A Neuroeconomic investigation into Anhedonia and Major Depression

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Abstract

Depression is a major public health issue, with an estimated lifetime prevalence of 11.6% in Australia (Australian Bureau of Statistics, 2008), and 14% in New Zealand (New Zealand Health Survey, 2012). Anhedonia is a key symptom associated with depression, and can be defined as a reduced hedonistic response to reward, or a reduced motivation to pursue them (Andrews & Thomson, 2009). The new field of neuroeconomics has generated increased interest in how decision-making is affected by mental illnesses such as depression (Hasler, 2011; Kishida, King-Casas, & Montague, 2010). The aim of my doctoral work is to examine how anhedonia and major depression affect economic decision-making. This paper will present the methodology of three studies currently in progress, and a fourth study in preparation.

Three groups of participants are being recruited: individuals with a diagnosis of Major Depression, healthy individuals with no history of mental illness, and healthy university students scoring high and low on a number of anhedonia measures. Participants complete two experimental tasks, while having their brain activity recorded via electroencephalography (EEG). The first task is a simple gambling task, in which participants choose between making a small or large bet to win varying amounts of money. In the second task, participants have to decide whether a cartoon face briefly flashed on-screen has a "long" or "short" mouth. This task has been previously shown to elicit differences between depressed and non-depressed individuals; with healthy individuals developing a bias towards the more frequently rewarded response, while individuals with depression do not. I will also outline a final study, which will use tDCS (transcranical Direct Current Stimulation) to modulate decision-making behaviour.

A Neuroeconomic investigation into Anhedonia and Major Depression

Depression is a major public health issue, with an Australian Government report identifying the 12-month prevalence for a Depressive Episode at 4.1%, and an estimated lifetime prevalence of 11.6% (Australian Bureau of Statistics, 2008); while recent statistics for New Zealand indicate a higher life-time prevalence rate of 14% (New Zealand Health Survey, 2012). World-wide, it is estimated around 151 million people world-wide suffer from major depression (WHO, 2008). Major depression is the leading cause of disability, in terms of "Years Lost to Disability" (YLD; "measure the equivalent years of healthy life lost through time spent in states of less than full health" (WHO, 2008; p36)) measures, for both men and women, although the burden of depression is around 50% higher for women.

Anhedonia is one of the key symptoms associated with depression, and can be defined as a reduced hedonistic response to reward, or a reduced motivation to pursue rewards (Andrews & Thomson, 2009). Anhedonia appears to represent a dysfunction in the brain's reward system, and while it appears to common to major depression, it can feature in non-clinical populations (Hasler, Drevets, Manji, & Charney, 2004). It has been suggested that the anhedonic symptoms associated with clinical depression have an evolutionary basis (Andrews & Thomson Jr, 2009).

While both economics and psychology concern themselves with understanding human behaviour, the advent of neuroeconomics has allowed for a synthesis of these two approaches (Loewenstein, Rick, & Cohen, 2008). Neuroeconomics represents a multidisciplinary approach to understanding human behaviour, combining theories and insights from economics, psychology and neuroscience to develop quantitative models of behaviour and the neural processes behind them (Glimcher, 2009).

EEG correlates of economic and social decision-making

Neuroimaging techniques such as electroencephalography (EEG) have been used in conjunction with economic games to examine the neural underpinnings of decision-making. EEG research into event-related brain potentials (ERPs), which are measured brain responses to stimuli, have identified a neural dissociation in the coding of reward magnitude and valence. In the case of the Ultimatum Game, Polezzi et al., (2008) found that feedback-related negativity amplitude reflected the distinction between fair and unfair offers, while a study by Boksem and De Cremer (2010) found that medial

frontal negativity amplitude (which is believed to have its source in the Anterior Cingulate Cortex, ACC, an important brain region for social decision-making) was larger for unfair compared to fair offers. Utilising a simple gambling task, researchers have found that the amplitude of one particular brain response (P300) varies in response to reward magnitude but not to reward variance, while the amplitude of the second brain response (FN) showed the opposite pattern (Sato et al., 2005; Yeung & Sanfey, 2004). Foti and Hajcak (2009) found in a simple monetary gambling task that FN amplitude, while larger for negative outcomes, was also inversely related to depression level in non-clinically depressed participants. They also found that P300 amplitude was inversely related to depression level in their sample. Thus it is possible that ERP differences could be a marker for altered decision-making processes in depression or anhedonia.

Modulating economic and social decision making via brain stimulation

These variations in brain activity provide a motivation for examining whether directly modulating brain activity at the scalp can affect decision-making. Transcranial direct current stimulation (tDCS) utilises a low-charge electrical field (typical studies in this area utilise a strength of 2 mA) to elicit changes in cortical excitability; anodal tDCS increases and cathodal tDCS decreases this excitability (Nitsche & Paulus, 2001).

Prior research using tDCS has highlighted the role it can play in improving our understanding of economic decision-making. A key study in this area has highlighted the role of the DLPFC on modulating decision-making behaviour under ambiguity (Fecteau, Pascual-Leone, et al., 2007). Specifically, bilateral tDCS (anodal left DLPFC/cathodal right DLPFC or anodal right DLPFC/cathodal left DLPFC) reduced risk-taking behaviour, compared to sham. In a task in which participants had to "pump" a computerised balloon, with each pump increasing both the amount of money gained, and the risk of the balloon "bursting" (and losing all the money earned on that trial), participants receiving the bilateral active tDCS treatment elected to pump fewer times. By contrast, unilateral tDCS (anodal left DLPFC/cathodal left supraorbital area or anodal right DLPFC/cathodal right supraorbital area) over the left or right DLPFC had no effect on risk-taking behaviour compared to the sham condition. Direct current stimulation of 2mA was applied in all active treatment conditions, with active stimulation beginning 5 minutes prior to task commencement and then continuing for the duration of the BART (Fecteau, Pascual-Leone, et al., 2007). A follow-up study examined the impact of tDCS on decision-making under conditions of risk, utilising the bilateral (i.e. stimulation to both the left and right DLPFC simultaneously) tDCS protocol outline above, was carried out (Fecteau, Knoch, et al., 2007). In this case, right anodal/left cathodal stimulation

resulted in decreased risk taking behaviour compared to left anodal/right cathodal (which had no effect compared to sham in this case) and sham treatments. Furthermore, right anodal/left cathodal stimulation resulted in faster decision RTs, and this suppression of risk-taking behaviour was not affected by variations in the amount of money participants could win from this task (Fecteau, Knoch, et al., 2007).

Another form of brain stimulation, rTMS (repetitive transcranial magnetic stimulation) has also been successfully utilised in studies of economic and social decision-making. For instance, low frequency (1 Hz) stimulation of the right DLPFC has been shown to affect economic decision-making, through increasing acceptance of unfair offers in a simple allocation game (Knoch, Pascual-Leone, Meyer, Treyer, & Fehr, 2006; van't Wout, Kahn, Sanfey, & Aleman, 2005), as well as altering risk preferences in a simple gambling task (Knoch et al., 2006).

A Neuroeconomic perspective on Major Depression and Anhedonia.

In recent years, increased attention has been paid to how mental illnesses, such as major depression, affect economic and social decision-making (Hasler, 2011; Kishida, King-Casas, & Montague, 2010). While a neuroeconomic approach to psychiatry is still in its infancy, early results are promising. Many neuroeconomic paradigms have their roots in game theory, which allows for hard, quantitative and testable models of how a particular disorder can affect valuations and preferences. Furthermore, economic rationality provides a "gold standard" to which the behaviour of individuals with and without mental illnesses can be compared to.

As depression and anhedonia influence how individuals respond to both pleasant and unpleasant stimuli (Kaviani et al., 2004), it is plausible that this disorder would alter their economic preferences and their decisions in more everyday situations. With respect to major depression, Harle, Allen and Sanfey (2010) reported that individuals with major depression were more likely to accept unfair offers in the Ultimatum Game, despite stating they experienced a stronger negative emotional response (e.g. disgust) to the unfair offers. As a result, the depressed group actually earned significantly more money overall than the control group (around $50 versus $43). The emotional reactions reported were similar to those find in a prior study (Harlé & Sanfey, 2007).

Prior research using tasks with differential rewards have been used to investigate individual differences in motivation or preference towards rewarding stimuli. These tasks have indicated that individuals experiencing depressive symptoms do not show the same motivation or preference towards rewarding stimuli, compared to non-depressed

individuals. While healthy, non-depressed participants typically develop a bias towards the more highly rewarded response (or a greater willingness to classify ambiguous stimuli as target), individuals with depressive symptoms do not (Henriques & Davidson, 2000; Henriques, Glowacki, & Davidson, 1994; Pizzagalli, Jahn, & O'Shea, 2005).

Study Aims and Rationale

The overall aim of the present set of studies is to examine how simple economic decision-making is affected by major depression and anhedonia. The present paper will discuss the methodology of three studies in progression, as well as a final study in preparation. Some initial results will be highlighted. Study One is a questionnaire study, which aimed to create a pool of high and low scoring anhedonia participants who could be recruited for the follow-up study (Study Two). The aim of studies two and three are to examine how anhedonia (study two) and major depression (study three) affect simple economic decision-making, both at the behavioural and neurophysiological levels. The aim of study four is to extend previous findings which show that tDCS can alter risky decision-making, by using a tDCS-EEG protocol to examine the neural correlates of behavioural change elicited by bilateral stimulation of the DLPFC.

Method

Study One

Overview

A total of 500 participants will be recruited from the first year psychology pool at Melbourne and Monash Universities. Participants receive course credit as part of their participation. As part of the consenting process, participants were asked if they wanted to participate in a follow-up study (i.e. Study Two) and those who agreed had their names added to a participant database. A range of personality questionnaire will be used, but with respect to calculating anhedonia scores, only the following scales are of interest: the Chapman Physical Anhedonia scale (Chapman, Chapman, & Raulin, 1976); the Chapman Social Anhedonia scale (Chapman et al., 1976); the Snaith-Hamilton Pleasure Scale (Snaith et al., 1995); the Temporal Experience of Pleasure Scale (Gard, Gard, Kring, & John, 2006). In addition, the Beck Depression Inventory (Beck, Steer, Ball, & Ranieri, 1996) was also administrated as a screening tool, to exclude potential participants who may be experiencing depressive symptoms (specifically, participants who scored over 13 on this measure were excluded from being in the high or low

anhedonia groups for the follow-up study, Study Two). Participants arrived at a computer lab in their respective universities, and after being consented, they completed computerised versions of the five questionnaires noted above, along with eleven other questionnaires and completed a brief demographic profile. Participants were instructed to answer each question as quickly and as accurately as they could, but not to think too hard about any one response, but instead just respond based on their initial "gut" feeling. Completion of the questionnaires typically took around 60 minutes and participants were debriefed at completion of the study.

Study Two

Participants

A total of 32 participants will be recruited, with 16 participants allocated to the high anhedonia group, and 16 participants to the low anhedonia group. Participants will be matched by age and gender. All participants are aged between 18-65 years old, right-handed and able to provide informed consent.

Five anhedonia scores were obtained across the four questionnaires for each participant. SAS 9.2 (SAS Institute, 2009) was used to run a principal components analysis (PROC FACTOR) was run on an initial sample of participants to calculate a single anhedonia factor score for each participant (with a mean of zero and a standard deviation of one), based on these five scores. Initially, participants with factor scores greater than +/-0.50 and who also had BDI scores of less than 13 were contacted to ask if they wanted to participate in the follow-up study; however due to the high correlation between anhedonia and BDI depression scores (which resulted in many high-scoring anhedonia participants being excluded), the threshold for selection into the high anhedonia group was lowered to scores of greater than +0.25 (the threshold for the low anhedonia group remained at -0.50).

Procedure

On arrival, participants were taken to the research laboratory and informed consent was obtained. Participants then underwent a clinical assessment to confirm that they were not suffering from any mental illnesses or conditions that might exclude them from the study, before having their depressive symptoms assessed by the Montgomery-Asberg Depression Rating Scale (MADRS) (Montgomery & Asberg, 1979). No participants met the criteria for Major Depression, and all participants scored below 6 on the MADRS.

Following the clinical assessment, participants were set-up for the EEG. EEG is measured using 64 Ag/Ag Cl electrodes embedded in a stretch lycra cap (Compumedics Quick-Cap), arranged according to the international 10-20 system. Additional electrodes were placed above and below the left eye and next to the outer canthus of each eye. EEG data was acquired using *NeuroScan* software and a *SynAmps 2* amplifier (Compumedics, Melbourne, Australia). Impedences were kept below 5 kΩ at the beginning of each recording and checked between the experimental tasks. Electrodes were referenced to a central in-cap reference (located between Cz and Cpz). The sampling rate was 500 Hz. At the time of writing, the EEG data is yet to be analysed.

Once the EEG cap was in place, participants completed two tasks (task order was counterbalanced across participants), a gambling task and a signal detection task. The gambling task was designed by the student researcher (Phillip Hall) using *E-Prime 2.0* (Psychology Software Tools, Pittsburgh PA). On each trial participants choose between a low risk gamble (with constant reward parameters, betting 2 cents to win 8 cents in all trials) and a high risk gamble (in which they bet 10c for a 50% chance to win either 0, 10, 20, 30 or 40 cents).

On each trial, participants were shown a screen displaying the two gamble choices, and outlining how much they could win or lose from each option, and given an unlimited time to respond. Following their response, they were informed as to the result of the trial: Participants were shown a yellow screen if they had won and a red screen if they lost, with details on how much they had won/lost on that trial as well as a running total of their earnings to date. This screen was displayed for 1500 ms, after which the next trial commenced. Participants completed four blocks of 80 trials, with the task taking around 25 minutes.

The second task was a signal detection task (SDT), designed by the student reseracher (Phillip Hall) using *E-Prime 2.0* (Psychology Software Tools, Pittsburgh PA). It used a similar procedure as that employed by Tripp and Alsop (1999) and Pizzagalli et al., (2005). At the start of each trial participants are shown a fixation point for 500 ms, before mouth-less cartoon face is presented in the middle of the screen. After a delay of 500 ms, participants are briefly shown a face for 100 ms, with either a short or long mouth, which is then immediately replaced by the previously shown mouth-less face. Participants are then tasked with deciding whether they saw a short or long mouth. This screen with the mouth-less face is displayed until participants make their response. Following their response, participants are shown either a correct feedback screen or a fixation point for 1750 ms, after which the next trial commenced.

The key feature of this task is that while short and long faces will occur equally often within each trial block, one face is reinforced (or rewarded) three times more than the other face (resulting in an asymmetrical reinforcer ratio). The aim here is to generate a response bias, or a preference for one response over another. Furthermore, a controlled reinforcer procedure (Johnstone & Alsop, 2000) was used: reward feedback was only provided for certain correct responses, based on a pseudorandom schedule: if a participant failed to make a correct response on a trial for which reward feedback was to be given based on this schedule, reward feedback will be delayed until the next correct identification of the same stimulus. Thus a failure to correctly identify a short face will result in the cessation of further reward feedback until a short face is correctly identified in a subsequent trial. This was to ensure that participants did in fact receive the reward feedback at the 3:1 ratio specified. For all other trials, participants were shown a grey screen instructing them to wait for the next trial. For half of the participants, correct identification of the short mouth resulted in three times more reward feedback than the long mouth, while this contingency was reversed for the other half of participants. Participants completed three blocks of 100 trials, and the task took approximately 20 minutes. At the completion of the two tasks, participants were debriefed, thanked for their participation and paid their earnings (AUS$30).

Study Three

Participants

A total of 32 participants will be recruited, with 16 participants in the depression group and 16 participants in the control group. Participants in the depression group will have been previously diagnosed with Major Depression and at the time of the experimental session, experiencing at least mild-levels of depressive symptoms (i.e. a MADRS score greater than 12). Where possible, we tried to recruit participants not currently taking any psychoactive medication. Participants in the control group will be healthy controls with no prior history of mental or psychiatric illness. Participants will be matched by age and gender. Participants will be aged between 18-65 years old, right-handed and able to provide informed consent.

Procedure

As per Study Two.

Study Four

Participants

We will recruit a total of 24 healthy participants for this study. Participants will be allocated to either a high anhedonia group, or a low anhedonia group, based on their responses to a number of anhedonia measures (as per Study Two). Inclusion criteria for the study are being aged between 18 – 65 years old; right-handed; no history of neurological or psychiatric illness and not taking any psychoactive medications; and able to provide informed consent. Participants will be excluded from the study if they have the presence of metal anywhere in the head (except the mouth), have had a prior serious head injury, neurological condition or other serious medical condition, or are currently pregnant.

tDCS Application

Direct current will be administered via a purpose-built, battery driven, Eldith DC-stimulator (NeruoConn GmbH, Germany). 20 minutes (30 seconds fade-in and 30 seconds fade-out) of 2mA anodal and cathodal tDCS will be delivered via two ductive rubber electrodes encased in saline soaked sponges (surface area = 5cm x 7cm) which will be held in place with a broad flexible band.

Participants will receive one session of active tDCS and one session of sham tDCS. Session order will be counterbalanced, with half the participants receiving active tDCS in the first session and sham tDCS in the second session, and the other half receiving sham tDCS in the first session and active tDCS in the second session.

Active tDCS: Participants will be allocated to one of two active tDCS groups. Participants in the anodal right DLPFC/cathodal left DLPFC group will have the anodal electrode placed at F4 (according to the international 10-20 system), and the cathodal electrode placed at F3 (international 10-20 system). Participants in the anodal left DLPFC/cathodal right DLPFC will have the anodal electrode placed at F3 (according to the international 10-20 system), and the cathodal electrode placed at F4 (international 10-20 system). These scalp sites has previously been validated by our group as an accurate estimate of individualized DLPFC anatomical topography (Fitzgerald, Maller, Hoy, Thomson, & Daskalakis, 2009). This tDCS application is consistent with prior tDCS research protocols in this area (Fecteau, Knoch, et al., 2007; Fecteau, Pascual-Leone, et al., 2007; Hecht, Walsh, & Lavidor, 2011; Minati, Campanhã, Critchley, & Boggio, 2012).

Sham tDCS: Sham (i.e. placebo) tDCS will be achieved by delivering 2mA tDCS for 30 seconds before turning off the current. Electrode placement will be identical to the active tDCS condition. This is a widely utilised form of sham tDCS designed to mimic the sensation associated with active tDCS, as this typically involves a period of localized scalp tingling or itching which fades after approximately 30 seconds. There is no evidence that this form of sham stimulation has a lasting biological impact.

The tDCS stimulator device to be used in this study allows for blinding of both the participant and the tDCS administrator to treatment condition, via a unique code (pre-programmed to deliver an "active" or "sham" tDCS session) assigned to each participant. Code designation will be done by an independent researcher prior to randomization of the first participant.

EEG Recording

Following the end of the tDCS stimulation, the tDCS stimulation pads will be replaced by EEG electrodes. Electroencephalography (EEG) will be acquired using 16 individually placed EEG electrodes and a *Synamps 2* EEG system. Electrodes will be placed on the scalp according to the international 10-20 system. EEG will be digitized at 10 kHz and online filtered (DC-3500 Hz).

Experimental Tasks

The experimental tasks have been developed by the student researcher using *E-prime 2.0* (Psychology Software Tools, Pittsburgh PA). Participants will be informed that they will be paid actual money based on their performance in these tasks. Participants will receive up to $25 in the first session and up to $35 in the second session, for $60 total. Participants will be informed that the payment amount depends on their performance in the two tasks. However the parameters will be set so that participants will make a minimum of $23 in the first session and $32 in the second session, and we expect the vast majority (if not all) participants to earn the full $60. It is expected that these tasks will take around 60 minutes to complete.

Ultimatum Game

The Ultimatum Game (Güth, Schmittberger, & Schwarze, 1982) is a popular economic game used to examine social decision-making. A typical trial involves the first player making an offer on how to split a sum of money (say $10) between player two and

themselves. Once the offer is made, player two can choice to accept this offer (in which case the proposed split goes ahead), or reject this offer (in which case both players get nothing).

In this study, all participants will take the role of player one in the first session, and player two in the second session. In the first session they will be asked to make a series of offers to their player two partners, on how to split $10. At the start of each trial, participants will be told who their partner (a number code) is on that trial. In the second session, they will be asked to accept or reject a series of "fair" (50/50 and 60/40 splits between player one/player two) and increasingly "unfair" offers (70/30, 80/20 and 90/10 splits) on splitting $10. In reality, the "partners" and partner offers will be a set of pre-programmed responses in *E-prime*. The primary variable of interest is the extent to which participants are prepared to accept unfair offers following active tDCS.

Gambling Task

The Gambling Task used in this study has been designed by the student researcher using *E-prime 2.0* (Psychology Software Tools, Pittsburgh PA). Participants will be asked to choose between two or three gamble options on each trial, in increasing reward and risk. Essentially, participants will choose between a "low reward, low risk" gamble, a "moderate reward, moderate risk" gamble, and a "high reward, high risk" gamble. The amount that can be won or lost, and the probability of this will vary across the options. The dependent variable will be risky choice on each trial (e.g. high risk choice versus low risk choice) and reaction time.

Procedure

On arrival at the first session, participants will be taken to the research laboratory and informed consent will be obtained. Participants will undergo a clinical interview to screen for any mental illnesses (MINI) and to assess for depressive symptoms (MADRS). They will be set-up for the tDCS-EEG session, in which they will be fitted with the EEG and tDCS electrodes. They will then receive 20 minutes of tDCS to F3 and F4 electrode sites. During the stimulation period they will participate in the Ultimatum Game (in the player one role). Following the end of this stimulation the tDCS electrodes will be removed and the F3 and F4 EEG electrodes will be fitted and participants will complete the Gambling Task.

A second session will be scheduled at least three days after the first session. The procedure will be identical to the first session, except there will be no clinical interview

(instead, participants will complete the personality questionnaires noted in the materials section) and they will complete the Ultimatum Game in the player two role. Participants will be debriefed at the conclusion of the second session.

Preliminary Results

Gambling Task

SAS 9.2 (SAS Institute, 2009) was used to analyse the behavioural data for 25 participants (9 participants in the depression group) for the Gambling Task. As the dependent variable "bet choice", was dichotomous (taking the value "0" for the low-risk choice, and "1" for the high-risk choice), a GEE approach (PROC GENMOD) was used. The independent variables were reward level and depression status. A main-effects model indicated that both reward level (χ^2 (4, N=25) = 86.15, p <.001) and depression status (χ^2 (1, N=25) = 4.56, p =.033) affected participants' probability of making a risky bet, as indicated by the odds-ratio. Specifically, as the amount that could be won from the risky bet increase, the probability participants' would select the safe bet (2 cents) over the risky bet (10 cents) declined, with p<.001 for all reward levels (e.g. a comparison between the highest (40 cents) and second lowest (10 cents) reward levels produced an OR = 28.77 (95% CI: [17.56, 47.14]), which declined to OR=2.34 (95% CI: [1.76, 3.02]) when the two highest reward levels (40 cents versus 30 cents) were compared). This result suggests that overall, participants were generally risk averse (across all reward levels), however the extent of risk aversion declined as the amount that could be won from the risky gamble declined.

Depression status also affected the participant behaviour, with depressed participants showing a greater probability of selecting the low-risk choice (OR=0.58, 95% CI: [0.36, 0.94]) compared to non-depressed participants. There was no significant interaction between reward level and depression status. A second GEE model examining the effect of anhedonia status, indicated that healthy participants scoring high on anhedonia also showed a greater probability of selecting the low-risk choice (OR=0.76, 95% CI: [0.50, 1.13), however this result was non-significant (χ^2 (1, N=14) = 1.78, p =.182).

Signal Detection Task

The SDT data for 22 participants (9 participants in the depression group) was analysed using a repeated measures ANOVA. Discriminability and response bias were calculated as per Tripp and Alsop (1999) and Pizzagalli et al. (2005).

Discriminability provides information about the task difficulty. If depressed and non-depressed groups find the SDT task equally difficult, it would be shown by similar discriminability scores between the two groups. Discriminability was calculated as follows:

$$Log\ d = \frac{1}{2}\log\left(\frac{Long_{correct} * Short_{correct}}{Long_{incorrect} * Short_{incorrect}}\right)$$

Where $Long_{correct}$ is the number of correct responses after long mouth presentation, $Short_{correct}$ is the number of correct responses after short mouth presentation, $Long_{incorrect}$ is the number of incorrect responses following long mouth presentation and $Short_{incorrect}$ is the number of incorrect responses after presentation of the short mouth.

Across the three blocks, mean discriminability scores were higher in participants with depression (log d = 0.552, SE = 0.068), compared to non-depressed participants (log d = 0.369, SE=0.057). A two-way ANOVA with block and depression group as factors indicated that this difference in mean discriminability approached significance ($F(1,20) = 4.24$, $p = .053$). This suggests that participants with depression may have found the task easier (i.e. were better at distinguishing between the short and long mouths). There was no main effect of block, nor was there a block x group interaction (both Fs < 1), indicating that participants' ability to discriminate between the stimuli did not change over the three trial blocks.

Response Bias provides information about the tendency for participants to develop a preference for the more highly rewarded response; in the present study, response bias provides a measure of the tendency of participants to select the "long mouth" response over the "short mouth" response (when long mouths are more frequently rewarded than short mouths).

$$Log\ b = \frac{1}{2}\log\left(\frac{Long_{correct} * Short_{incorrect}}{Long_{incorrect} * Short_{incorrect}}\right)$$

A repeated measures ANOVA using response bias as the dependent variable and depression status as the independent variable was conducted. While participants with depression showed a smaller response bias than non-depressed participants, as expected, the sample size was too small to detect a significant difference $F(1, 20) = 2.16$, $p=.157$.

Discussion

While the sample sizes are currently too small to formulate any definitive results, the preliminary findings do support the view that neuroeconomic paradigms can make a valuable contribution towards increasing our understanding of mental illness. The current results suggest that depressive symptoms can result in a set of cognitive biases which make affected individuals more risk-averse, as shown by a reduced willingness to engage in risky gambles. However the effect is essentially a "level" effect – participants with depression are still more likely to place a risky bet as reward level increased, but they require a larger potential reward before they are willing to take a risk. Future work will incorporate the EEG data into the analysis, to examine if there is a neural correlate to this effect.

As mental illnesses are often associated with alterations in emotional processing (e.g. depression is associated with anhedonia), neuroeconomic research paradigms can further enhance our understanding of the role of emotions in strategic behaviour and how mental illnesses such as depression alter these decision-making processes. Neuroeconomic paradigms may also be possible candidates for more objective treatment response measures, to complement traditional clinical assessment measures (e.g. examining alterations in reward responsiveness following treatment using gambling games).

References

Andrews, P., & Thomson Jr, J. (2009). The bright side of being blue: Depression as an adaptation for analyzing complex problems. *Psychological review*, *116*(3), 620–654.

Australian Bureau of Statistics. (2008). *2007 National Survey of Mental Health and Wellbeing: Summary of Results (4326.0)*. Canberra: Australian Bureau of Statistics. Retrieved from http://www.abs.gov.au/AUSSTATS/abs@.nsf/Latestproducts/4326.0Main%20Features12007?opendocument&tabname=Summary&prodno=4326.0&issue=2007&num=&view=

Beck, A., Steer, R., Ball, R., & Ranieri, W. (1996). Comparison of Beck Depression Inventories-IA and-II in psychiatric outpatients. *Journal of personality assessment*, *67*(3), 588–597.

Boksem, M., & De Cremer, D. (2010). Fairness concerns predict medial frontal negativity amplitude in ultimatum bargaining. *Social neuroscience*, *5*(1), 118–128.

Chapman, L., Chapman, J., & Raulin, M. (1976). Scales for physical and social anhedonia. *Journal oj Abnormal Psychology*, *85*(4), 374–382.

Fecteau, S., Knoch, D., Fregni, F., Sultani, N., Boggio, P., & Pascual-Leone, A. (2007). Diminishing Risk-Taking Behavior by Modulating Activity in the Prefrontal Cortex: A Direct Current Stimulation Study. *The Journal of Neuroscience*, *27*(46), 12500–12505. doi:10.1523/JNEUROSCI.3283-07.2007

Fecteau, S., Pascual-Leone, A., Zald, D. H., Liguori, P., Théoret, H., Boggio, P. S., & Fregni, F. (2007). Activation of Prefrontal Cortex by Transcranial Direct Current Stimulation Reduces Appetite for Risk during Ambiguous Decision Making. *The Journal of Neuroscience*, *27*(23), 6212–6218.

Fitzgerald, P. B., Maller, J. J., Hoy, K. E., Thomson, R., & Daskalakis, Z. J. (2009). Exploring the optimal site for the localization of dorsolateral prefrontal cortex in brain stimulation experiments. *Brain Stimulation*, *2*(4), 234–237.

Foti, D., & Hajcak, G. (2009). Depression and reduced sensitivity to non-rewards versus rewards: Evidence from event-related potentials. *Biological Psychology*, *81*(1), 1–8.

Gard, D. E., Gard, M. G., Kring, A. M., & John, O. P. (2006). Anticipatory and consummatory components of the experience of pleasure: a scale development study. *Journal of Research in Personality*, *40*(6), 1086–1102.

Glimcher, P. W. (2009). *Neuroeconomics: Decision making and the brain*. Academic Press. Retrieved from http://books.google.com/books?hl=en&lr=&id=g0QPLzBXDEMC&oi=fnd&pg=PP2&dq=neuroeconomics+book&ots=i9c9oLME-m&sig=0-IcYXaSJLoZOFLFUyiYCj8m3CE

Güth, W., Schmittberger, R., & Schwarze, B. (1982). An experimental analysis of ultimatum bargaining. *Journal of Economic Behavior & Organization*, *3*(4), 367–388.

Harlé, K. M., Allen, J. J. B., & Sanfey, A. G. (2010). The Impact of Depression on Social Economic Decision Making. *Journal of Abnormal Psychology*, *119*(2), 440–446.

Harlé, K. M., & Sanfey, A. G. (2007). Incidental Sadness Biases Social Economic Decisions in the Ultimatum Game. *Emotion*, *7*(4), 876–881.

Hasler, G. (2011). Can the Neuroeconomics Revolution Revolutionize Psychiatry? *Neuroscience & Biobehavioral Reviews*.

Hasler, G., Drevets, W. C., Manji, H. K., & Charney, D. S. (2004). Discovering endophenotypes for major depression. *Neuropsychopharmacology*, *29*(10), 1765–1781.

Hecht, D., Walsh, V., & Lavidor, M. (2011). Bi-frontal direct current stimulation affects delay discounting choices. Retrieved from http://www.tandfonline.com/doi/abs/10.1080/17588928.2011.638139

Henriques, J. B., & Davidson, R. J. (2000). Decreased responsiveness to reward in depression. *Cognition & Emotion*, *14*(5), 711–724.

Henriques, J. B., Glowacki, J. M., & Davidson, R. J. (1994). Reward fails to alter response bias in depression. *Journal of Abnormal Psychology*, *103*, 460–460.

Johnstone, V., & Alsop, B. (2000). Reinforcer control and human signal-detection performance. *Journal of the experimental analysis of behavior*, *73*(3), 275–290. doi:10.1901/jeab.2000.73-275

Kaviani, H., Gray, J. A., Checkley, S. A., Raven, P. W., Wilson, G. D., & Kumari, V. (2004). Affective modulation of the startle response in depression: influence of the severity of depression, anhedonia, and anxiety. *Journal of Affective Disorders*, *83*(1), 21–31.

Kishida, K. T., King-Casas, B., & Montague, P. R. (2010). Neuroeconomic Approaches to Mental Disorders. *Neuron*, *67*(4), 543–554.

Knoch, D., Pascual-Leone, A., Meyer, K., Treyer, V., & Fehr, E. (2006). Diminishing reciprocal fairness by disrupting the right prefrontal cortex. *Science*, *314*(5800), 829.

Knoch, Daria, Gianotti, L. R. R., Pascual-Leone, A., Treyer, V., Regard, M., Hohmann, M., & Brugger, P. (2006). Disruption of Right Prefrontal Cortex by Low-Frequency Repetitive Transcranial Magnetic Stimulation Induces Risk-Taking Behavior. *The Journal of Neuroscience*, *26*(24), 6469–6472.

Loewenstein, G., Rick, S., & Cohen, J. D. (2008). Neuroeconomics. *Annual Review of Psychology*, *59*(1), 647–672.

Minati, L., Campanhã, C., Critchley, H. D., & Boggio, P. S. (2012). Effects of transcranial direct-current stimulation (tDCS) of the dorsolateral prefrontal cortex (DLPFC) during a mixed-gambling risky decision-making task. *Cognitive Neuroscience*, *3*(2), 80–88.

Montgomery, S. A., & Asberg, M. (1979). A new depression scale designed to be sensitive to change. *The British Journal of Psychiatry*, *134*(4), 382–389. doi:10.1192/bjp.134.4.382

Nitsche, M. A., & Paulus, W. (2001). Sustained excitability elevations induced by transcranial DC motor cortex stimulation in humans. *Neurology*, *57*(10), 1899–1901. doi:10.1212/WNL.57.10.1899

Pizzagalli, D. A., Jahn, A. L., & O'Shea, J. P. (2005). Toward an objective characterization of an anhedonic phenotype: A signal-detection approach. *Biological psychiatry*, *57*(4), 319–327.

Polezzi, D., Daum, I., Rubaltelli, E., Lotto, L., Civai, C., Sartori, G., & Rumiati, R. (2008). Mentalizing in economic decision-making. *Behavioural Brain Research*, *190*(2), 218–223.

SAS Institute. (2009). *SAS software, Version 9.2*. SAS Institute Inc Cary, NC.

Sato, A., Yasuda, A., Ohira, H., Miyawaki, K., Nishikawa, M., Kumano, H., & Kuboki, T. (2005). Effects of value and reward magnitude on feedback negativity and P300. *NeuroReport*, *16*(4), 407–411.

Snaith, R., Hamilton, M., Morley, S., Humayan, A., Hargreaves, D., & Trigwell, P. (1995). A scale for the assessment of hedonic tone the Snaith-Hamilton Pleasure Scale. *The British Journal of Psychiatry*, *167*(1), 99–103.

Tripp, G., & Alsop, B. (1999). Sensitivity to reward frequency in boys with attention deficit hyperactivity disorder. *Journal of Clinical Child Psychology*, *28*(3), 366.

Van't Wout, M., Kahn, R. S., Sanfey, A. G., & Aleman, A. (2005). Repetitive transcranial magnetic stimulation over the right dorsolateral prefrontal cortex affects strategic decision-making. *NeuroReport*, *16*(16), 1849–1852.

WHO. (2008). *The global burden of disease: 2004 update*. World Health Organization.

Yeung, N., & Sanfey, A. G. (2004). Independent Coding of Reward Magnitude and Valence in the Human Brain. *J. Neurosci.*, *24*(28), 6258–6264.