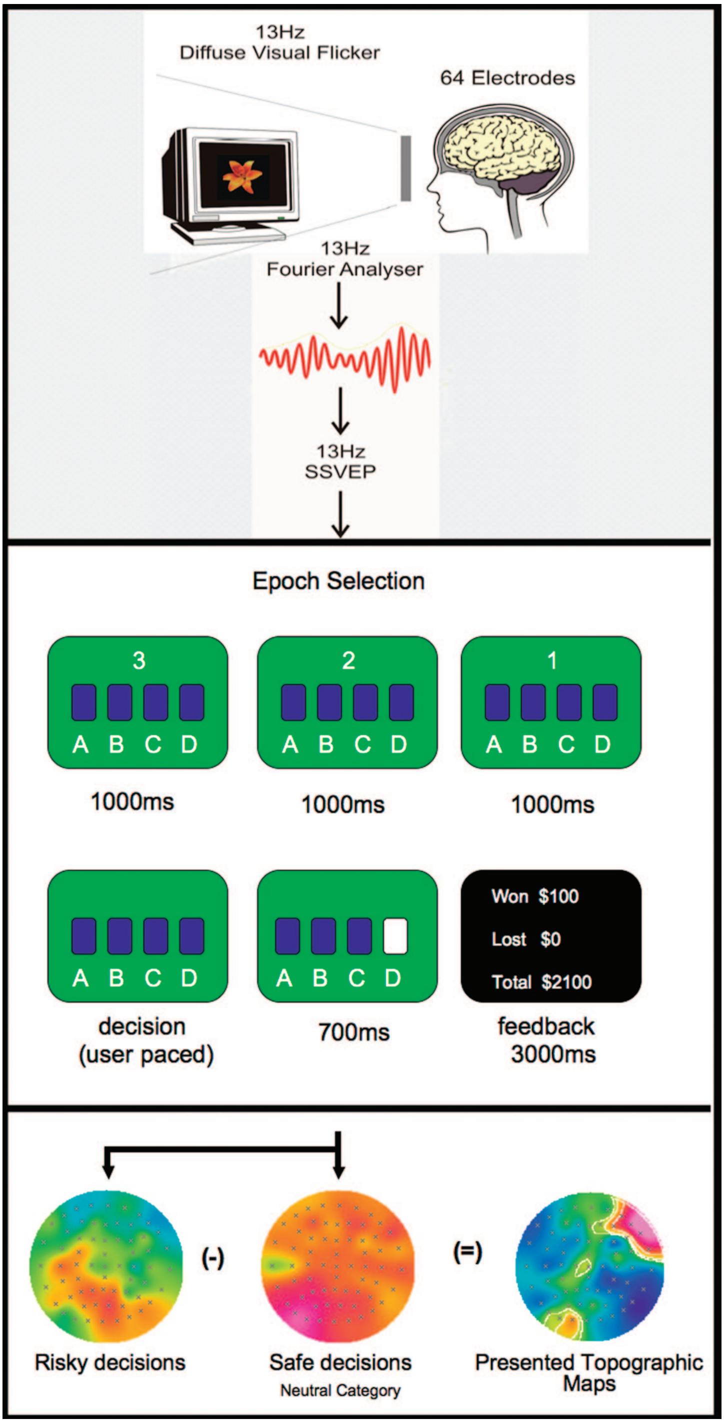

Figure 1. Example of stimuli presentation during the decision-making task, delivery design of SSVEP, and SSVEP analysis.

were checked for artifact as described by Silberstein and colleagues (1995). Decisions were marked by a button press at the time of each card selection, and data selection was achieved with the following procedure. For each card selected, a 4-s epoch of SSVEP data was analyzed. This started 3 s prior to each card selection and ended 1 s after. Epochs for safe decks (A and B) and for risky decks (C and D) were averaged together to yield a total of two separate averages (safe and risky). Another two separate averages were similarly attained by averaging together epochs for high frequency of gain decks (A and D) and low frequency of gain decks (B and C). Prior to cross-subject averaging, weighted averages were obtained for each participant to account for intersubject variation in SSVEP amplitude that exists between subjects (Silberstein et al., 1995; Silberstein et al., 1990). A control task similar to the DMT was used to obtain normalization factors for each participant. Normalization factors were then obtained for each Participants SSVEP amplitude time series. A normalization factor is equal to the mean SSVEP amplitude across all electrode sites (Silberstein et al., 1995). The amplitude normalization factor is obtained by calculating the mean amplitude for each electrode site then averaging them to get a single value. All participants' SSVEP amplitude time series were divided by the amplitude normalization factor prior to cross-subject averaging. This provides intersubject comparable data while preserving the proportionality of results (Silberstein et al., 1995).

Steady state visually evoked potential cross-subject averaging. The SSVEP epochs for safe decisions were averaged across all participants. This was repeated for SSVEP epochs corresponding to risky, high FOG, and low FOG decisions. Cortical processing associated with safe or risky decisions was obtained by subtracting the average SSVEP epochs corresponding to safe decks from the average SSVEP epochs corresponding to risky decks. Cortical processing associated with high or low FOG decisions was obtained by subtracting the average SSVEP epochs for low FOG decks from the average SSVEP epochs corresponding to high FOG decks. The resultant differences in cortical processing between risky and safe decisions and high and low FOG decisions are presented as difference maps in amplitude and phase using a spherical spline interpolation procedure. Reductions in SSVEP amplitude have been described as being akin to reductions in alpha activity (Silberstein et al., 1995; Silberstein et al., 1990). Reduction in alpha activity are interpreted as an increase in regional cortical processing (Silberstein et al., 1995). A positive phase difference between risky and safe decks represents a phase advance or speeding up of activity for risky relative to safe decks. A positive phase difference is similarly interpreted between high and low FOG decks. In this way, a phase advance can be expressed as a latency decrease indicating faster conduction through the cortex. Conversely, a phase lag can be expresses as a latency increase or slowing of conduction through the cortex (Gray et al., 2003).

The statistical strength of differences in amplitude and phase for cortical activity associated with both the risky versus safe and high versus low contrasts was displayed in Hotellings T (two-tailed) topographical maps. In considering the appropriate threshold for statistical significance, Silberstein and Cadusch (1992) suggest that five factors are necessary to represent the spatial dimensions of the data. Therefore, rather than correcting for multiple comparison across 64 electrodes which can increase the chance of a Type I error, the p value was divided by five (0.05/5). For a single comparison, a significance threshold of $p < .01$ was therefore used to determine the consistency of differences in phase and amplitude across participants.

Results

Behavioral Analysis of Safe Versus Risky Decks

The mean DMT scores for each of the four blocks of 20 trials are displayed in Table 2 below, along with the respective FOG scores.

A repeated measures analysis of variance (ANOVA) was conducted to assess whether a pattern of card selection that increasingly favored safe decks was evident as participants progressed from Block 1, Block 2, Block 3, and Block 4 of the DMT. A significant within-subjects main effect was found for decision-making scores across the blocks of 20 trials, $F(3, 57) = 7.10$, $p < .001$. Simple contrast of

Table 2
Means and Standard Deviations for Measures of Decision Making

Measure and condition	*M*	*SD*
Decision-making scores (risky vs safe)/20 trials		
Block 1	−3.30	6.81
Block 2	−1.0	11.51
Block 3	3.65	8.36
Block 4	6.20	8.43
Total DMT score	5.50	25.42
Number of cards selected from each deck		
High FOG deck A	27.05	11.70
Low FOG deck B	17.45	8.91
Low FOG deck C	14.80	8.53
High FOG deck D	20.35	8.89
Total FOG score	18.80	25.02

Note. $N = 20$. DMT = decision-making task; FOG = frequency of gain.

within-subjects effects indicated a significant difference between average DMT scores at Block 1 and Block 3, $F(1, 19) = 7.85, p < .05$, as well as between Block 1 and Block 4, $F(1, 19) = 13.16, p < .01$. More safe and fewer risky cards were selected in the last two blocks of 20 trials than were selected in the first block of 20 trials. Therefore, participants' performance during the DMT significantly improved in the second half of the task.

Behavioral Analysis of High Versus Low FOG Decks

To assess whether individuals would also demonstrate a pattern of card selection favoring high FOG decks, the mean number of cards selected from each deck (A, B, C, and D) as displayed in Table 2 were analyzed. A repeated measures ANOVA revealed a significant within-subjects effect between the number of cards selected from each deck type, $F(3, 57) = 3.89$, $p < .05$. Polynomial within-subjects contrast revealed a significant difference between the average number of cards selected from high FOG decks (A and D) and low FOG decks (B and C), $F(1, 19) = 11.30, p < .01$. Participants therefore showed a pattern of card selection that favored high FOG decks.

SSVEP Topographic Changes

The relationship between cortical processing and patterns of card selection was then examined. SSVEP processing associated with safe and risky decisions were first analyzed approximately 1,000 ms preceding a card selection. The resulting amplitude and phase difference maps as well as the Hotellings *T* topographical map are displayed in Figure 2. Cooler colors reflect increased amplitude and phase lag (increased latency/slower conduction through the cortex) during risky decision making relative to safe decision making. Conversely, warmer colors reflect amplitude decreases and phase advance (reduced latency/faster conduction through the cortex). In the Hotellings *T* topographical map, warmer colors illustrate areas of increased statistical significance of within-subjects effects with Hotellings *T* corresponding to *p* values of 0.01, 0.005, and 0.001 (corrected for multiple comparisons). These levels of significance correspond to Hotellings *T* values of 2.86, 3.17, and 3.88, respectively, with 19 degrees of freedom. Significant difference values in SSVEP amplitude and latency for risky versus safe contrasts reaching $p < 0.001$ were then correlated with total DMT scores to assess the relationship between cortical activity and behavioral measures of decision making during the DMT. Analysis of the task was then broken into two halves of 40 trials, and the above procedure was repeated on the two corresponding sets of data and displayed in Figure 2. In total, six correlations were performed at this stage between total DMT scores and values of SSVEP amplitude and latency reaching $p < 0.001$. This included two during analysis of the total DMT (amplitude and latency in the right DLPFC) and four during Block 1 (amplitude and latency in the right DLPFC and left fusiform gyrus).

SSVEP processing associated with high and low FOG decks were then analyzed as per the safe versus risky analysis above. Significant difference values for SSVEP amplitude and latency were then correlated with total FOG scores to assess the relationship between cortical activity and patterns of card selection during the DMT. This involved two correlational analyses between total FOG scores and the SSVEP amplitude and latency in the left DLPFC during the entire DMT. Analysis of the task was again

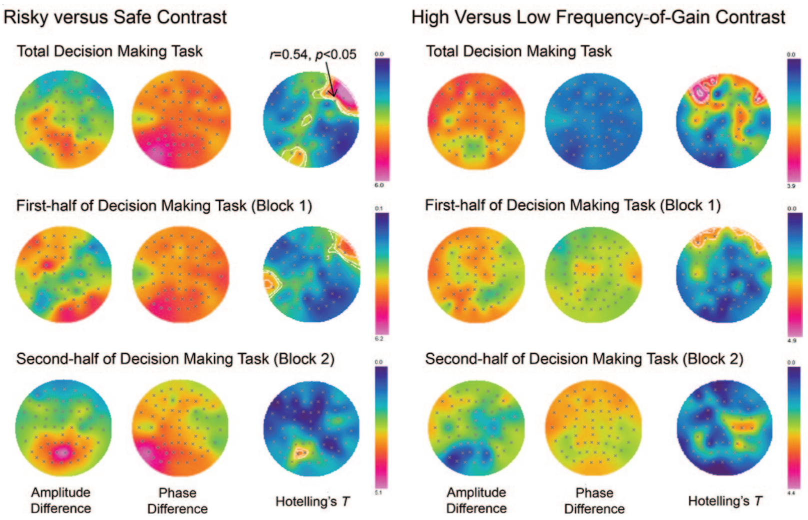

Figure 2. Amplitude and phase difference maps as well as the Hotellings T topographical map for analysis corresponding to the Somatic Marker Hypothesis and the Frequency of Gain model.

broken into two halves of 40 trials, and the above procedure was repeated on the data and displayed in Figure 2.

The difference maps in Figure 2 show an increase in SSVEP amplitude in the right DLPFC for risky relative to safe decks approximately 1,000 ms prior to card selections. At this time, there also appears to be advances in phase for risky relative to safe decks across most of the cortex. The corresponding Hotellings *T* map indicates that the increases in amplitude and phase advances over the right DLPFC are statistically significant ($p < .001$). Total DMT scores moderately correlated ($r = .54$, $p < .05$) with advances in phase for risky relative to safe decks in the right DLPFC; however, this relationship did not survive correction for multiple comparisons.

The difference maps in Figure 2 corresponding to the risky versus safe contrast show an increase in SSVEP amplitude in the right DLPFC and left middle temporal gyrus/fusiform gyrus for risky relative to safe decks approximately 1,000 ms prior to selecting cards during Block 1 of the DMT (Homan, Herman, & Purdy, 1987). Phase advances for risky relative to safe decks are also apparent across most of the cortex apart from the left fusiform gyrus.

The corresponding Hotellings *T* map for Block 1 indicates that the increase in amplitude and advance in phase in the right DLPFC as well as the increase in amplitude for risky relative to safe decks in the fusiform gyrus are statistically significant ($p < .001$). No statistically significant correlations were apparent between total DMT score and SSVEP amplitude or phase for risky relative to safe decisions during Block 1 or Block 2 of the IGT.

The difference maps in Figure 2 corresponding to the high versus low FOG contrasts show a decrease in SSVEP amplitude for high relative to low FOG decisions across the prefrontal cortex. Phase lags are also evident across the cortex for high relative to low FOG decisions. The corresponding Hotellings *T* map indicates that the decrease in amplitude and phase lag in the left DLPFC is statistically significant ($p < .001$). It also appears that the decreases in SSVEP amplitude and phase lag are statistically significant in a small area of the right DLPFC. Total FOG scores did not significantly correlate with differences between high and low FOG cortical processing in the right or left DLPFC approximately 1,000 ms prior to selecting cards.

Figure 2 does not show significant differences in amplitude or phase at $p < .001$ when the FOG contrasts were analyzed as two blocks of 40 trials. No significant correlations between total FOG scores and SSVEP amplitude or phase approximately 1,000 ms prior to card selections were apparent.

Discussion

Results of the present study supported the hypotheses that participants would demonstrate a pattern of card selection favoring both the “safe” decks as well as the “high FOG” decks during a computerized interpretation of the IGT.

These two patterns of card selection were also associated with distinct patterns of cortical activity. The hypothesis that differences in cortical activity in the right DLPFC would be observed prior to making risky (vs. safe) decisions was supported. The hypothesis that differences in cortical processing prior to making decisions associated with high relative to low FOG decks would be evident was also supported. Results supported the hypotheses based on Knoch and colleagues (2006) as well as Manes et al. (2002) that differences in cortical processing in the right DLPFC would be observed prior to making risky decisions. The hypotheses based on Fukui and colleagues (2005) that the magnitude of cortical activity would correlate with performance during the DMT was partially supported as a significant positive correlation occurred between total DMT score and phase advances for risky relative to safe decisions, but no other significant relationships of this sort emerged. The results of the current study corroborate the findings of previous FMRI studies (Fukui et al., 2005) using an imaging modality that reflects a more primary measure of neural activity than the hemodynamic response and which has a temporal resolution that may allow greater precision in delineating the time course of neural events.

Lastly, as expected, differences in cortical possessing between safe and risky options were evident in the first half, rather than the second half of the DMT, approximately 1,000 ms prior to card selections. Contrary to expectations, however, differences in cortical processing between high and low FOG options were not evident in the second rather than the first half of the DMT at this time.

Individuals demonstrated a pattern of decision making that, according to the SMH, could be attributed to the influence of somatic information guiding decisions away from risky options. Yet, participant’s pattern of card selection also showed a preference for high FOG decks indicating that a FOG analysis may also have contributed to decision-making behavior. For this reason, the SMH and the FOG model of decision-making may in fact be complementary.

The significant difference in cortical processing observed for risky relative to safe decisions in the right DLPFC during the DMT approximately 1,000 ms prior to card selection is congruent with the function associated with this area according to the SMH and Knoch and colleagues (2006). That is, the differences in cortical processing in the right DLPFC may be indicative of somatic markers inhibitory influence on internally generated prospective options, guiding attention away from undesirable outcomes. The role of the right DLPFC may possibly be secondary or at least complementary to the specific processes of emotional assimilation related to the decision making. The positive correlation between total DMT score and phase advancement for risky relative to safe decisions provides further support for this notion.

When cortical processing associated with risky versus safe decisions were analyzed for each half of the DMT separately, results suggested that the functions associated with the right DLPFC approximately 1,000 ms prior to card selection were most prominent during the first 40 trials of the task. This differentiation of cortical activity in the right DLPFC was coupled with significant variation in cortical processing in the left fusiform gyrus, whereby increases in amplitude for risky relative to safe decisions were observed.

Although the fusiform gyrus has been identified as responsive to language (Binder et al., 1997) and facial priming (Kanwisher, McDermott, & Chun, 1997), it may more generally be associated with the generation of mental images for object representation as well as the differentiation of relevant versus nonrelevant objects (Dehaene, Le Clec’H, Poline, Le Bihan, & Cohen, 2002; McCarthy & Puce, 1997). Druzgar and D’Esposito (2001) suggests that activity in the fusiform gyrus is sustained by attentional mechanisms of the prefrontal cortex in a manner that suppresses representations of nonrelevant stimuli and thus facilitates attention toward relevant stimuli. The cortical processing simultaneously observed in the current study may therefore be representative of an attempt of the right DLPFC to suppress representations of nonrelevant stimuli in the fusiform gyrus and thus facilitate attention toward representations of relevant stimuli. These distinct patterns of cortical processing occurring approximately 1,000 ms prior to card selections were not evident in the second half of the DMT. This explanation should be interpreted with some caution, as the results are based upon the selected epoch (1,000 ms prior to card selections) only.

Insufficient consensus has emerged on the role of left DLPFC in decision making (Bechara & Damasio, 2005), and even less can be said for the cortical processes associated with the FOG model. The current study identified decreases in amplitude and phase lag for high relative to low FOG decisions in the left DLPFC. Although significant differences in cortical processing were also observed in the right DLPFC, this was interpreted as residual evidence of the inhibitory influences of risky options resulting from a disproportionate number of risky versus high FOG cards selected as compared to low FOG card selections.

Houde and colleagues (2000) suggests that the left DLPFC may be involved in inhibiting previously active sort criteria, self-talk, object, and spatial working memory. More specifically, other research has suggested that activity in the left DLPFC may act as a general integration center where behaviorally relevant rewards are compared to information from other cortical areas for the formulation of a response (Heekeren, Marrett, Bandettini, & Ungerleider, 2004; Heekeren, Marrett, Ruff, Bandettini, & Ungerleider, 2006; Marschner et al., 2005). Although intuitively it would seem likely, the results of the current study do not suffice a stipulation regarding whether these functions were recruited for a frequency analysis during the DMT. Based on behavioral results, it is tentatively proposed that the decrease in amplitude and phase lag for the high relative to low FOG contrast in the left DLPFC may represent a reduction in inhibition of high FOG decks and perhaps an increase in inhibition for low FOG decks. Nevertheless, the results of the current study suggest that cortical processing in the left DLPFC is specifically associated with an analysis of high versus low FOG decisions during the DMT. Further research is necessary to elucidate precisely how this activity relates to decision making, as no significant differences in cortical processing were observed at the $p < 0.001$ level when the FOG contrast was performed on the two halves of the task separately. For reasons mentioned above, this should not necessarily be interpreted as a lack of FOG analysis during either half of the DMT.

Applying the results of the current study to intertemporal choice in the business and economic realms advocate the involvement of past experience, emotional labels, and analysis of the frequency of gains and losses in the decision-making process. Individuals are capable of learning what options are associated with favorable outcomes in their work—this information can be provided in terms of the emotion labels previously assigned to those outcomes. In this way, alternatives associated with a negative valence are inhibited, and thus decisions are guided away from those options. As such, individuals may simultaneously make choices based upon the frequency with which an option returns gains. Options that are most frequently rewarded and least frequently punished are favored.

This line of reasoning resembles an emerging theory in the field of business and economic decision-making named the Expected Utility (EU) model. The EU model proposes that such decisions are the product of the alternative with the highest “value” and “probability” of outcome (Sanfey, Loewenstein, McClure, & Cohen, 2006). According to this model, value relates to an options’ reward (or punishment) and the probability refers to the likelihood of that happening. An alternative interpretation of the EU model that may provide grounds for further research emerges from the results of the current study. That is, value is attained via the attribution of an emotional valence (via the right DLPFC) and probability is analogous to FOG computations (associated with cortical processing in the left DLPFC). This proposal is not incompatible with the results derived from the cognitive modeling studies of Busemeyer and Stout (2002) and Ahn et al. (2008).

Such a model could be applied to an infinite number of intertemporal choices involving a trade-off between alternating costs and benefits with differing outcomes over time. For example, when deciding whether to buy shares now or later, an individual’s past experience with such circumstances may influence the emotional valance attributed to each option. Simultaneously, an individual may compute the frequency with which buying particular shares will likely result in an immediate or future financial gain or loss.

Although an individual can never be 100% certain on how their shares (or other decision-making processes) are going to fare in the future, greater understanding of the processes involved in coming to "any" decision is beginning to unfold from a neuropsychological perspective. The current study suggests that such ambiguous decisions involving a trade off between immediate and long-term consequences may involve the recruitment of the right DLPFC for somatic labeling and inhibition options, left fusiform gyrus for object representations of options, and the left DLPFC for an analysis of the associated frequency of gain or loss. These findings suggest that somatic labeling may have important behavioral consequences in intertemporal choice situations. It will be important to verify these results in the context of a behavioral paradigm that more fully represents more ecologically plausible contexts involving payoff schedules where intertemporal dependencies exist.

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