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Decision making in uncertain environments: a resting state EEG study

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Abstract

Prior studies have shown that punishment and reward sensitivity influences decision making in a gambling task with a stable and predictable environment. Some unpublished data suggest that this also holds true in unpredictable situations in which the application of reversal learning is needed to optimally perform in a gambling task. The behavioral inhibition system (BIS) regulates and processes punishment, while the behavioral activation system (BAS) does this for rewarding stimuli. It is claimed that the neurobiological substrates of the BIS and BAS can be found in the prefrontal cortex, more specifically in the alpha band of an EEG signal (8-12 Hz). A right-sided asymmetry in the PFC indicates a higher sensitivity to punishment, while left-sided asymmetry indicates a higher sensitivity to reward. This research will try to further investigate the effects on the BIS and BAS as determined by EEG recordings on decision making in a gambling task where reversal learning is needed. The main hypothesis of the present study is that the amount of reversal learning in an uncertain environment can be predicted by measurements of an asymmetry found in the alpha band (8-12 Hz) in baseline EEG. It was expected that a right-sided asymmetry would correlate positively with reversal learning while a left-sided asymmetry would correlate negatively with reversal learning. A novel task was used that consisted of changing reward-punishment contingencies to induce reversal learning. Reversal learning was measured by determining a behavioral adaptation index calculated from task performance. Self-reported BIS and BAS data was obtained through a questionnaire. Resting state EEG data was recorded and a frontal asymmetry index was subtracted from this data.

The main hypothesis was not supported by the present research; Results showed that EEG asymmetries calculated from the alpha band (8-12) from baseline EEG recordings did not predict reversal learning. Furthermore, self-reported BIS and BAS scores did not correlate with frontal asymmetry, failing to support the notion that such an asymmetry reflects differences in punishment sensitivity. Finally, self-reported BIS and BAS scores did not correlate significantly with reversal learning, indicating that under uncertain circumstances punishment sensitivity does not affect task performance.

Conclusively, none of the hypothesis were confirmed by this study. However, one effect was found that could indicate that reversal learning might be affected by situational factors. The self-reported BIS scores correlated negatively with reversal learning in a certain part of the task. This indicates that self-reported BIS scores can predict reversal learning, but only under certain circumstances such as previous and starting situation. Still, this finding was not sufficient to support the hypothesis in the present study. More research is advised to gain insight in the effect of situational factors on reversal learning as determined by either frontal asymmetry or self-reported BIS and BAS scores.

Keywords: EEG, BIS, BAS, punishment sensitivity, reversal learning, environmental change, decision making

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Introduction

The daily lives of humans consist of making decisions: from the moment one gets up (or doesn’t) and goes to sleep again, hours later. It would be wonderful if people always picked out the choice that resulted in the best possible outcome. According to expected utility theories the optimal choice can be determined by a simple calculation: pick the option that has the highest expected value. The highest expected value is the probability of that option resulting in the wanted outcome multiplied by the inherent value of that option in terms of how positive it can be considered (Laplace, 1812). Unfortunately, people do not seem able to make this simple calculation. Herbert A. Simon has coined this phenomenon *bounded rationality* (Simon, 1957). This states that the capacity of people to make rational decisions is restricted by their cognitive capacities, the information to which they have access and a finite amount of time in which the decision must be made. People cannot take into account every single detail at the same time and are often unaware or uninformed of additional information that might be of help in making a decision. They will notice the pressure of time and realize they will have to use the resources available to them at a given time, and are not able to explore alternatives. The stress that comes from the pressure of time may result in a more narrow attentional focus and thus a low attentional control, which limits the flexibility of people in where they direct their attention towards and how they divide it (Kahneman, 1973). This will further diminish the ability to consider multiple aspects of a problem. Therefore, people have to rely on other sources of information to decide what they deem to be the best decision to make and, so they rely on other methods, such as using heuristics. Heuristics are shortcuts to make quick decisions, they often result in good outcomes, but decision making may go wrong when heuristics are being used. One example of this is framing which describes the event in which people make different decisions depending on how the problem is presented (Tversky & Kahneman, 1981). A different one, which is of interest in the present study, is the affect heuristic or gut feeling. This states that people can base their behavior and decision-making on their current emotions. A way to manipulate emotions is by inducing negative and positive affect by means of punishing or rewarding someone. How someone reacts to punishment and reward differs individually and seems to be a large part of one’s personality. The theory that states that the sensitivity towards either reward or punishment influences decision-making has been called the Reinforcement Sensitivity Theory (RST) (Corr, 2008). One of the best known theories concerning sensitivity to reward and punishment and on which the RST was built is the theory about the behavioral inhibition system (BIS) and the behavioral activation system (BAS), concepts coined by the researcher Gray (1987). The BIS regulates behavior associated with active avoidance and processing of punishment cues. The BAS, on the other hand, is associated with approach related behavior and processing of reward; individuals with a more active BAS are more sensitive to reward. Research concerning the effect of punishment sensitivity on decision making in predictable situations has shown that people who are more sensitive to punishment, and thus have a more active BIS, will perform better on the Iowa Gambling Task (Bechara. Damasio, Damasio, & Anderson, 1994), where the key to good task performance is to avoid the punishment received by exhibiting risky behavior Previous research has indicated that differences between the concepts of BIS and BAS seem to arise too when looking at the effects on decision making in unpredictable situations (Schutter, Meuwese, & van Honk, unpublished data). In this research an uncertain task environment was created by using a gambling task with a fixed rule that changed without the participant being made aware of the change. This rule determined whether a more risky approach or a more conservative was preferred to lead to an optimal outcome, by either punishing or rewarding decisions. To perform the task optimally, participants had to notice and adjust their behavior to a change in rules adequately and as quickly as possible. This shifting of strategies is called *reversal learning*, a term coined by Bechara and colleagues (Bechara, Damasio, Tranel, & Damasio, 2005). Following the previously mentioned research (Schutter et al., unpublished data), people with a more active BIS show less reversal learning and thus perform worse at the task, while no such effect seems to hold true for people with a more active BAS. This finding is opposite to the findings concerning the performance on the Iowa Gambling Task in a situation without uncertainty and a fixed rule (Bechara et al., 2004). A theory which could explain this finding is that people with a more active inhibition system will be affected by the uncertainty inherent in the task to be performed and that the new situation they are faced with will cause anxiety, because they become afraid of possible punishment. Because of this anxiety and stress, they will fall back on the use of heuristics and show stereotypical behavior: they will give priority to avoiding punishment and stick to a strategy they know worked in the past and thus they will fail to show rule learning and adjust to the new situation.

For a long time, the concepts of BIS and BAS existed only in Gray’s theory and ways to measure these phenomena were composed of questionnaires (Carver & White, 1994). A large body of research has accumulated to the point where it might be stated that the neural correlates of the behavioral inhibition system and the behavioral activation system could be pinpointed. Research of the differences in emotional behavior between patients with either unilateral left-hemispheric damage and unilateral right-hemispheric damage has shown that patients with unilateral left-hemispheric damage showed more catastrophic reactions while joking behavior was seen more often in patient with unilateral right-sided hemispheric damage (Gainotti, 1972). These findings led to further research and eventually to the notion that an asymmetry in the anterior regions of the brain could be associated with different states of affect, with activity in the right hemisphere correlated with negative affect and activity in the left-hemisphere correlated with positive affect (Davidson, Ekman, Saron, Senulis, & Friesen, 1990). Further research has shown that, more specifically concerning punishment sensitivity, the experience of reward can be associated with more activity in the left frontal cortex as measured by low levels of alpha (8-12 Hz) , while the experience of punishment is related to lower levels of alpha (8-12 Hz) in the right frontal cortex (Sobotka, Davidson, & Senulis, 1992). Research done by Richard Davidson (1997) has included the BIS and BAS from Gray's theory (Gray, 1987) in regards to the previously mentioned asymmetry. In their research, higher self-reported scores for the BAS correlated with a more active left-hemispheric cortex, while higher self-reported scores for the BIS correlated with a more active right-hemispheric cortex. They found that the asymmetry in the prefrontal cortex explained the largest amount of variance for the self-reported measures of BIS and BAS strength. However, asymmetry in the prefrontal cortex did not correlate with general levels of either positive affect or negative affect. This led to Davidson's theory that an asymmetry in the prefrontal cortex can be correlated with the behavioral inhibition system and the behavioral activation system, coined by Gray (Gray, 1987). According to the theory of Davidson, right-sided activation is associated with negative feelings that lead to withdrawal and left-sided activation can be associated with positive feelings that lead to approach. However, further research has indicated that affect may not even play a role in this correlation. It was found that anger, a negative emotion that often leads to approaching behavior, was correlated with a higher activity in the left prefrontal cortex (Harmon-Jones, 2003). Consequently, it could be stated that the asymmetry found in the prefrontal cortex solely correlates with motivational behavior regardless of the corresponding trait affect. When this fact is brought into relation with Gray's theory of the behavioral inhibition system versus the behavioral activation system, it can be expected that people with a more active behavioral activation system (BAS) will show more left-frontal activation, while people with a more active behavioral inhibition system (BIS) will show the opposite, namely more activation in the right side of the frontal cortex.

This research will try to gain more insight in the role of sensitivity to punishment when the situation in which a person finds himself is not predictable, but holds some amount of uncertainty and so expand the database on this specific kind of information. To extend the present study even further, the correlation between a resting EEG of the frontal lobes of the human brain and reversal learning will be investigated.

Taking into account that a more active left lateral frontal lobe activity as measured by low levels of alpha (8-12 Hz) is associated with the behavioral activation system and that a more active right lateral frontal lobe is associated with the behavioral inhibition system (Davidson & Sutton, 1997; Harmon-Jones, 2003), it is expected that the same correlation will be found between the data obtained from self-reported measures of the behavioral inhibition system (BIS) and the behavioral activation system (BAS) and the asymmetry measured by the EEG of the frontal lobes.

Taking into consideration the assumption made in a previous unpublished study (Schutter et al., unpublished data) that in the event of an uncertain situation people with a more active BIS will stick to their beliefs about what worked in the previously known situation and will consequently fail at reversal learning and thus perform worse in a novel and unknown situation, it is expected that a significant negative correlation will be found between right-sided asymmetry of the frontal lobes when looking at the alpha band of the EEG (8-12 Hz) and the degree of reversal learning and that a significant positive correlation will be found between left-sided asymmetry of the frontal lobes when looking at the alpha band of the EEG (8-12 Hz) and reversal learning. In contrast, one could argue that a more highly active BAS will result in a better performance on the task since the behavioral activation system is associated with seeking out the most rewarding choice and thus promoting searching behavior even if risks for losing have to be taken. It is expected that people with a more active BAS will show reversal learning to a higher degree and will perform better on the uncertain gambling task. The main hypothesis of this research is that it is expected that task performance as measured by to what degree participants show reversal learning can be predicted by the asymmetry of the frontal lobes derived from baseline EEG recordings. It is expected that a right-sided asymmetry will correlate negatively with reversal learning and a left-sided asymmetry will correlate positively with reversal learning. Hypotheses’

Methods

Participants

A total of 30 healthy right-handed non-smoking participated (23 male) with a mean age of 22.4 (SD= 3.8). All participants had normal or corrected-to-normal vision. None of the participants reported a history of psychiatric or neurological conditions.

Participants received course credit or financial compensation for participation. All volunteers were naïve to the aim of the study, and written informed consent was obtained from all participants. The study was in compliance with the standards set by the Declaration of Helsinki (Seoul Amendments).

Reversal learning task

The task is an adaptation of the Iowa Gambling Task (Bechara et al., 1994) in which participants can get punished (lose money) or rewarded (win money) depending on the decision that has been made. The Iowa Gambling Task has a fixed rule and to create an uncertain environment, aspects of the Wisconsin Card Sorting Task (Berg, 1948) have been implemented. Following this known task, the rule which leads to the optimal decision-making strategy shifts unbeknownst to the participant. To perform the task optimally, the participant has to show reversal learning: they have no notice a change in the rule and adjust to the new situation as quickly as possible.

The stimuli that were used were schematic depictions of cards with numbers on them. The stimuli were presented in the center of the screen against a white background. All stimuli were black numbers on white cards on a black background in the first half of the trial, but in the second half of the trial, the colors *red* and *green* were also used.

The entire experiment contained 120 trials (not counting two practice trials), divided into three equally large parts. In the first part of the experiment, 70% of the trials favored a safe choice; in the second part, 70% of the trials favored a risky choice and in the third and last part of the experiment, 70% of the trials favored a safe choice again. This division into three parts was unknown to the participant and the participant was instead made to believe the experiment consisted of six rounds, as shown on the screen after every twenty trials. These six rounds will be considered blocks from now on, and each real phase – as determined by the set-up of the experiment – exists of two blocks.

Reward-punishment sensitivity

Reward- and punishment sensitivity was determined by self-reported measures obtained through the questionnaire developed by Carver and White (1994). This questionnaire consisted of 20 statements. Participants had to score on a 4-point Likert scale to what degree they found the statements applied to them.

EEG recording

Resting state electric brain activity was recorded using the Biosemi ActiveTwo system (Biosemi, Amsterdam, The Netherlands) at a 2048 Hertz sampling rate from 32 Ag/AgCl pin electrodes (Fp1, Fp2, AF3, AF4, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, PO3, PO4, O1, Oz, O2) placed over the scalp according to the International 10/20 EEG system. The ground consisted of the active common mode sense and passive driven right leg electrode. Electrooculogram (EOG) was recorded from four electrodes placed on the suborbital and supraorbital of the right eye and on the external canthi of both eyes to monitor vertical and horizontal eye movements.

Apparatus

A DELL GX280 computer with a DELL monitor were used to display each trial. The stimuli were presented with a resolution of 1280 x 1024 and a refresh rate of 60 Hz.

Participants were seated in a dark room while viewing the computer screen at a distance of 80 cm. For the registration of the manual responses, a USB mouse was used. The experiment was both created and presented with the use of E-Prime version 2.0.

Procedure

Upon arrival to the laboratory, participants were given verbal and written information about the study. Next volunteers were asked to sign informed consent and were asked to sign a form stating they were accepting the stated terms and agreeing to taking part in the experiment. They were asked to fill out the orthogonally-dimensioned behavioral inhibition system (BIS) and behavioral activation system (BAS) self-report questionnaire by Carver and White (1994) on the computer to determine their sensitivity to reward and punishment.

Subsequently, participants were connected to the EEG device by using the 32-electrode EEG cap and four EEG electrodes that were places on the face: one near the outer corner of each eye, one above the right eye and one below the right eye. This way eye blinks could be accounted for, if necessary.

Participants were seated in a chair in a dimly lit room and were given information about the baseline condition, in which the room would be made as dark and silent as possible. Participants were asked to simply relax and stare straight ahead into the dark and they were told that the experiment leader would occasionally ask them to open or close their eyes and that this would happen after approximately every 60 seconds during the entire baseline recording, which would last for four minutes. The experimenter excluded themselves from the experiment by using a folding screen as to have minimal influence on the baseline condition. The participant would start with their eyes open for one minute, they were asked to close their eyes for one minute. These two conditions were both repeated again, which resulted in four minutes of baseline EEG data.

After the baseline recording, participants were then told the experiment was about to start and they received verbal and written information about the task and how to perform it.

> “You will be playing a gambling task with fictional money involved. Each trial you will be presented with a choice between a high amount of money and a low amount of money, depicted by two squares with in each a number – a high and a low one. You can make your choice by pressing the left mouse button for the high amount or the right mouse button for the low amount. After you’ve made your choice, one of the numbers will turn green while the other will turn red - indicating which amount has lost and which amount has won in the current trial. The number that has turned green is the option that has won that round, while the number that has turned red has lost that round. If the option you picked turns green, the amount depicted on that card will be added to your grand total; if the option you picked turns red, the amount depicted on that card will be deducted from your grand total. The goal is to complete the experiment with as much money as possible. If you could wait for my signal, you may start. Please call me when you have completed the experiment.”

Once again, the experimenter would retreat as to have as little influence on the performance of the participant as possible and once all the software was ready, the participant would be told they could manually start the experiment.

First, the stimulus appeared on screen and participants could make their decision. There was no time limit in which their decision had to be made, so the presentation time of the stimulus was variable for each participant. After participants had made their decision, there was a latency of 500 ms before feedback was given through the adjustment of the colors of the cards to respectively green or red; this feedback lasted for 2000 ms. After that phase, participants were shown their score for 1500 ms before the program continued to the next trial automatically.

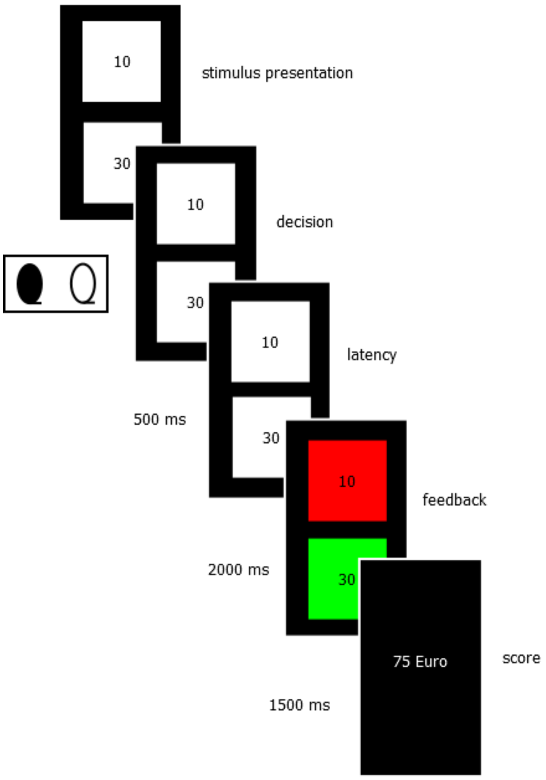

Figure 1. Schematic depiction of one trial.

The participant would then complete all 120 of the trials and would call the experimenter whenever they were ready. The research leader would disconnect the facial EEG nodes and take off the EEG cap. The participant got the option as to wash their hair to get rid of some residue conduction gel. To complete the experiment, participants were debriefed and given the option to leave behind their e-mail address so that they could be contacted when the results of the experiment were in.

Data reduction and statistical analyses

Multiple sets of data were obtained. Firstly, for each participant their respective BIS and BAS scores were calculated from the self-report questionnaire by Carver and White (1994). To analyze this data, average scores for both the BAS and BIS were calculated.

To get a measurement for reversal learning, an index of behavioral adaptation was calculated, according to the following formula: (((% low risk Phase 1 - % low risk Phase 2) / (% low risk Phase 1 + % low risk Phase 2)) + ((% low risk Phase 3 - % high risk Phase 2) / (% low risk Phase 3 + % low risk Phase 2)) / 2), with "low risk" being the percentage of low risk decision making they had shown in a specific phase. This resulted in data in a ranger from -1 to 1, with 0 being no reversal learning,1 being optimal reversal learning and -1 indicating opposite reversal learning. A general behavioral adaptation index was calculated to give an impression of reversal learning concerning the overall experiment and to see if the experiment actually initiated reversal learning. Furthermore, behavioral adaptation indices were calculated to indicate reversal learning between phases and between blocks to gain more insight in the global measurement of reversal learning.

Raw EEG data was referenced to the average EEG signal. It was decided that only the data in which participants had their eyes closed during the resting EEG would be used, since the amount of data meeting these criteria was sufficient for analysis. Therefore, there was no need to account for eye blinks. This resulted in two minutes of EEG data for each participant. Next, the EEG was broken down into chunks of 2 seconds in duration each. Only the F3 and F4 nodes were taken into consideration, since these are located at the frontal regions which are of interest for this research (Sobotka et al., 1992). These nodes were separated from the entire dataset before continuing the analysis. A band-pass filter (1-50 Hz- 48bD/oct) was applied and through artifact rejection all changes in voltage larger than 50 mV were being rejected from the dataset. Subsequently, a fast Fourier Transform analysis was applied to the remaining data, which included the delta band (1-3 Hz), the theta band (4-7 HZ), the alpha band (8-12 Hz), and the beta band (13-30 Hz). The difference in power between the F3 and F4 nodes was calculated according to the following formula: (F4-F3)/(F3+F4). A positive result indicated more activity located near the F3 node in comparison to the F4 node and thus implying a right-sided asymmetry. On the other hand, a negative result indicated more activity located near the F4 node in comparison to the F3 node, implying a left-sided asymmetry.

To determine whether the task used in the present study to did in fact elicit reversal learning, the behavioral adaptation index will be analysed in general as well as per phase and per block. The index of frontal asymmetry is correlated with self-reported BIS and BAS scores. Subsequently, self-reported BIS and BAS scores are also correlated with the indices of behavioral adaptation in general, per phase, and per block. Lastly, frontal asymmetry is correlated with the indices of behavioral adaptation in general, per phase, and per block.

Results

Response reversal learning

For each phase the percentages of the amount of times they had chosen the low-risk option were determined. Further analysis revealed that phase 1 and phase 2 differed significantly (*t* = 5,374; *p*< .001) and that phase 2 and phase 3 differed significantly as well (*t*= 4,381; < *p*= .001). Table 1 and Figure 2 depict that participants took significantly fewer low-risk decisions in phase 2 as compared to phase 1 and took significantly more low-risk decisions in phase 3 as compared to phase 2.

Table 1. Mean percentages and standard deviations of low-risk decision making in each phase.

	Phase 1	**Phase 2**	**Phase 3**
M	58.17%	40.83%	58.50%
SD	14.78	12.89	17.44

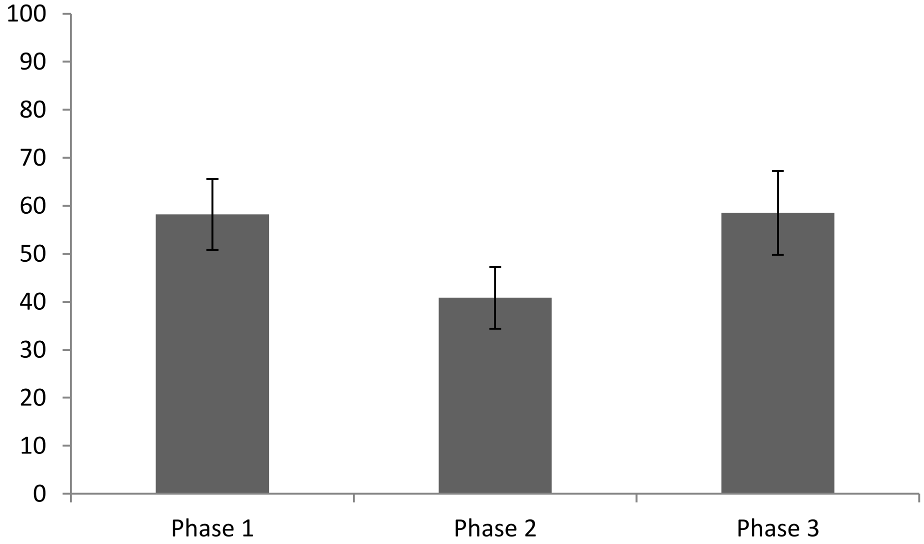

Figure 2. Mean percentage low-risk decision making per phase.

The same analysis was done for the performance ratings of the participants per block (see Table 2 and Figure 3). Each phase consisted of two blocks and these were the different rounds of trials the participants were being made aware of while performing the task. Further analysis revealed that each phase and its following phase differed significantly from one another (see Table 3).

Table 2. Mean percentages and standard deviations of low-risk decision making in each block.

	Block 1	**Block 2**	**Block 3**	**Block 4**	**Block 5**	**Block 6**
M	55.50%	60.83%	45.83%	35.83%	54.00%	63.00%
SD	13.67	18.01	13.59	18.53	19.89	18.22

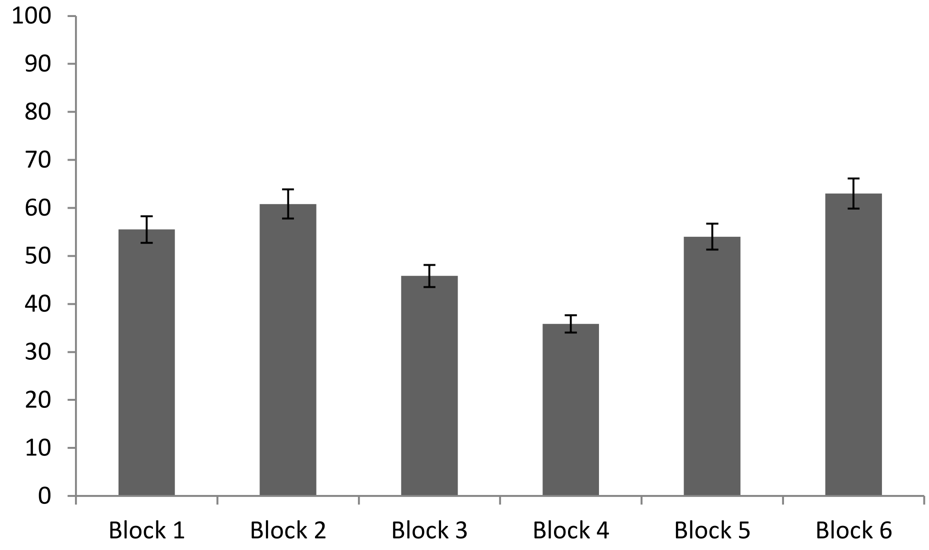

Figure 3. Mean percentage low-risk decision making per block.

Table 3. A comparison of low-risk decision making between each block and its successor.

	t	**Sig.**
Block 1 – Block 2	-2.400	.023
Block 2 – Block 3	4.287	.000
Block 3 – Block 4	2.769	.010
Block 4 – Block 5	-3.377	.002
Block 5 – Block 6	-3.191	.003

Reward and punishment sensitivity

Table 4. Pearson's r and level of significance for the correlation between BIS and BAS self-reported measurements as obtained from the questionnaire by Carver & White (1994) and the different EEG channels.

		Delta	**Theta**	**Alpha**	**Beta**
BIS	**r**	.043	.088	.074	-.090
	Sig.	.821	.644	.698	.635
BAS	**r**	.066	-.109	-.127	-.003
	Sig.	.730	.565	.503	.988

Table 5. Pearson's r and level of significance for the correlation between the general behavioral adaptation index and the BIS and BAS self-reported measurements as obtained from the questionnaire by Carver & White (1994).

		BIS	**BAS**
Behavioral Adaptation	**r**	.092	.040
	Sig.	.629	.836

Table 6. Pearson's r and level of significance for the correlation between the index of behavioral adaptation per switch in phase and the BIS and BAS self-reported measurements as obtained from the questionnaire by Carver & White (1994).

		BIS	**BAS**
Phase 1 - Phase 2	**r**	.085	.046
	Sig.	.655	.810
Phase 2 - Phase 1	**r**	.094	.025
	Sig.	.621	.895

Table 7. Pearson's r and level of significance for the correlation between the index of behavioral adaptation per switch in block and the BIS and BAS self-reported measurements as obtained from the questionnaire by Carver & White (1994).

		BIS	**BAS**
Block 1 – Block 2	**r**	-.043	-.215
	Sig.	.820	.254
Block 2 – Block 3	**r**	.007	-.148
	Sig.	.970	.436
Block 3 – Block 4	**r**	.147	.217
	Sig.	.439	.250
Block 4 – Block 5	**r**	.246	.159
	Sig.	.190	.401
Block 5 – Block 6	**r**	*-.592*	-.194
	Sig.	*.001*	.306

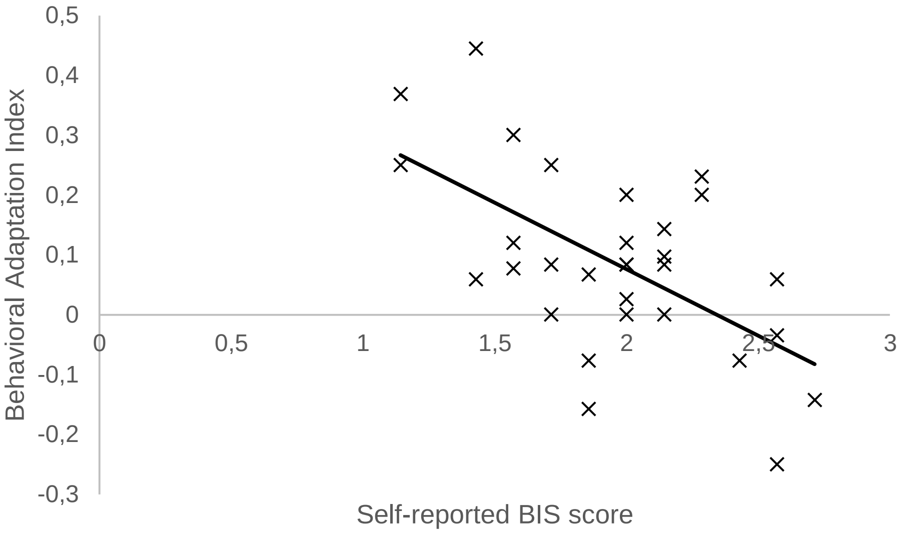

Figure 4. The correlation between the self-reported BIS scores and the corresponding indices of behavioral adaptation for the transition of block 5 to block 6 in the experiment.

As can be seen in Table 4, no significant correlations were found between the BIS and BAS measurements and the different EEG channels, consisting of the delta band (0-3 Hz), the theta band (4-7 HZ), the alpha band (8-12 Hz), and the beta band (13-30 Hz).

No significant correlation was found when relating measurements from the BIS and BAS questionnaire and the general adaptation index (see Table 5), this was the same when BIS and BAS measurements were compared to the indexes of behavioral adaptation belonging to the switches in phases (see Table 6). Only one significant correlation was found when comparing the indexes of behavioral adaptation from the different blocks and the measurements from the BIS and BAS questionnaire; there was a significant negative correlation between the self-reported BIS score and the behavioral adaptation index from the first block of phase three to the second block of phase three (*r* = -.592, *p* = .001, *a* = .05) (see Table 7 and Figure 4). This suggests that participants with a higher self-reported BIS score were significantly worse at applying reversal learning within phase 3 of the experiment, in which risky behavior was preferred.

Behavioral Adaptation Index and EEG recordings

Table 8. Pearson's r and level of significance for the correlation between the general behavioral adaptation index and the different EEG channels.

		Delta	Theta	Alpha	Beta
Behavioral Adaptation	**r**	-.059	-.125	-.053	.025
	Sig.	.756	.512	.779	.897

Table 9. Pearson's r and level of significance for the correlation between the index of behavioral adaptation per switch in phase and the different EEG channels.

		Delta	Theta	Alpha	Beta
Phase 1 - Phase 2	**r**	-.048	-.119	-.069	-.025
	Sig.	.800	.531	.719	.897
Phase 2 - Phase 1	**r**	-.071	-.121	-.023	.104
	Sig.	.709	.523	.905	.586

Table 10. Pearson's r and level of significance for the correlation between the index of behavioral adaptation per switch in block and the different EEG channels.

		Delta	Theta	Alpha	Beta
Block 1 – Block 2	**r**	-.028	-.005	-.041	-.011
	Sig.	.883	.981	.830	.954
Block 2 – Block 3	**r**	-.067	-.074	-.150	-.111
	Sig.	.723	.697	.428	.560
Block 3 – Block 4	**r**	.040	-.032	.153	.112
	Sig.	.834	.868	.421	.554
Block 4 – Block 5	**r**	.013	-.060	.071	.113
	Sig.	.945	.751	.708	.551
Block 5 – Block 6	**r**	-.081	-.011	.001	.060
	Sig.	.671	.954	.995	.753

As shown in Table 8, no significant effects were found between the general index of behavioral adaptation and the asymmetry found in the different EEG channels. Further analysis showed that the indexes of behavioral index between phases (see Table 9) and the indexes of behavioral adaptation between blocks (see Table 10) yielded the same results in that no significant correlations were found between the respective behavioral adaptation indices and the different EEG channels.

Discussion

The aim of the present study was to determine whether a frontal asymmetry found in the alpha wave band (8-12 Hz) could predict reversal learning in an uncertain task environment. It was expected that a right-sided asymmetry would negatively correlate with reversal learning and that left-sided asymmetry would positively correlate with reversal learning.

To measure reversal learning, a behavioral adaptation index was calculated. The index of behavioral adjustment (i.e. how quickly and consistently participants changed their strategy) did not correlate with the channels from the EEG recordings. No significant correlations were found between a global index of behavioral adjustment that indicates the degree of reversal learning expressed by participants in relation to the EEG channels (see Table 8). This did not change when the different EEG bands - which included the delta (1-3 Hz), theta (4-7 HZ), alpha (8-12 Hz), and beta band (13-30 Hz) - were compared to indices of behavioral adjustment at smaller scales, such as between phases (see Table 9) or between blocks (see Table 10 10). Only one significant effect was found that indicated a significant negative correlation between the self-reported score of the BIS variable on the questionnaire by Carver and White (1994) and the behavioral adaptation score between the two blocks of the third phase of the task. This result implies that participants with a more active behavioral inhibition system showed significantly less amounts of reversal learning which led to worse adaptation of their behavior within the third phase of the experiment. This result is not deemed strong enough to support the hypothesis, since this was the only significant result found in this study. However, the aforementioned finding may be considered partial support.

Following the data shown in Figure 2 and Figure 3 and supported by the information that the changes from phase to phase and block to block were significant, it can be concluded participants did adjust to the changing of the rule that determined the optimal strategy to perform the task. In Phase 2, participants chose the low-risk option significantly fewer times than in Phase 1 and changed their strategy again when they entered Phase 3: participants chose the low-risk option significantly more often in Phase 3 than in Phase 2. This learning curve can be viewed in more detail in Figure 3, where the transition to different strategies can be viewed more clearly. This seems to rule out the idea that the lack of evidence to support the proposed hypothesis is due to a failure in how the task was carried out by the participants. Furthermore, what can be concluded is that, even though the task was made slightly more difficult in comparison to a previous study (Schutter et al., unpublished data) in which a ratio of 80-20 was used instead of the 70-30 ratio that was used in the present study. Overall, participants still showed response reversal learning to the strategy desirable for a specific phase or block, since all phases differed significantly when compared to the previous or following one - the same was true for all blocks.

The hypothesis based on the work of Davidson & Sutton (1997) that stated that an EEG alpha asymmetry in the frontal lobes of the brain correlates with the strengths of the behavioral inhibition system and the behavioral activation system, could not be confirmed. According to the present study, EEG recordings did not correlate with data obtained through the orthogonally-dimensioned behavioral inhibition system (BIS) and behavioral activation system (BAS) self-report questionnaire by Carver and White (1994). An aspect that is worth noticing is that the total variability of both the BIS and BAS scores was very low in the present study. The average scores for the measurement of the strength of the behavioral inhibition system had a minimum of 1.14 and a maximum of 2.71 – resulting in an achieved rang of 1.57 on a possible range of 3 (from 1 to 4). The average scores for the measurement of the strength of the behavioral activation system had a minimum of 1.15 and a maximum of 2.77 – resulting in a range of 1.62 on a possible range of 3 (from 1 to 4). Lack of variance could have contributed to the lack of significant results and if both variables would consist of data spreading over a larger range, it might have made a difference for the outcome. A proposal for future research into the current matter might involve a pre-experiment screening as to ensure that participants on the full spectrum of the possible score of either BIS and BAS are included in the study.

Furthermore, some slight alterations have been made to the task used in the current that may have contributed to the fact that no significant correlation has been found in this case, when some of these effects have been found in the past (Schutter et al., unpublished data) .

Firstly, a reverse punishment scheme was used. In previous research (Schutter et al.), participants were encouraged to adopt a more risky decision-making strategy in the first phase, then a more conservative strategy in the second phase and again a more risky strategy in the third and last phase. In the current research, this scheme was altered, so that participants were rewarded when they took on a more conservative decision making strategy in the first phase, a more risky strategy in the second phase and lastly, a more conservative strategy in the third phase. This may have caused a difference in results, since the initial starting phase in the current research was different then it was in previous research (Schutter et al., unpublished data). One of the assumptions made was that the variable of BIS correlates negatively with the behavioral index adaptation - this could have been found in previous research (Schutter et al., unpublished data), since it is assumed that people with a stronger behavioral inhibition system activity will prefer making more conservative decisions. The fact that the starting phase previously encouraged risky decision making could have had a major impact on their task performance overall. Since the punishment scheme was reversed for the present study, the impact of the promotion of risky decision-making on participants with a more active behavioral inhibition system would be absent, resulting in a lack of significance when looking at the correlation between the BIS score and the behavioral performance index. This could also explain why the present study found a significant negative correlation between the score on the variable BIS on the orthogonally-dimensioned behavioral inhibition system (BIS) and behavioral activation system (BAS) self-report questionnaire by Carver and White (1994) and the behavioral adaptation index between the two blocks of the third phase. It might be that individuals with a more active behavioral inhibition system only perform less on a task when they have been confronted with a preceding situation in which risky decision-making has been promoted. This is in line with the idea that BIS people when taken out of their comfort zone will experience uncertainty and rely on a previous strategy that worked for them. Another result that could be concluded is that people who have a more active BAS do not experience much trouble performing on the task in both variants of the reward and punishment scheme, since the scores for BAS didn’t correlate with the behavioral adaptation index in previous research (Schutter et al., unpublished data) and did not correlate either in the current study. This could mean that response reversal learning is driven by the BIS and punishment sensitivity – a notion that will require further research.

For future research, both punishment and reward schemes should be taken into consideration within the same experiment, since that might lead to more insight in the possible effect of the sequence or starting phase of the punishment and reward scheme in predicting reversal learning on the basis of either a BIS or a BAS score. Of course, more participants will result in more reliable results and perhaps when future experiments will take gender into account, different effects might be found between men and women.

Another possibility might be an adaptation to the analysis of the results instead of the experiment itself. A different kind of data that can be obtained from the EEG analysis might have shed a different light on the current results and might help in the future in obtaining more insight in the ability to learn and the concepts of BIS and BAS. This measurement is the so-called theta/beta ratio, which is a comparison between the amount of activity in the theta band (4-7 Hz) and the activity in the beta band (13-30 Hz). Previous research has shown that individuals with ADHD show a larger theta/beta ratio when comparing the theta channel of the EEG of the beta channel of the EEG (Barry, Clarke & Johnstone, 2003). Because of this, the theta/beta ratio is considered an indirect measurement for the motivational circuit. A large theta/beta ratio has been associated with less regulation exerted by the brain and less regulation results in a diminished ability to learn new things. To link this measurement to the concepts of BIS and BAS, quite essential terms in the current study, a few more assumptions have to be made. In the past, the concept of BIS has been associated, if not paralleled, to neuroticism, one of the five traits of the known Big Five (McCrae & Costa, 1987). No straightforward theory has been developed about the correlation between neuroticism and the ability to regulate actions and reactions. Some studies assume that neuroticism is positively correlated with self-regulation; people that are high in neuroticism tend to worry a lot, which leads to an increase in chance of succeeding on a task (Tamir, 2005). However, other studies claim that people high in neuroticism are worse at self-regulation (Boekaerts, Pintrich & Zeidner, 2000). Based on this, another assumption can be made, namely that persons high in neuroticism will have more problems when it comes to learning, something that has already been proved in the past (Komarraju, Karau, Schmeck & Avdic, 2011). A correlation between the theta/beta ratio and risk-taking has been found when using the Iowa Gambling Task, but only for individuals who score high on the BIS scale (Massar, Rossi, Schutter, & Kenemans, 2012; Schutter, & van Honk, 2005). Therefore, it could be argued that an effect in behavioral adaptation could have been found in the present study when using data concerning the theta/beta ratio to determine the activity of the behavioral inhibition system, with a smaller theta/beta ratio being associated with a more active behavioral inhibition system and thus a lower behavioral adaptation index, following the hypothesis posed earlier in the present study and based on the findings in previous unpublished research (Schutter et al., unpublished data).

Future research on the topic of the influence of punishment sensitivity, determined by the amount of asymmetry in the frontal lobes obtained through EEG measurements, on decision making under uncertain circumstances could take into account the different criticisms on the findings of the present study and hope to gain a more clear insight into the workings of the aforementioned mechanism.

In conclusion, in the present study no evidence could be found that EEG measurements of the alpha band (4-8 Hz) of a baseline EEG recording could predict reversal learning. The association between a frontal asymmetry as measured by low-levels of alpha activity and the BIS and BAS was not found in the present study. However, the present research did give some insight in how situational factors, such as sequence presentation and starting phase, may have an influence on reversal learning – primarily under the influence of the activity of the behavioral inhibition system.

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