EYE MOVEMENT AS AN INDICATION OF PROACTIVE AND REACTIVE CONTROL IN SWITCH/REPEAT TASKS

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

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Two main components for effective cognitive control are top-down and bottom-up processing. Top-down processing is described as the ability to use previously known information to create, seek out and achieve a goal. Bottom-up processing is described as making a reactive decision, based off the immediate sensory information available. Top-down predictions and bottom-up sensory processing must work simultaneously to interpret one's current surroundings for the purpose of decision making. We believe that top-down and bottom-up processes are also correlated with a person's innate level of impulsivity. This project aims at using eye-tracking data to determine if there is a correlation between where and how quickly a participant will look at a given stimuli before making a decision. Then, we aim at determining if a participant will proactively set their gaze in a certain location before a stimulus is given, indicating top-down control when making their decision. This study will provide more insight on the question of how we, as humans, make daily decisions.

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SECTION I

INTRODUCTION

According to the literature, the two main components for effective cognitive control are top-down and bottom-up processing. Top-down processing is described as the ability to piece together known information to create and achieve goals. This type of processing is seen as a higher, more efficient and proactive way of making decisions due to its deliberate and calculated characteristics (Braver, 2012). With top-down processing, the brain uses previous knowledge as well as the expected outcome to interpret the sensory cues given. Rather than using previous knowledge or preplanning during decision making, bottom-up processing makes reactive decisions based off of immediate sensory information available. Decisions are put off until current sensory information is gathered; no preplanning required. A recent study done by Mathews et. al. suggests that top-down predictions and bottom-up sensory processing must work together to accurately interpret incoming sensory stimuli for the purpose of decision making (Mathews, Cetnarski & Verschure, 2014).

Cognitive control relies on the ability to coordinate and order thoughts that are influenced by local incoming stimuli to maintain and achieve goals in everyday life. (Braver, 2012). However, with such large amounts of constant, incoming stimuli, there must be a system used to filter information. Affect-biased attention, as defined by Morales et. al., is a subconscious process that filters out sensory information deemed unnecessary in the moment, further promoting the incoming stimuli that can better contribute to and influence the decision-making process (Morales, Fu & Perez-Edgar, 2016). Further, affect-biased attention allows us to be proactive in our decisions through top-down processing (Todd, Cunningham, Anderson &

Thompson, 2012). By using our surroundings to make informed decisions, we avoid the unreliability that reactive, bottom-up thinking presents.

However, while bottom-up processing is generally seen as a less efficient model of thought processing, there is evidence that it plays a large role in influencing our decisions (Orr & Weissman, 2011). Using a version of the Stroop task, Orr and Weissman found that, when presented with a choice between two tasks, participants were more likely to choose the option that they had encountered most recently. This indicated that a bottom-up bias was present during decision making. Further, Orr and Weissman found that when bottom-up biases strengthened, top-down control weakened.

Eye-tracking methods have been useful in areas such as marketing to discover visual attention patterns in the average consumer. Cognitive neuroscience has also begun using data gathering techniques such as these to further our knowledge of the decision-making processes. They say that the eye is the window to the soul, so could eye-tracking be used to uncover the neural mechanisms that occur within the brain when forming a decision? Eye-tracking research has revealed a difference in the decision-making process of participants who rely more heavily on top-down or bottom-up thinking. In 2016, Konovalov and Krajbich conducted an experiment identifying participants as either model-based or model-free learners. The term model-based corresponds to what we have referred to as top-down learners and model-free refers to what we have referred to as bottom-up learners. Participants were given choice options that would be more or less likely to lead to a reward. This experiment found that model-based learners seemed to predetermine their choice before the options were presented to them as well as look at the best option first and only the best option. Their eyes did not tend to oscillate much between the two options provided. Model-free learners were found to be more likely to re-evaluate the values of each symbol during each new trial, using the given information to form a decision rather than pre-planning a decision (Konovalov & Krajbich, 2016). In a study done by Krajbich and Rangel (2011), participants were provided with more than two choice options to determine if the same sort of decision-making mechanisms used in binary decision-making are used when multiple possibilities are available. In this experiment, participants were given the option of three different snack choices on a screen. They were allotted as much time as they needed to choose between the three choices presented. During this time eye-tracking data was collected. The results found that the same mechanisms used in decision-making when two options were presented are also used when three options are presented. Using their drift-diffusion model, Krajbich and Rangel were actually able to predict the participant's choice based off of visual fixations and the level they had previously rated the options on the value scale (Krajbich & Rangel, 2011).

Pupillometry has also been useful in uncovering further details the decision-making process. Recently, Brunyé and Gardony (2017), were able to quantify uncertainty in a decision. Through eye tracking, variations in pupil diameter, duration of gaze as well as other factors varied based on the level of certainty when making a decision. As a result, the data indicated that the pupils tend to dilate before making a decision especially if the participant is uncertain of their decision. Similarly, Preuschoff et. al., 2011 used pupillometry to determine that an increase in pupil dilation is also present in moments of surprise, for example, when a reward is given in an unexpected context. These results also suggest that pupil dilation can be an indicator that learning has occurred (Lavin et. al., 2014). Using a task-switching paradigm Frober et. al., 2020, found that pupil dilation increased in the presence of the prospect of increasing high rewards, and in participants with higher switch rates. Conversely, pupil dilation decreased in the presence of increasing low rewards of when a task remained the same. These findings support the findings of Lavin et. al., 2014 as well as introduce the idea of cognitive flexibility being monitored and observed through pupillometry.

Eye-tacking studies such as these have proved that much can be discovered of decision-making based on studying the eyes. However, much is still left to discover. While it is evident the decision making can be monitored and interpreted with eye-tracking data, could the differences in how we make decisions be affected by our personality? For example, we have discussed how some relay more or less heavily on either top-down or bottom-up control when making decisions. Because bottom-up control is related to a more reactive approach, could the level of one's impulsivity predict their reliance on this type of control? Further, could eye-tracking data help predict a person's level of impulsivity or pre-planning when making a decision? In this study, we attempt to answer some of these questions by using eye-tracking data and a task-switch paradigm to find a correlational relationship between gaze reaction time and a participant's level of impulsivity.

SECTION II

METHODS

Participants

Due to the unforeseen events surrounding the COVID-19 virus in spring 2020, the necessary data from participants was not able to be gathered in time for the completion of this LAUNCH URS thesis. For simplicity, the language used for the remainder of the Methods section will be as if participants did go through the experiment. All procedures were approved by the Texas A&M University College Station Institutional Review Board.

Apparatus

This experiment was conducted on a Dell PC (monitor dimensions 22 x 23 in; viewing distance 61.5 cm; display resolution 1920 x 1018 pixels). Eye-tracking was done using a Tobii Pro Fusion eye tracking device (sampling rate of 120 Hz). The experimental study was conducted using PsychoPy programming. For responses, participants used a QWERTY-keyboard. In order to rule out any unwanted visual effects caused by the differences in luminance of certain colors presented during the practice, non-reward and study trials, two isoluminant colors on the Teufel scale were used. The display background was a blueish hue (RGB: 105, 198, 241), while the images and stimuli were an orangish hue (RGB: 243, 188, 119).

Stimuli

During the experiment, each trial began with a fixation cross, followed by a reward cue. The reward cue could be one of four shapes (square, diamond, hexagon or star). Unknown to the participant, each reward cue offered the possibility of a different reward value. After the reward cue, participants were presented with a voluntary switch task. The task screen contained a fixation cross at its center with a number (125, 132, 139, 146, 160, 167, 174, or 181) above and a letter (B, D, F, H, S, U, W, or Y) below. Participants were instructed to choose one of these tasks per trial. During the number task, participants indicated whether the number presented was greater or less than 153. If greater than 153, participants pressed the 'L' key. If less than 153, participants pressed the 'J' key. During the letter task, participants indicated whether the letter was closer to 'A' or closer to 'Z'. If closer to 'A', participants pressed the 'D' key. If closer to 'Z' participants pressed the 'F' key. These key mappings were counterbalanced across participants. *Figure 2* gives a clear example of what one of these trials looked like.

Procedure

Personality Scales

Participants began the experiment by taking the Barratt Impulsiveness Scale (BIS-11). This scale is a self-reported, 30 item questionnaire that tests for the personality trait of impulsiveness. After the BIS-11, a second self-reported questionnaire is given, called the BIS/BAS Reward Responsiveness Scale. This scale measures both the Behavioral Inhibition System (BIS) and the Behavioral Activation System (BAS). The BIS refers to a person's tendency to avoid negative outcomes while the BAS refers to a person's tendency and motivation to pursue goal-orientated outcomes.

Practice Trials

Before beginning the experimental portion of the study, practice trials were given to ensure that all participants understood the task before beginning the actual experiment. This minimized errors in results due to lack of understanding of the task. The practice trials mirrored the non-reward trials given before the study trials.

Non-Reward Trials

After the completion of both scales and the practice trials, participants proceeded to the reaction time trials. The reaction time trials consisted of 64 trials that mimicked the study trials without the possibility of gaining any reward. During this time, participant's response times to each trial were measured and recoded. *Figure 1* shows an example of one trial from the practice trials. Reaction times were recorded during each trial to assist with rewarding points during the study trials which will be discussed in the next paragraph.

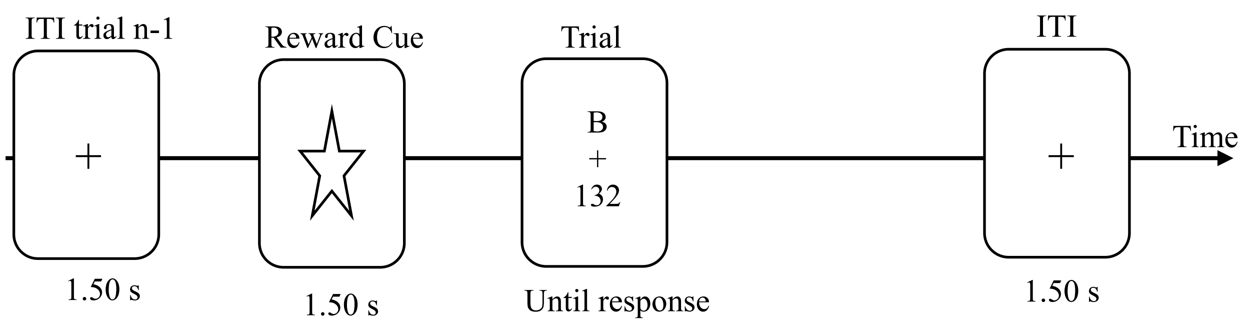

Figure 1. Example of a reaction time trial

Study Trials

Study trials were the same format as the non-reward trials, but these trials could receive rewards. The study trials consisted of 10 blocks of 32 trials each. The shapes presented in the beginning of each trial indicated the possible reward value obtainable for that trial, although participants were unaware of this. Both the diamond and star shapes offered a maximum of 7 points; the highest point value possible. However, the ability to earn the maximum 7 points was only available on 80% of the trials involving a diamond or star. Further, the maximum amount of points could only be obtained if the participant's reaction time was in the fastest 1/3 of reaction times recorded during the non-reward trials. *Figure 2* shows an example of one trial from the study trials. Response times were recorded and participant's gaze was tracked for each trail.

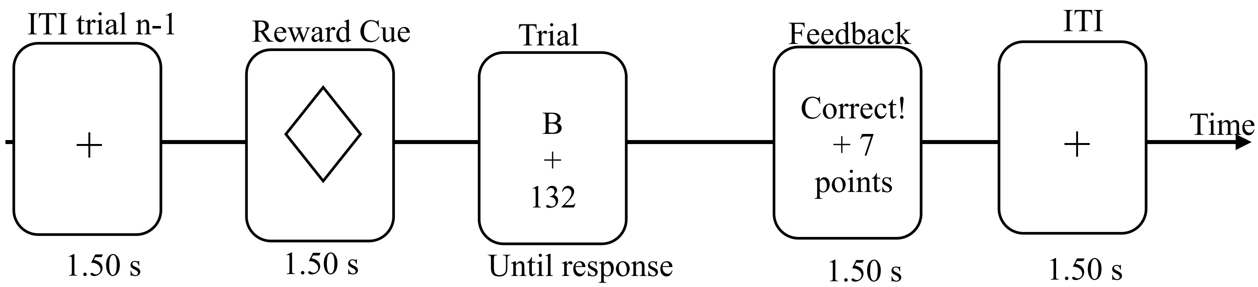

Figure 2. Example of a study trial

SECTION III

RESULTS

Unfortunately, due to the unforeseen events surrounding the COVID-19 the necessary data for the completion of this project was unavailable at the time of its deadline. All of the results presented in this section of the paper are the expected outcomes of this study.

Task Choice

During the experiment, participants would have been instructed to switch between tasks at a rate that allowed them to perform both tasks 50% of the time. If participants complied with these instructions, task choice, as reflected by the average switch rate in participants would have been expected to be near 50%. However, people are often biased to repeat tasks, as switching is difficult and sometimes perceived as averse (Orr et al., 2011; Arrington & Logan, 2004). Fröber et. al., 2020, on which the design of this study is based, found that when reward is increased from one trial to the next, participants are more likely to switch tasks, compared to when reward remained high, decreased, or remained low. We expected to replicate these findings.

Gaze Reaction Time

Eye-tracking would have allowed us to measure gaze reaction time, or the amount of time between when a reward cue is presented and when the participant shifts their gaze to their chosen task for that particular trial. We expected these results to correlate with each participant's scores on the impulsivity questionnaires given at the beginning of the experiment. The higher that a participant scored, the longer their gaze reaction time would have been. We expected to find a positive relationship between gaze reaction time and level of impulsivity. Conversely, participants who scored low on the impulsivity questionnaires were expected to have very low gaze reaction times. Using the eye-tracking data, we would also have been looking for eye movement during the reward cue, for an indication that participants may have mentally chosen a task before the tasks were presented. We would have expected this to occur more often in participants who scored low on impulsivity.

Pupil Dilation

We also expected to find a correlation between pupil dilation and switch rate. Previous studies have shown greater pupil dilation when a reward is given in a novel context. As switch rate increases and rewards are given during the new tasks, pupil dilation was expected to increase, giving a positive correlation between switch rate and pupil dilation.

SECTION IV

CONCLUSION

The aim of this study was to gain further insight in the relationships between impulsivity and decision-making as well as the relationship between reward and pupil dilation by using eye-tracking data. Due to the circumstances of the COVID-19 virus, data collection was interrupted and results were incomplete. This discussion will cover the implications of the possible results that we expected to occur.

Beginning with task choice, participants were asked to switch between the two tasks so that they are switching about 50% of time. According to previous research, an increase in switch rates would have also increased reaction time, while decreasing accuracy. The increase in reaction time supports the idea of task set inertia; an idea further explored in Evans et. al., 2015 using memory tasks. The degree of task set inertia present between participants could also have been correlated with a participant's impulsivity scores. Further research could be conducted to determine if cognitive flexibility, partially reflected by task set inertia, varies between people depending on set personality traits. Additionally, Fröber et. al., 2020 found a link between switch rate and reward. Further studies could expand on the degree of effect between switch rate and reward as it relates to a person's tendency towards impulsivity.

We expected to find a positive correlation between gaze reaction time and impulsivity. This result would have supported our hypothesis of impulsivity being an indicator of bottom-up processing. Impulsivity indicates a lack of pre-planning. This relates to the idea of bottom-up processing in that bottom-up processing indicates a lack of proactive thinking and relies more on a tendency towards reactive thinking. In this study, a longer gaze reaction time would suggest a more reactive approach when choosing a task. If gaze reaction time was longer in participants who scored highly on the impulsivity questionnaires, this would support the notion that the more impulsive individuals tended to lean more towards a reactive approach when completing the study. It was expected of participants with low scores on the impulsivity questionnaires to either have short gaze reaction times, or to preplan which task they wanted to choose for that trial. Preplanning would have been measured by a participant's gaze shifting to either the top or bottom half of the screen, in the direction of the task they chose for that trial during the reward cue. Shifting their gaze before the tasks are presented would indicate that, upon seeing the reward cue and inferring the possible amount of points attainable, participants would "predetermine" the task that they were going to complete for that trial.

In a study done by Sibley et. al., 2011, pupil dilation was linked to learning. In this study, we expected to find an increase in pupil dilation as switch rates increased. The theory posits that pupil dilation increases when rewards are presented in a novel context. As switch rate increases, participants would receive rewards during new tasks. We expected learning to occur subconsciously as participants discovered which reward cues offered the maximum seven points during which tasks. As this learning occurred, pupil dilation would have increased more often, supporting the theory.

Eye-tracking studies have expanded the decision-making literature. New theories and discoveries are being made by studying the human eye, specifically in decision-making. This study aimed at further uncovering the relationship between the personality trait of impulsivity and decision-making techniques. When conditions allow, the true results of this experiment will not only bring new insight into how we make decisions, but they will also bring new truth to the adage, "*the eyes are the windows to the soul*".

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