Universidade Federal do Rio Grande do Sul
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Multiple psychophysiological measures as indexes of uncertainty and risk in decision making

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Doctorate Thesis

Porto Alegre
September 2017

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Thesis presented as a partial requirement to obtain the degree of Doctor in Psychology.
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September, 2017

ACKNOWLEDGEMENTS

It is particularly hard to come up with a detailed list of the people that deserve this space after all these years. If this work is finally finished is only because of a number o people that were instrumental for this achievement. I will try to thank them all, apologizing in advance if I forgot somebody!

Family first! To all my family (mom, dad, my brothers, nephews (Pedro), niece (Isa) and a special mention to my godson, Bruno), and to my godmother, Titida: Thank you for all the support, understanding and the help.

To Keitiline Viacava. You were the one who told me about the whole submission process and helped me (both before and during the doctorate). I'm forever thankful!

To my advisor, Prof. Dr. Gustavo Gauer. For every crazy idea I had came a calm and thoughtful orientation. Could not have been luckier to spend these years learning from you. Hope this work is minimally worthy of having your name on the cover.

To Prof. Dr. William Barbosa Gomes for the welcome and the teachings!

To all the members of the lab (BioSig and LaFeC). Gerson, Guilherme, Alex, Fran, Juliana, Rebeca, Tiagão, Roberta, Tuila, João, Ana, Bruna, Isadora, Luiz, Gabriela (both of them), Roberta, Camila, Marcos, and everyone else who ever was there with us. If this work has some measure of quality it is only because of you. To all the times of hard word (both in the lab and in the pub), thank you.

To Professor Richard Gonzalez who so kindly welcomed me at the University of Michigan for what was one of the truly best experiences of my life. To everyone at the Institute for Social Research and the Biosocialmethods Collaborative. Jeannette Jackson, Alicia Carmichael, Donna Walter, Debbie Bourque, Bob Kaikati, Shannon Mejia, Vineet Raichur, Karen Nielsen, Syed Mahdi. Can't begin to explain the importance you had in this work and in my life. I'm forever thankful for everything!

To all my dear friends that were actually my family during my stay in Ann Arbor. Vivian, Felipe, Fábio, Miro, Déa, Joyce, Eduardo, Ghazi, Paola, Joice, Luciana, Nathalia, Raymond, Matheus, Carolina, Greg, and Addie. To Udae Sandhu, it'll probably take me a lifetime to thank you for everything you have done.

To all the Professors and staff at the Instituto de Psicologia of the Universidade Federal do Rio Grande do Sul. Especially to Jáder and Silvio for the constant and kind help.

To all my long date friends: João Almeida and Bruna Caldas (with special mention to my godson JP and his little sister Alice), Vicente Krolikowski, Eduardo Martins, Dante

To my grandmother Noemia Berthier Guedes (*in memoriam*).

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INTRODUCTION

Decision making is a pervading phenomenon in everyday life, and is broadly defined as choosing one preferred option from a set of possible alternatives (Shafir, 1999). Decisions range from the mundane, such as choosing among brands of shampoo, to sensitive domains as in medical diagnostics and treatment options. Due to characteristics of the human species´ environment and of cognitive processing, decisions involve four key parameters: uncertainty, risk, complexity and satisfaction - or satisficing (Taghavifard, Damghani, & Moghaddam, 2009; Campbell, 1988; Simon, 1955). At any rate, those key elements suffer a direct influence from environmental factors such as importance, time frame and individuality degree (Gomes, 2007). All of them, depending on their magnitude, can add to the depletion of much of an individual´s cognitive capacity, and in so doing hinder the decision process and its outcome.

Herbert Simon (1955) was among the first scholars to call attention to a linkage between economics and psychology, stating that an understanding of decision processes may actually benefit from studying the agent´s behavior. The prevalent idea in the mid 1900´s was that human decision making was nothing more than an agent´s choosing of the alternative that would provide the maximum outcome possible. That characterizes a normative theory, one that states how the decision should occur, with the decision process described by a single utility function. That implies that the agent knows all the information available regarding the problem and precisely computes which among the alternatives will maximize her return. That might be true in a few instances, such as in "small world" problems. However, in most cases, individuals do not possess all information, nor do they act according to unlimited rationality all the time. Uncertainty, the time available, environmental contingencies and limited cognitive capacity often blur the frontiers between what is a real rational choice and a choice based on a subjective account of the world as perceived by the subject (Simon, 1959).

Von Neumann and Morgenstern´s expected utility theory (1953) was closely related to the rational model described by Simon. It states that the probabilities of the alternatives are actually known, that is, the agent knows the probabilities and the outcomes of every alternative, making the choice process less demanding. That should be as easy as factoring the outcomes weighted by the probability of occurrence. The main problem is that for this theory to be valid, the subject must always acquire and process enough information about the problem, about the environment and about how the environment will respond to the decision she is about to make. However, as Simon (1959) and Camerer and Weber (1992) assert, that is not the case for most everyday decisions.

Human beings present but a subjective understanding of the world and that understanding varies, sometimes dramatically, from individual to individual. In order to account for such variability, Savage (1955) introduced the concept of Subjective Expected Utility (SEU). The decision maker must choose between certain acts that depend on the occurrence of a given state and will generate a consequence. For each act and each state, the individual will attribute a subjective probability for the outcome. Choosing then comes down to one act being preferred over the other.

Problems and scenarios often expose various degrees of uncertainty and risk (Volz & Gigerenzer, 2012) which may remain static or can fluctuate up to the point of actual choice. Uncertainty is common in decisions in ecological settings, and arises when critical information about the situation and the possible choices is unknown, incomplete, or ambiguous. Risk is present in most decisions where individuals have at least some information that makes it possible to state the probabilities of each alternative occurring if chosen. The higher the uncertainty and risk levels, the more cognitive capability an individual must invest in the problem. Acquiring information is necessary in order to diminish uncertainty and properly weigh risk.

Uncertainty

Uncertainty can be defined as a lack of either information or cognition (Nobre, Tobias & Walker, 2010), and resolving it is an important trait to successfully engage in adaptive behavior (Bland & Schaefer, 2012). In the first case, the individual or members of a group simply do not have enough information in order to complete the decision process in the preferable way. That may happen due to faulty information acquisition process (Nobre et al., 2010) or if the cost of obtaining the necessary information is too high (Taghavifard, Damghani, & Moghaddam, 2009). On the other hand, lack of cognition means that the individual or members of a group might possess the necessary information but lack the capacity for processing and interpreting such information in a way that permits its proper use in the decision making process.

Levels of information vary within each decision. For a given choice a certain amount of information can be considered optimal for the decision maker to proceed with the analysis (Fifić & Buckmann, 2013; Frey, Hertwig, & Rieskamp, 2014; Söllner, Bröder, Glöckner, & Betsch, 2014). Reaching that level provides the individual with a more detailed account of the problem at hand and can facilitate the choice by having more accurate data in order to calculate the possible scenarios and their outcomes. The right amount of information diminishes the levels of residual uncertainty. Residual uncertainty is composed by the facts

that remain unknown after the consideration of the possible scenarios is accomplished, once the information acquisition and processing is made. Courtney, Kirkland, and Viguerie (1997) proposed four distinct and increasing levels of residual uncertainty. At the first level, residual uncertainty in a given decision scenario is so small that it hardly hinders the decision process; the probabilities can be easily calculated and heuristics and strategy tools can be used to facilitate the process. At a second level, although the future is not easily predictable, a probability of outcome can be calculated. At this level, if the outcome is predictable, the influence on the decision process would be great, the decision makers might be able to calculate the possible outcomes of the key residual uncertainties. At the third level of residual uncertainty, a few potential outcomes are possible and a number of variables might define it, although the outcome is almost unpredictable. Many scenarios must be taken into account and the decision makers must pay attention to the right cues that predict a scenario change. At the fourth level, residual uncertainty is so high that it is practically impossible to calculate the probabilities involved. It is also very difficult to even think of a plausible scenario to consider. The military coup that took place in Egypt in early 2013 is an example of this fourth level. Who will be the next person to govern Egypt? How will he or she trade with other countries? Will he or she rewrite the country´s constitution? Those are questions that are very hard to answer due to the lack of information that could help decrease residual uncertainty. According to Bland and Schaefer (2012), uncertainty might arise when changes in the prevailing Stimulus-Response-Outcome (S-R-O) model is violated. However, that is not the only way, they say, that uncertainty becomes present in a decision making process. It also appears when individuals are confronted with problems in obtaining or processing pieces of information, somewhat similar to the levels of uncertainty discussed above.

Meder, Lec, and Osman (2013) discuss the concept of uncertainty from a different perspective. They propose that uncertainty can reside in the agent itself, in other people (as in a group setting), or in the world –as the environment imposes limits of time and resources. Not only are there different sources of uncertainty, but the levels of uncertainty often changes as time passes. One risky decision might have a possible number of outcomes preserved, but the probabilities may change, or both the outcome and the probabilities can be different. In that context, five distinct decision making settings regarding uncertainty are suggested: i) certainty; ii) risk where the outcome and probabilities are known; iii) a "Black Swan", where there might be an unknown event or events; iv) the Knightian uncertainty, where the outcomes are known but the probabilities are unknown, and v) radical uncertainty, where both outcome and probabilities are unknown.

Risk

Along with uncertainty, risk is a prominent characteristic of many decision situations. In Knight´s (1921) classical definition, risk is a measure of uncertainty where the probabilities of a given outcome are known. Risk is ubiquitous, often serious. It is possible to gain from risks just as much as lose from them and they help decision makers to decide in uncertain scenarios. With risk individuals are prevented from controlling the outcomes, should they not possess adequate information regarding the problem (Taghavifard et al., 2009).

When individuals are making a decision there are certain probabilites that each alternative may return a given consequence that can be translated into a hazard (harm to somebody or something) or an opportunity (Yoe, 2012). A person that drinks alchool and chooses to drive afterwards has a higher probability of crashing than a person that did not consume alchool. That is a case in which a hazard might occur. On the other hand, a person that comits years and several amounts of money on education has a greater probability of higher income than a person that did not, hence an opportunity. To assess risk means attempting to determine the outcome of the alternatives available alongside with the probabilities of the consequences they entail. According to Taghavifard et al. (2009), the determination of probabilities is the process of comunicating uncertainty between the agents. The sources of uncertainty in that case might come from beliefs, environmental conditions, cognitive capacity, emotions, etc.

Taghavifard et al. (2009) propose two opposing poles between which lays risk: ignorance and complete knowledge. Ignorance is equivalent to ambiguity (Camerer and Weber, 1992). A decision scenario where the decision maker has no information or knowledge presents the greater amount of risk given that there is no possibility of actually knowing what might happen. If the decision maker has some knowledge , there is still risk in the situation, but the chance arises to use a probabilistic model (subjective probabilities, bayesian inference, etc.) and calculate the chances of outcomes and consequences. However, if the decision maker has complete knowledge about the scenario and the problem, she can use a deterministic model and decide toward the best alternative with maximum return and no risk. In that case risk is absent because complete knowledge allows the individual to know the consequences of each alternative. In doing so, if there are no consequences or no probability of them happening, there is no risk.

Information acquisition

As Taghavifard et al. (2009) discuss, it is only possible to know the risks inherent in a decision if the individual diminishes the residual uncertainty in the choice (Courtney et al., 1997) through information acquisition. Every day individuals receive a considerable amount of information in many ways, auditory, visual, tactile, and emotional stimuli can all be a source of new information. To acquire information is to search both internally and externally for elements that can affect the decision process. Each piece of information has great importance to the decision maker, either by improving the quality of the decision or by impairing the ability to decide given that the amount of information is so great that her performance will be deteriorated (Di Caprio, Santos-Arteaga, & Tavana, 2014). When information reveals itself and is processed by the decision maker, it is possible to move from a situation of uncertainty to a situation of risk, that is, the decision maker now knows enough information about the problem that she can at least subjectively infer a probability for each outcome (Di Caprio et al., 2014).

Pretz, Naples, and Sternberg (2003) discuss the role of experts and the fact that too much information can actually impair the decision process. An expert possesses a great deal of knowledge, acquired by experience and information gathering. The authors propose that when an expert in chess plays with slightly different rules her performance will actually be worse than that of a player that is new to chess and plays the same modified game as the expert. Too much information can become suboptimal for the decision maker (Di Caprio et al., 2014) and not enough information will prevent the decision maker from calculating risks properly and brings the decision process to one of most uncertainty (Taghavifard et al., 2009). On the other hand, Frey et al. (2014) propose that there is no way to determine when the right amount of information is reached and no further acquisition needs to be done, at least in decisions from experience, although they also say that there may be benefits in small samples and frugal search. The question that remains is, how does a decision maker knows that he/she acquired enough information to go through with the process?

Many researchers are investigating the subject of information acquisition and when individuals stop searching for information and proceed to decide. Gigerenzer (2000) proposes a model of "fast and frugal" processes used to decide in decision environments where both time and knowledge are restricted. By searching past information and knowledge in order to recognize elements regarding the decision and cues about those elements, the Take the Best (TTB) heuristic searches for the best cue in order to make a choice. In the experiments depicted by Gigerenzer (2000) when people where asked which of two German cities was the most populated, it is most likely that an individual will use TTB if she decides only by

recognizing one of the cities. Even so, the individual might seek cues about each city from memory. According to the subjective validity of the cue, the one with the highest ranking is considered the best and thus appropriate for a decision. Very little information search and acquisition is made. Stern, Gonzalez, Welsh, and Taylor (2010) conducted and experiment in which individuals were presented with two decks with varying proportions of red and blue cards. Four draws of cards were made and at each draw the individual would have to state from which deck the card had been drawn from. Each draw represented new information about the decision. After all four draws participants would have to make a final decision as to which deck supplied the cards for the draws or they could decline to choose. It is clear that each new information presented changed or reaffirmed the decision made by the individual. When conflicting information was presented (two draws were red cards and two were blue) individuals mostly declined to choose, inferring a 50% chance to each deck. When all draws were the same color, by the third draw individuals were already confident from which deck the draws were made.

Fifić and Buckmann (2013) have probed the use of stopping rules by individuals. Stopping rules might determine the moment where the decision maker stops, or should stop, searching for information and actually decide. The authors reviewed some options of stopping rules that might require higher or lower cognitive demands. The first one is the so-called optimal stopping rule for evidence accumulation. It is based on Bayesian inference and implies that there should be an optimal number of pieces of information that need to be acquired. In their example the optimal stopping rule is three. This number represents that the individual will search for positive (+1) and negative (-1) pieces of information and will only stop searching when the sum of the search reaches either +3 or -3, in which case the individual will choose the option represented by the positive or negative sum, in their example to proceed or not with a risky cancer treatment. There is great criticism regarding this rule. In order to calculate the optimal number there is a need to have a perfect knowledge of the situation and enough calculating skills to solve it through Bayesian probability (Fifić & Buckmann). This option requires great amounts of time, knowledge and cognitive abilities. In most cases in the real world there are limited amount of each available to the decision maker. They then propose a stopping rule selection theory based on bounded rationality.

They suggest two rules that do not depend on high amounts of knowledge about the environment and the situation. The first one is the fixed sample size. This rule entails that the decision maker will determine a sample size before the beginning of the information search process, for example five. The individual will then search for information and will make her choice based on the valence that appears the most (positive or negative). The other rule is

called runs stopping rule. In this case the decision maker will begin the search for information without determining a fixed sample. She will stop searching when a streak of either positive or negative pieces of information is found, three consecutive positive opinions for example.

The stopping rule selection theory proposes that each individual might use different stopping rules given time and cognitive efforts available (Fifić & Buckmann, 2013). That is because there is no evidence that one single stopping rule can account for all responses from individuals. According to Fifić and Buckmann (2013) each individual will search a decision operative space in which the rules and values are stored. Given a decision situation the individual will then retrieve a stopping rule – a process that the authors call cast-net retrieval. Much like fishing, each individual will select a space and a net size to cast and retrieve a stopping rule that will be applied. What is considered in order to cast a net in the decision operative space is the level of uncertainty in the environment, time frame, cognitive demand, and accuracy expectancy (Fifić & Buckmann, 2013). After the stopping rule is selected, the individual will then proceed to collect information and finally decide.

Other elements also influence the information acquisition process. Frey et al. (2014) found that a facial expression of fear or the subjective feeling of fear both causes the individual to search for more information. Söllner et al. (2014) discovered that when intruding incompatible information appears, individuals trained in the TTB heuristic would not stop searching for information when they were supposed to if following TTB. Individuals rather adapted their information search, choice and confidence judgment processes to the content of such intruding information. It is widely recognized that the amount of information available and acquired by each individual will augment complexity levels in the decision situation, much like what happened with the intruding information.

Complexity

Uncertainty, according to Nobre et al. (2010), is intimately connected with complexity. As was already discussed, uncertainty is closely related to the amount of information acquired and processed by a given individual and her understanding of the situation at hand. With more information about a situation it is easier for an individual to calculate probabilities (either objective or subjective) and assess risk levels (Taghavifard et al., 2009). However, the more complex the environment or the task presents itself, the more difficult it is to collect information and reduce residual uncertainty.

Brum (2011) states that complex systems are affected by the emergence of phenomena resultant of nonlinear interrelationships that may throw the system out of its natural balance requiring that this disorder created must fall back into order by self organization. The decision

making process may share such description. After all, one needs to make a decision in order to reorganize some part of a greater system (that can be the individual itself or a group, say a family unit) that was shaken out of a state of balance by the emergency of a circumstance, fact or phenomena. In simpler words, one needs to eat if she feels hungry. The greater system that is the body needs nourishment. Food intake must be provided. At this point the system is in disorder, out of homeostasis. Self organization occurs when that individual eats something. The decision in this case is as simple as choosing what to eat.

A human being is an open system that also participates in other equally open systems. There is a perpetual exchange of information, matter and energy (Brum, 2011) between the outside world and the inside part of any system. The higher the level of exchanges, the more complex the system is. However, there have been few attempts to study the effects of complexity systematically (Brehmer, 1992).

Nobre et al. (2010) state that systems may vary in structure and interactions. They may be extremely simple and stable, or complex and dynamic. At the core of the interactions between the parts of a system are its abilities, defined by Nobre et al. (2010) as cognition, learning and knowledge capabilities. The greater the complexity of the environment, more information and cognitive abilities must the individual have in order to make an adaptive decision.

Campbell (1988) conceives of complexity in three ways. The first regards complexity as a psychological experience. The main point in this view is that the reactions of the individual to the task outweigh the characteristics: increases in task complexity may tax cognitive resources and lead individuals to employ strategies that minimize the amount of information considered. Experience with the decision context may minimize the impact of complexity, however, with knowledge and strong preferences leading to a more focused, information-minimizing search (Queen, Hess, Ennis, Dowd, & Grühn, 2013). Individuals cope with complexity within the decision process by simplifying the dimensions existent in the problem (Mintz, Geva, Redd, & Carnes, 1997). They essentially withdraw certain dimensions in order to diminish the amount of information and calculations required to consider the alternatives and outcomes.

A second aspect of complexity is the opposite of the first, with complexity as an interaction between the person and her abilities in relation to the task demands. As stated by Simon (1959), "As the complexity of the environment increases, or its speed of change, we need to know more and more about the mechanisms and processes that economic man uses to relate himself to that environment and achieve his goals" (p. 279). The way the task presents itself to the individual and also the way she perceives the task are very important to determine

the decision making conditions. Problem representation (Pretz et al., 2003) and the framing effect (Kahneman, 2011) are examples. If a task presents itself in an ill structured manner or the decision maker does not have sufficient ability to understand the facts pertaining to a problem, the level of perceived complexity will be higher.

From a third and final perspective, complexity is an objective task characteristic (Campbell, 1988). In this view, complexity is related to and influenced by a myriad of task characteristics. How a task is set up ranging from information load, number and magnitude of stimulations, existence of subtasks and conflicting or non-conflicting paths and possible outcomes, among other qualities, may cause variations in complexity levels. All of those can require high cognitive demands from an individual. The most important fact in this perspective is that the task can present itself in many ways and the configuration of the task will increase complexity levels (Campbell, 1988). There is no way to gauge which of the task characteristics will determine a rise and/or decrease in complexity. Each particular task may present itself with a combination of any characteristics. For example, a task can have a great amount of information and multiple paths for the decision maker to choose from. That alone can set up a highly complex environment. However if the outcomes for each alternative are easily distinguishable and the decision maker has a very clear set of preferences than there should not be a significant amount of complexity, given that the information load and the multiple paths will not matter, the preferred outcome will be easily chosen.

Campbell (1988) also proposes an integrative framework for complexity. It would arise in the presence of various paths to reach the desired state, the presence of multiple outcomes, the presence of conflicting interdependence within the paths and the presence of uncertain links among paths and outcomes. All of these require acquisition and analysis of information. The information load, diversity and rate in which it changes are closely related to the task attributes and very influential on perceived task complexity (Campbell, 1988; Di Caprio et al., 2014). The term *perceived* is used because acquirement and analysis of information depend on cognitive performance by the decision maker, so a given individual might perceive a task as very complex whereas another individual might perceive it with a low complexity level. In essence, complexity depend both on subjective and objective criteria regarding characteristics pertaining to the task and the individual and its relation to the task. The decision making process can suffer from the intricate complexity amongst the alternatives while considering each path that can be chosen and the consequences of that action (Taghavifard et al., 2009). This integrative view of complexity is the one that will be adopted by this thesis.

Decisions in dynamic scenarios

The elements and characteristics of decision making discussed so far (uncertainty, risk, information acquisition and complexity) are prevalent in the decision process. In a given situation there might be varying levels of uncertainty, information load imposed, satisficing threshold, risk levels, etc. Real world situations are constantly changing and those changes might significantly alter the characteristics of the situation. In other words, they are mostly dynamic, rather than static. Decision makers must know when they are facing dynamic environments in order to adjust decision strategies and processes.

Dynamic decisions occur because of certain environmental elements that must be considered, such as importance, time frame and degree of individuality (Gomes, 2007). Dynamic changes in decision scenarios can produce changes in perceived expectations of rewards and non rewards (Mushtaq, Stoet, Bland & Schaefer, 2013). The objective characteristics of the task in complex systems also may turn a static decision scenario into a dynamic one. Given the information load, number of alternatives and the rate of change of information a decision can become more intricate. Lastly, each individual´s preference will have a role to play. Simon (1955) stated that each individual possesses a set of preferences and that her decisions will be affected by them. An important concept arises, that of satisficing. Each decision is made with a specific goal in mind, be that an objective or subjective one. An individual will come to a decision when a certain threshold is reached. Such threshold has a different value (emotional, financial, etc.) for each person.

We may consider a decision such as buying shampoo. One person may not care that much about brand, specific type of hair that the shampoo attends to, perfume, or other additional characteristics it may have. In that case, the choice is fairly easy, it might either be a purchase following an advice or a price based one. That is a situation with low risk of hazard, but also low opportunity. There is no need to calculate probabilities of outcomes since they will not end in drastically different outcomes. Although high in uncertainty about different characteristics, the information the person has is enough in order to make a decision. Satisfaction should be attained easily since this decision is of no greater importance and pertains only to this individual.

In order to evaluate how dynamics may play a role even in simple decisions, let us regard a consumer behavior scenario. A different person needs shampoo. She needs a specific type of shampoo given her hair type. Moreover, this person needs the shampoo to have certain vitamins and it must have a nice perfume. Any brand cannot suffice, it must be one that is renowned, however it must be within a reasonable price. When asking some friends, all kinds of advices were given, some were positive about some brands, some were negative about other

brands. After all advices she got down to a list of mainly four potential brands. This scenario portraits a more dynamic environment; uncertainty is higher, risk of hazard (both physical and emotional) is higher, complexity given the information load and dimensional features is also higher and finally the satisfaction threshold is fluctuating (this person might settle for a more expensive brand given the benefits and vice-versa). Importance here is great, as this person values her hair very much. Even with all the information, the individual summed up a list of four brands. That means multiple paths and multiple outcomes are available. The advices she received were not enough to allow her a single path choice. In this case, the individual is susceptible to new, conflicting or not, information. A single advertisement or a new advice from a friend or professional can affect the whole process. The possible brands the individual might consider as a viable option can either increase or decrease.

Dynamic decisions occur in environments where the states of affairs change both autonomously and due to the agent´s actions and decisions (Brehmer, 1992). That interaction and the results that come from it changes criteria linked to the decision and the environment. Some strategies proposed by game theory and applied to everyday decision making can serve as an example. The case of brinkmanship, or pushing dangerous events to the limit of disaster is discussed by Dixit and Nalebuff (2008). In this situation, agents use brinksmanship in order to force the other party to accept their terms. In most cases, the strategy is only used as a last resort. When this strategy is used uncertainty and risk change dramatically.

An example of such changes goes as follows: two countries are negotiating the end of a trade embargo. Peaceful negotiations are happening and at this stage there are several scenarios that can be played and levels of deals that can be reached. So far, risk and uncertainty remain at an economic level. Now suppose one of the nations gets tired of negotiations and starts using brinksmanship to try and seal the deal on its own terms. Should the opposing nation decline the terms, there will be a nuclear strike on its cities. Now, what was once an economic discussion is also a matter of homeland security. Also, where there had been hundreds of possible combinations of a deal, now there are only a few: the opposing nation accepts the deal and there is no nuclear war; the opposing nation may call on the threat and either receives a nuclear strike or see that the threat was actually a bluff, in which case the scenario will dramatically turn once again. From a single unilateral decision, there has been a large change in the environment, time necessity, uncertainty and risk within the whole decision.

Bland and Schaefer (2012), in the discussion about the S-R-O models, further explain the actions of a dynamic decision scenario. They propose a scenario where people would choose a particular restaurant because the know that roughly about 8 out of 10 times they go

there their favorte dish will be available. That will remain true and steady, given that the scenario show no signs of possible changes. However, Bland and Schaefer (2012) propose, imagine that the chef is not the same anymore. Thus what was once a 80% chance of having the favorite dish served is now different (and uncertain) because there is little information about the new chef. A dynamic change altered most of the decision making settings for this particular type of problem. This changes may elicit an expectation of decrease in rewards (Mushtaq et al., 2013) which may change the whole decision process.

Strategies in decision making

Decisions involve a choice amongst several alternatives. Before the choice is actually made individuals must choose the criteria on which to rely in order to pick an alternative. The larger the set of alternatives and the criteria available, the more complicated and cognitively demanding is the process of choosing. In order to try and solve problems or to reach a decision, individuals resort to strategies based on methods that they may not even be aware of. Some of these behaviors and strategies violate the assumptions made by normative decision theories. Amongst such strategies are those discussed by game theory, heuristics and multi-attribute decision making.

Dixit and Nalebuff (2008) explain several strategies used in game theory, from the most basic ones like in the prisoner dilemma to more complex ones such as creating a political strategy for an election campaign. The aforementioned brinkmanship strategy is one of the strategies explained by game theory. Mainly used in negotiation of all sorts, it involves information acquisition and an alleged knowledge of the opponent´s action and reaction to a given decision or environmental setting. Game theory proposes very objective views regarding a scenario analysis. There are very helpful tools that can be used: decision trees, payoff matrixes and backward reasoning. A decision tree is simply a graphical way to represent a problem and the paths available. It can represent the actions both individually or of every individual in the game. Dixit and Nalebuff (2008, p. 37) exemplify a decision tree using a classical situation in the Charlie Brown cartoons. Lucy normally deceives Charlie Brown by asking him to come and kick a football while she holds it to the ground. When Charlie Brown is about to kick the ball, Lucy takes the ball away and Charlie Brown ends up kicking nothing but air and falls on the ground. When Lucy calls Charlie Brown to kick the ball he can represent his action by a decision tree as depicted by Figure 1.

```
                                            Put ball away
                                    Lucy
                    Accept
          Charlie
                    Reject              Let Charlie kick
```
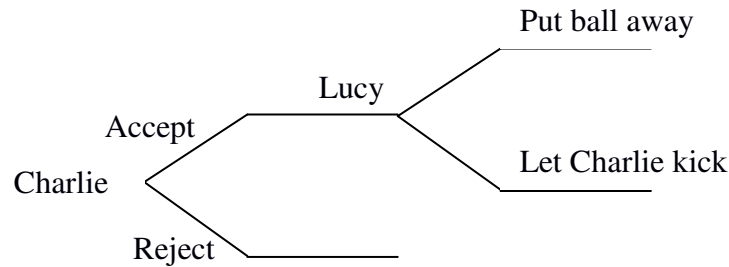
Figure 1. Decision tree example

In this situation, Charlie Brown can either accept or reject the invitation that Lucy made. If he rejects it he will not kick the ball but there is no chance that Lucy will deceive him and he winds up with his back on the ground. On the other hand if he accepts the invitation, the next action is now Lucy´s responsibility. She can either hold the ball and let Charlie Brown kick it or she can take the ball away and watch Charlie Brown fall. The decision maker can look at this decision tree and calculate probabilities of the paths and outcomes.

The payoffs of every outcome can be depicted in the tree but only to the subject of the decision, in the above case, Charlie Brown. However it is common to represent the payoffs of both agents participating in the game. In order to do so all the payoffs are depicted in a payoff matrix. Taking the Charlie Brown example one possible way to construct a payoff matrix is, as per Figure 2:

		Lucy	
		Let kick	Put ball away
Charlie Brown	Accept	-1 2	2 -1
	Reject	0 0	0 0

Figure 2. Payoff Matrix example

If Charlie Brown accepts Lucy´s invitation and Lucy actually lets him kick the ball, Charlie Brown will be very happy and gets a payoff of two. Lucy, although allowing her friend to be happy, will be sad because the main purpose of the invitation was to deceive Charlie Brown. She gets a payoff of minus one. On the other hand, if Charlie Brown accepts the invitation and Lucy takes the ball away making him fall, he will be very sad to have been

deceived and gets a payoff of minus one. Lucy will be very happy to have had deceived Charlie Brown yet another time and gets a payoff of two. Finally, if Charlie Brown decides to reject Lucy´s invitation there will be no gain or loss for either, they will both get a payoff of zero. The payoff values depicted here are a mere example.

With the decision tree, for visualizing the paths and outcomes, and the payoff matrix, for weighting the payoffs for each outcome, the decision maker can now resort to backward reasoning to help in the decision making process. Charlie Brown will see that if he accepts Lucy´s invitation he might actually kick the ball or he can fall to the ground. He will want to kick the ball, after all that action represents the greater payoff for him. Analyzing the payoff matrix Charlie Brown should know that the most probable outcome, if he accepts Lucy´s invitation, is that he will fall. That is the case because Lucy as a rational agent will know that if Charlie accepts she will have a greater payoff by taking the ball away. There is no chance that she will let him kick. This strategy for Lucy dominates all others. In this situation, Charlie Brown must reject Lucy´s invitation. Although that represents a lower payoff compared to what he could get (zero against two), he knows for a fact that if he accepts he will get the worst payoff (minus one). Alas, backwards reasoning allows the decision maker to analyze the situation, the paths available, and the payoffs given every decision and make a more rational choice. It is important to note that both the decision tree and the payoff matrix examples given above are very simple. However they can depict multiple players and paths along a decision situation.

Game theory rests on a mathematical foundation. In the prisoner dilemma, for instance, it is mathematically proven that it is in the best interest of both players not to confess to the crime (that way both will suffer the smaller conviction time). In another application, it is often thought that penalty kicks in soccer are something of a "lottery", meaning one can never say precisely if it will be converted in a goal or not. However, it is possible to calculate a more probable manner to both kick and defend a penalty kick. But still there are psychological and emotional elements to every decision process. Even though a given individual can calculate payoffs and path probabilities he can act on emotional cues. Charlie Brown can give Lucy the benefit of the doubt, being that they are friends, and actually try to kick the ball against all odds of falling.

Even though many strategies can be followed in a decision process, many times people fall prey of cognitive shortcuts or heuristics. Heuristics are a well known subject of study in the judgment and decision making field. Most famously studied by Amos Tversky and Daniel Kahneman it is one of the most important topic related to decision making. Heuristics are a sort of shortcut to reach a decision, many times violating the assumptions of classical

economics and game theory. They are based on certain criteria and sensible to how the problem is presented to the decision maker. Representativeness, availability, adjustment and anchoring (Tversky & Kahneman, 1974) are the main heuristics individuals may use. Each one of these heuristics may lead to cognitive biases that might hinder the decision itself. Since this is a well known subject there is no need to discuss it at length in this thesis. If more information is needed please see Tversky and Kahneman (1974), Brighton and Gigerenzer (2012), Gigerenzer (2000), Hogarth (1991), Kahneman (2011), Pachur, Todd, Gigerenzer, Schooler, and Goldstein (2011) and many others for a more detailed view.

Zanakis, Solomon, Wishart, and Dublish (1998) discuss several methods for multi-attribute decision making. In everyday life we can base our choices on single or multi-attributes. Choosing a product only for its brand is an example of single attribute based choice. However, choosing a product based on brand, price, benefits, and design is an example of multi-attribute decision. There is one important issue with multi-attribute decision making. Most of the times different attributes are conflictive. A particular brand might be cheap but also has a lower life span and an unattractive design. Zanakis et al. (1998) compared five methods when solving the same problem. The methods utilized were simple additive weighting, multiplicative exponent weighting, analytic hierarchy process, elimination and choice expressing reality, and technique for order of preference by similarity to ideal solution. They found that as the number of criteria, alternatives and the distributions grow, all methods tend to arrive at a similar result.

Mintz et al. (1997) discuss two main strategies, one alternative-based, more complex and demanding involving compensatory tradeoffs; and one dimension-based, less complex and demanding involving non-compensatory tradeoffs. Information has a pivotal role in the strategy selection regarding the static or dynamic environment where the problem is set upon. The authors developed a platform that can be used to trace the process of analyzing the strategy choice. For each problem there is a matrix composed of the alternatives and decision dimensions. By conducting an experiment they found that decision makers consider different strategies to arrive at a decision. They first start with cognitive heuristics to diminish the number of possible alternatives in a dimension basis and then conduct an alternative based decision.

Psychophysiology

There is a growing interest in psychophysiology and decision making in academia. It is due to the advancement of technology and the popularization of equipments that more and more people are using techniques and hardware to measure psychophysiological data.

Cacioppo, Tassinary and Bernston (2007) discuss largely the benefits and challenges associated with measuring and understanding psychophysiological data within an experimental design. As Cacioppo, Tassinary and Bernston (2007, p.3) states, the effort to understand psychophysiological measures can be achieved by: "An understanding of the physiological system(s) under study and the bioelectrical principles underlying the perceptual and output responses being measured contribute to the plausible hypotheses, appropriate operationalizations, laboratory safety, discrimination of signal from artifact, acquisition and analysis of the physiological events, legitimate inferences based on the data, and theoretical advancement."

In a sense, psychophysiology can be described as the observation and correlation of psychological and behavioral phenomena with physiological events that happen in the body (Cacioppo, Tassinary & Bernston, 2007). Although reduced, this definition can encompass the possibilities provided by the field. Solnais, Adreu-Perez, Sánchez-Fernández and Andréu-Abela (2013), when discussing the benefits of neuroscience to consumer research, propose a framework where there can be beneficial measures of nervous system activity. They separate consumer behavior in four parts: i) decision making, ii) rewards; iii) memory, and iv) emotions. Although separate, these parts are largely composites of the decision making process, as it was discussed above. Understanding not only the behaviors associated with these parts, but also the physiological and sometimes automatic responses of the body are of great importance to the study of decision making. That is justified by the fact that not all effects of different manipulations in decision scenarios can be explicitly informed by participants in form of a particular behavior or self-report.

There are several ways that those four parts (and most other decision making features for that matter) can be measured by psychophysiology. Mostly, it is relied on different equipments that can be used one at a time or even integrated, gaining more information to explain the phenomena. Cacioppo, Tassinary and Bernston (2007), Holmqvist, Nyström, Andersson, Dewhurst, Jaordzka and van de Weijer (2011), Luck (2014), Engelke, Darcy, Mulliken, Bosse, Martini, Arndt, Antons, Chan, Ramzan, and Brunnström (2017), amongst others, provide an extensive and very thorough discussion about the main equipments and techniques available. The focus is on both the central nervous system and the autonomic nervous system, thus providing the possibility of broad analysis of physiological events. The main possibilities associated with psychophysiology research are discussed below.

Central Nervous System (CNS) analysis is made mainly with neuroimaging and neuroscientific techniques. They are:

- Electroencephalography (EEG): Technique that measures changes in voltage on the scalp given experimental manipulations resulting in changes in cognitive states. Usually this technique is applied with the use of a cap containing several electrodes (currently there are devices ranging from 8 to 256 electrodes). These electrodes come into contact with the individuals' scalp and measure the voltage of the cortical neuronal clusters that are in the vicinity of the electrode. Voltage changes can be measured through specific events of the experiment, previously programmed, whose main technique of analysis is called Event Related Potentials (ERP) and power spectrum analysis. This is one of the most used techniques among decision making studies. Larger details about these techniques can be found in detail in Luck (2014).

- Functional Magnetic Resonance Imaging (fMRI): It measures what is called a Blood Oxygen Level Dependent (BOLD) method, which generally is the amount of oxygenated blood in brain regions. It is a fairly expensive and time demanding technique. However, it has great spatial resolution and can assess changes in even the innermost areas of the brain (which cannot be assessed by other brain imaging techniques). fMRI estimates hemodynamic changes to the stimuli proposed.

- Functional near-infrared Spectroscopy (fNIRS): This technique measures the hemodynamic changes that can result in inferences about a state or behavior. It follows the same principle of the fMRI when measuring the concentration of oxyhemoglobin (oxygen rich hemoglobin) in brain regions. The difference between fNIRS and fMRI is that fNIRS uses reflexes produced by light beams in the near infrared spectrum that detect the concentration (or lack of) oxygen in hemoglobin. fNIRS is considered a less invasive technique than fMRI. Also, fNIRS has a poor spatial resolution but a very accurate temporal resolution.

- Other techniques: There are many other techniques that can be used to measure central nervous system and brain functioning. Positron Emition Tomography (PET), single positron emission computerized tomography (SPECT), Magnetoencephalography (MEG), Transcranial Magnetic Stimulation (TMS), and lesion studies, are examples. However, most of them (except for MEG) are invasive and thus not of interest to decision making study in the general population. They are, however, of great

importance to clinical and pathological assessments, which goes beyond the scope of this thesis.

Autonomic Nervous System (ANS) analysis is composed of different equipments that focus on different systems. Those measures are the loci of most of the difficulty in researching and correlating the physiological measures to psychological events. The main difficulty is in properly eliciting ANS arousal within experimental contexts.

- Electrocardiography (ECG): Measurement of the voltage changes caused by the electrical activity of the cardiac fibers during the moments of systole and diastole. These variations form the heartbeat cycle promote as a result a complex of waves that may be related to changes in emotional arousal and task engagement. This technique is widely used in clinical settings, but its use in psychophysiological experiments tends to utilize, for the most part, measurements such as heart rate and heart rate variability. Both measures have in common the measurement of the distance between the R wave peak intervals.

- Electrodermal Activity (EDA) or Galvanic Skin Response (GSR): Measures the electrical resistance in the skin, highly regulated by the sweat secreted by the sweat glands. Changes in electrodermal activity are usually associated with activation of the Autonomic Nervous System in the process of emotional arousal and engagement.

- Electromyography (EMG): Measures the electrical changes in the muscles. It is mainly used to assess voluntary or involuntary contraction and relaxation of muscles in different experimental settings. It is also used as a tool to aid EEG experiments with the measurement of blinks and eye movements, which are largely related to EEG artifacts and are thus used to adjust the EEG signal.

- Eyetracker: It is the measurement of eye movements and contractions and retraction of the pupil. Using infrared sensors and a camera, it is possible to check the corneal reflex and assess where each individual is fixating their eyes or if there were changes in pupil diameter in response to a stimulus. These measures are commonly related to attentional, emotional, and engagement processes.

As it can be seen from the list above, each equipment focuses on a different system and can provide only so much data about it. For example, an ECG cannot tell us anything about cognitive processing or which part of the computer screen an individual is focusing in a particular moment. This task is best resolved by an EEG and an Eyetracker, respectively. Still, psychophysiology provides somewhat of a fast track to understanding some of the innermost phenomena in the human body and their correlates to human behavior. It is, as Cacioppo, Tassinary and Bernston (2007) states, a scientific field that is still in its infancy. It spanned from human and animal anatomy research, being highly influenced by Philosophy and Psychology after, and nowadays greatly beneficiated from the current technological leaps.

The main challenge in advancing psychophysiological research, according to Cacioppo, Tassinary and Bernston (2000, p. 12) is to successfully relate the psychological and physiological domains in the following elements:

1. A one-to-one relation, such that an element in the psychological set is associated with one and only one element in the physiological set and vice versa;
2. A one-to-many relation, meaning that an element in the psychological domain is associated with a subset of elements in the physiological domain;
3. A many-to-one relation, meaning that two or more psychological elements are associated with the same physiological element;
4. A many-to-many relation, meaning that two or more psychological elements are associated with the same (or overlapping) subset of elements in the physiological domain;
5. A null relation, meaning there is no association between an element in the psychological domain and that in the physiological domain.

Cacioppo, Tassinary and Bernston (2007) go on to state that only the first and the third possibilities are the ones that can successfully specify the relation between psychological and physiological elements, as proposed by current experimental design.

It was not the purpose of this section to exhaust all possibilities and to thoroughly discuss and present each psychophysiological measure. This endeavor is highly recommended and should be done by consulting the literature cited above and many other studies and technical notes available. The aim of this list is to introduce the most used psychophysiological equipments.

Decision making processes: integrating the concepts

Deciding involves weighing the potential outcomes, their consequences and the probability embedded in any course of action (Taghavifard et al., 2009). In order to do so, an individual must be able to acquire and process several information that may come in several types and amounts. The information obtained during the decision process allows for the decision maker to assume or calculate with more accuracy the alternatives, outcomes and mainly the probabilities of them happening (Taghavifard et al., 2009). However, there is no need to choose one single alternative. Given the right amount of information and calculation one can, obeying his preferences, assemble a mix of alternative choices.

If one is to decide under utter uncertainty, it is likely that risk, criteria and alternative assessment will be mainly based on the individual´s attitude towards the unknown (Taghavifard et al., 2009). Tversky and Kahneman (1992), Leboeuf and Shafir (2003), Ariely (2008), amongst others provide some examples of behavior made with some degrees of uncertainty (sometimes the individual is not aware that she does not have any information whatsoever about the problem).

Taghavifard et al. (2009, p.6) state that in a risky scenario individuals make mistakes mainly because of "false assumptions, not having an accurate estimation of the probabilities, relying on expectations, difficulties in measuring the utility function and forecast errors". Those aspects are closely related and an actual effect of fluctuating levels of uncertainty, information acquisition, cognitive processing and behavior. As far as complexity goes, the integrative framework proposed by Campbell (1988) covers some important points, mainly because of its relationship with the task as presented to the individual. This framework proposes multiple paths and outcomes and also considers the conflicts that may emerge from these paths. The information load, information diversity and the rate of information change are thus vital characteristics to the decision process. Combining these characteristics results in higher cognitive demands in order to analyze the paths and calculate possible outcomes, its probabilities and risks associated.

Given what was seen so far it is possible to assume that the decision process is influenced by several factors that vary in intensity. All factors may or may not be in play at the same time (Campbell, 1988; Di Caprio et al., 2014; Dixit & Nalebuff, 2008; Gomes, 2007; Kahneman, 2011; Simon, 1959; Taghavifard et al., 2009). Table 1 depicts the factors and how they can vary and or be affected. It is important to note that the factor may repeat themselves given the different characteristics of the environment.

A first aspect to be considered relates to environmental elements. They will shift the environment from static to dynamic. The higher the intensity of the elements, the more

dynamic the environment presented to the decision maker. If a scenario is dynamic it poses a more pressing challenge on the decision maker in order to successfully respond to the elements. Brehmer (1992) states that the study of dynamic decision making needs to attain more attention in psychological research although it is somewhat difficult to fit dynamic situations in normative standards and experimental methods might lack the proper power to do so. Moreover, environmental elements, such as time constraints, influence the way the decision maker acquires information (Di Caprio et al., 2014). Without information the decision maker will have his capacity to infer probabilities regarding the decision at hand severely hindered.

Organizational settings present relevant examples of highly dynamic decision problems (Gomes, 2007). Consider a group that is responsible for drafting the budget for the next fiscal year in a company. The individuality degree is very low, the decision is made in a group setting and affects a large number of people. It is of great importance because it represents the immediate future of the company. It has a tight time frame, it is normally done with no more than a couple of months deadline. The information load is almost astronomical, data needs to be considered from each and every part of the company. From Human Resources to macroeconomic indexes, every bit of information needs to be considered. And information may change rapidly. New laws, economic policies, bad performance, employee strike, are among a very wide range of possible changes that can occur. Given the amount of information load and the rapid rate of change of information there are literally millions of possible alternatives combinations that can be reached (Campbell, 1988). Finally, the satisfaction threshold is very hard to reach. Every stakeholder has a specific satisficing threshold. The scenario depicted is highly dynamic and is one that happens at least every year for most of the organizations around the world.

This scenario necessarily entails that the group will probably never acquire enough knowledge in order to diminish residual uncertainty to a minimum and make a decision with risk probability properly calculated and weighted amongst the alternatives. In order for this group to reach a decision they will be forced to acquire a great amount of information from data of the year's performance and of economic indexes. After the information is acquired they will have to process that information and also calculate what they mean in order to forecast scenarios and provide possible alternatives for the company´s future. That requires great cognitive abilities. Since high residual uncertainty is the most likely depiction of uncertainty, the group will base its choice on subjective probabilities highly influenced by each member preferences and past knowledge. But in order to reach a decision all risks must be calculated, since a bad year for a company can reflect great hazards in all dimensions and a good year

may present great opportunities for everyone. Alas, in this scenario risks are very hard to calculate and predict. In order to solve such a problem the group will certainly use different strategies.

Table 1. Factors that influence the decision process

Key elements	Static Environment	Dynamic Environment
Importance, time frame, information load, number of alternatives, rate of change of information and satisficing threshold	Enough knowledge should be attained easily	Enough knowledge should be hard to attain
Information load, number of alternatives, rate of information change and satisficing threshold	Low residual uncertainty	High residual uncertainty
Importance, individuality degree, information load, number of alternatives, rate of information change and satisficing threshold	Proximal to a deterministic model (risk can be calculated objectively)	Proximal to a pure uncertainty model (risk will be calculated subjectively)
Importance, time frame, individuality degree, information load, number of alternatives, rate of change of information and satisficing threshold	Less cognitive capacity required	More cognitive capacity required
Importance, time frame, individuality degree, information load, number of alternatives, and rate of change of information	Little information acquisition needed	Great information acquisition required
Information load, number of alternatives, and rate of information change	Expected utility axiom	Subjective expected utility axiom
Importance, time frame, information load, number of alternatives, and rate of information change	Single decision strategy	Poliheuristic decision strategy

The opposite can also be true. A decision can be as simple as choosing what to eat for breakfast on a Sunday morning. There is no pressing importance, each person can take as much time as they want, the set of preferences regarding food is quite explicit and firm therefore satisficing threshold should be fairly easy to obtain. There is also no need for much information and there is little probability of it changing. This static environment produces very low residual uncertainty (Pretz, Naples & Sternberg, 2003) given that each person knows what they like to eat for breakfast, there will be little risk of hazard nor does it present a huge opportunity. There is little need for large consumption of cognitive processing resources. The decision maker should simply follow a simple maximization strategy: will I have toasts and coffee or pancakes and milk?

So far it is possible to visualize that the decision process is made up of inextricably intricate elements and parameters of characteristics. The elements can vary both independently and in a joint fashion. Decisions are made with very simple or very complex goals in mind.

Uncertainty and risk levels arise given the environmental settings and how each individual or group of individuals will perceive and relate with that environment. The more complex an environment is clearly more cognitive effort needs to be set forth. However, not only the environment plays a pivotal role in the process, but also there is the case of the individuals needs and behavior towards the wanted outcome of a decision. The elements that were defined as key concepts in the first paragraph of this section have competing definitions. Also, very few were the attempts to place them together for analysis. Before the research question and the objectives of this thesis are outlined, a more detailed description of the key concepts and dimensions is required in order to understand how this research will treat them.

THE PRESENT THESIS

Decision making can be viewed as the process of finding the best option from all of the feasible alternatives (Chen, 2000) in order to achieve an overall goal or desired state (Brehmer, 1992). It may be construed on two principles: I) there is an effort to seek and acquire information regarding the decision and desired state; and II) the information, scenario characteristics and the decision itself are moderated by risk and uncertainty. Two general questions arise from that understanding: 1) What is the role of information and what are individuals' strategies as to information acquisition?; and 2) How these interactions and strategies are affected by uncertainty, and risk both in a psychological and physiological domain?

Decision making involves an intricate process cognitively and procedurally speaking. There is no consensual classification system regarding uncertainty (Meder et al., 2013) and complexity, thus their true impact on the decision making process is still unknown. Also, there is a lack of an understanding of how individual cognition and physiology works in different decision situations, especially when facing complex and uncertain problems. The problem is how to measure and manipulate different levels of uncertainty, risk and complexity in an experiment in a way to represent similar levels of those concepts in real life and in real decision making processes. Moreover, the experiments that are used are not clear enough on whether they are testing risk or uncertainty (Meder et al., 2013) and the vast majority of them analyzes uncertainty and complexity separately. The questions that this thesis sought to answer were: 1) How do individuals carry on information acquisition in order to make a decision?; 2) Which strategies do individuals use to decide in scenarios with varying levels of uncertainty and risk?

Objectives

In order to answer the questions posed, there is a need to better understand the process of information acquisition and the effects of uncertainty and risk in a decision process. Once these concepts are made clearer there should be an attempt to manipulate them in a proposed dynamic scenario.

Considering said objectives, this thesis aimed at measuring and manipulating levels of uncertainty and risk in problems that are to be solved by individuals in order to investigate how they react and strategize when facing varying levels of these elements. The strategy in this line of research is to approach the problem of decision making across levels of possible emergence. It starts at the individual or ecological level by investigating processes involved in information acquisition in uncertain, risky and complex decision settings. That was accomplished through a modification of the paradigms proposed by Fifić and Buckmann (2013), Stern et al. (2010) and Söllner et al. (2014) regarding information acquisition and stopping rules for information acquisition with the measurement of electroencephalographic, heart rate and eyetracking measures. Information acquisition is a necessary condition for a sound decision. Belief updating is a process in which the levels of certainty or uncertainty are changed due to the appearance of new information. This is closely related to information acquisition as it is a linear consequence of the latter and can even modulate it. The basic question is whether there is such a thing as a perfect moment to stop the acquisition process. Some scholars use the terms stopping rules in order to determine some sort of general rule of thumb that predicts when an individual should stop looking for information and actually make a decision. Still on the ecological level, this thesis will also analyze the process of belief updating. The paradigm used by Stern et al. (2010) was replicated using electroencephalographic, heart rate and eyetracking measures.

Moreover, there is a need to understand the psychophysiological correlates of the information acquisition, belief updating and the decision process under uncertain and risky scenarios. This objective will advance to further levels, especially the ones on the psychological and physiological domains, proposed by Cacioppo et al. (2000). By measuring different psychophysiological and behavioral data, it was attempted to verify the correlates between psychological and physiological phenomena in the decision making process.

Summarizing, the main objective of this thesis is to understand the information acquisition process in risky and uncertain scenarios, and its integrated electrophysiological correlates. Specifically, this thesis aimed to:

- Understand information acquisition strategies
- Analyze choice in risky and uncertain scenarios

- Verify electrophysiological correlates of decision in risky and uncertain scenarios
- Attempt to integrate psychophysiological measures as a way to better understand the decision phenomena.

CHAPTER 1 – STUDY 1

Study 1 – Stopping rules in information acquisition at varying probabilities and consequences: an integrated psychophysiological measures approach

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Abstract

An experiment aiming to assess the use of stopping rules in information acquisition was performed. An exploratory experimental paradigm was used. Participants (47 healthy individuals) were requested to make a decision in 24 financial scenarios with the possibility of buying information pieces. Participants were able to accept, reject or choose not to decide. Behavioral, EEG, ECG and Eyetracker data were recorded and integrated offline for analysis. Results showed that participants followed primarily Bayesian calculations in order to determine when to cease information acquisition and decide. Participants would tend to rely more on the valences (BAL) of the information acquired (positive or negative) than on sheer quantity. Acceptance tended to be made with mean positive BAL, rejection with mean negative BAL and procrastination with mean zero BAL. Uncertainty was seen to affect the information acquisition and decision process; EEG data suggest Slow Cortical Potentials at fronto-central electrodes for risk with low consequences and uncertainty with high consequences. Eyetracker data shows greater mean fixation time for decisions and information areas of interest (AOI). Heart rate data shows no difference in scenarios and/or information acquisition behavior, meaning that the decision scenarios did not elicit significant emotional engagement. Integrated psychophysiological measures were of important assistance to the conclusions given that they provided information as to what happened or not both behaviorally and physiologically.

Keywords: decision making; information acquisition; uncertainty; risk; EEG; ECG; Eyetracker; slow cortical potential; integrated psychophysiological measures.

Introduction

As Taghavifard, Damghani and Moghaddam (2009) discuss, it is only possible to know the risks inherent in a decision if the individual has a relatively small degree of uncertainty. One way to diminish levels of uncertainty is by reducing residual uncertainty (Courtney, Kirkland & Viguerie, 1997) through information acquisition. To acquire information is to

search both internally and externally for elements that can affect the decision process. In their daily lives individuals receive a considerable amount of information through various modalities. Auditory, visual, tactile, emotional stimuli can be sources of new information. Each piece of information has some importance toward deciding either by improving the quality and quantity of information or by impairing an individual´s ability to decide given that the amount of information is so great that the performance will be deteriorated (Di Caprio, Santos-Arteaga, & Tavana, 2014). When information reveals itself and is processed by the decision maker, we find a transition from a situation of uncertainty to a situation of risk. In other words, the decision maker now knows enough information about the problem so that he is able subjectively infer a probability for each outcome (Di Caprio et al., 2014).

Pretz, Naples, and Sternberg (2003) discuss the role of experts and the fact that too much information can actually impair the decision process. Too much information may be suboptimal for a decision maker (Gigerenzer, 2000; Di Caprio et al., 2014), whereas not enough information will prevent him from calculating risks properly and brings the decision process to one of most uncertainty (Taghavifard, Damghani & Moghaddam, 2009). On the other hand, Frey, Hertwig and Rieskamp (2014) propose that there is no way to determine when the right amount of information is reached and no further acquisition needs to be done, at least in decisions from experience, although they also say that there may be benefits in small samples and frugal search. The question that remains is: how does a decision maker knows that it has acquired enough information to go through with the process?

Fifić and Buckmann (2013) probed the use of stopping rules by individuals. Stopping rules might determine the moment where the decision maker stops, or should stop, searching for information and actually decide. The authors reviewed some options of stopping rules that might require higher or lower cognitive demands. The first one is the so-called optimal stopping rule for evidence accumulation. It is based on Bayesian inference and implies that there should be an optimal number of pieces of information that need to be acquired. This option requires great amounts of time, knowledge and cognitive effort. In most cases in the real world there are limited amounts of each available to the decision maker. They then propose a stopping rule selection theory based on bounded rationality.

Two rules are suggested that do not depend on high amounts of knowledge about the environment and the situation. The first one is the fixed sample size. This rule entails that the decision maker will determine a sample size before the beginning of the information search process, for example five. The individual will then search for information and will make the choice based on the valence that appears the most (positive or negative). The other rule is called runs stopping rule. In this case the decision maker will begin the search for information

without determining a fixed sample. Individuals will stop searching when a streak of either positive or negative pieces of information is found, three consecutive positive opinions for example.

Cognitive demand and the search for a stopping rule might reflect high levels of task engagement. That is, the individual is fully focused on solving the problem and anticipates the outcomes of the decision given each new information. This situation represents higher use of brain resources, especially in frontal areas. Few studies focus their analysis on pre-stimulus ERPs, especially when decision making is concerned. Böckner, Bass, Kenemans and Verbaten (2001) studied one form of Slow Cortical Potential (SCP). They found a Stimulus-Preceding Negativity at fronto-central electrodes in fear-induced trials. Oswald and Sailer (2013) found fronto-central SCPs before and after response in a temporal discounting task.

Other elements also influence the information acquisition process. Frey, Hertwig and Rieskamp (2014) found that both a facial expression of fear or the subjective feeling of fear may cause an individual to search more information. Söllner, Bröder, Glöckner and Betsch (2014) discovered that when intruding incompatible information appears, individuals trained in the TTB heuristic would not stop searching for information when they were supposed to if following TTB. Individuals rather adapted their information search, choice and confidence judgment processes to the content of such intruding information. It is widely recognized that the amount of information available and acquired by each individual will augment complexity levels in the decision situation, much like what happened with the intruding information.

Psychophysiological differences can also predict and/or mediate the decision making behavior in uncertain or risky scenarios. Studer, Scheibehenne and Clark (2016) found that arousal measured by heart rate and electrodermal activity is mediated by risky scenarios, especially when rewards are explicit to the participants. Clark, Li, Wright, Rome, Fairchild, Dunn and Aitken (2012) found that there is a decrease in heart rate in risk avoidant choices when threats of electrical shocks are implicated. Berker, Rutledge, Mathys, Marshall, Cross, Dolan, and Bestmann (2016) found that uncertainty correlated with stress responses measured by saliva, subjective uncertainty ratings, changes in pupil size and electrodermal activity. Wang, Zheng, Huang, and Sun (2015) demonstrated differences in P300 amplitude in medial electrodes during risky and ambiguous decision scenarios involving bets. Similar results were found by Kogler, Sailer, Derntl, and Pfabigan (2016) in a gambling task. They found pronounced differences in P300 and feedback-related negativity between uncertain and certain conditions. Cui, Chen, Wang, Shum, and Chan (2013) found lateralized differences in P300 amplitudes during the Iowa Gambling Task. They found that advantageous decks elicited differences in the left hemisphere and disadvantageous decks elicited differences in the left

hemisphere. Ramírez, Ortega, and Del Paso (2015) used the Balloon Analog Risk Task and found that low high frequency heart rate variation was a predictor of greater risk aversion.

Given the studies outlined above, it is possible to conclude that different psychophysiological measures can shed light on underlying processes and/or better explain decision behavior in risky or uncertain scenarios. However, to the best of our knowledge, little was done so far as to using psychophysiological measures in an integrated way in this line of study. By integrated we mean two or more psychophysiological measures being acquired at the same time. Although some studies aforementioned did use heart rate and electrodermal activity, the measures focused on autonomic nervous system responses. Central nervous system was not in play in those studies. Engelke, Darcy, Mulliken, Bosse, Martini, Arndt, Antons, Chan, Ramzan, and Brunnström (2017) discuss the importance and propose that researcher make use of integrated (or multimodal, in their words) psychophysiological measures. According to the authors, exploring integrated measures can better explain and provide a wider understanding of constructs.

Moreover, the measures and studies revised so far all focus the analysis on the behavior that happens after the decision is made. Little attention is paid to what might have come before the decision. That is a crucial understanding that can help shed light on what makes an individual cease information acquisition and proceed to a decision.

Given what was discusses until now, the objective of this study is to analyze, in an experimental form, based on the works of Fifić and Buckmann (2013), Stern et al. (2010) and Söllner et al.(2014), if individuals do use stopping rules in the information acquisition and evidence accumulation processes. Also, we try to understand the integrated psychophysiological correlates of information acquisition and decision in risky and uncertain scenarios. We hypothesize that individuals will select different strategies given the conditions of the experiment, as proposed by Fifić and Buckmann (2013). The experimental nature of this study lies on the fact that the analysis will be wider than in other studies. Given that, to the best of our knowledge, no studies have analyzed the time frame leading up to the decision, there is a need to cast a wider net in order to verify possible effects of uncertainty and risk in the information acquisition and decision. In this sense we expect that the results found will usher the need for confirmatory studies in order to engage in an attempt to replicate the more important findings.

Participants

In this experiment 47 individuals of both sexes without self-reported diagnosis of psychiatric or neurological disorders performed an information acquisition and financial

decision task. All participants are aged between 18 and 45 years of age with normal or corrected-to-normal vision and right-handed. A total of 53 individuals from the University of Michigan PsychPool participated. One was excluded due to cancellation of participation, two were excluded due to problems in ECG waves (trident looking R peaks), and three were excluded due to problems with EEG waves (impedance problem, 75% artifact rejection and problem with EEG acquisition software)

Instruments

Participants were presented with 24 economic/financial decision scenarios. The scenarios were presented written in a single paragraph. In all scenarios participants chose whether to accept or reject the proposed situation, they could also choose not to decide at all (representing a procrastination behavior). For every scenario there were 20 information pieces available for purchase. Participant could decide without buying any information. The information, when purchased (pressing the "I" key on the keyboard) was presented only as "positive" or "negative" about the scenario. A positive information meant that the participant should accept or purchase the product/service depicted in the scenario. A negative information meant that the participant should decline. The reason the information displayed only those words was to avoid undesired framing effects. A positive or negative information is related to an advice or information search on the internet or TV advertisement. Each information had a price ($1 for the first 10 information and $2 for the other 10). All participants began the experiment with a fixed amount of fictitious money, should they spend too much on the first scenarios they will not have enough money to finish all scenarios. There was no analysis made regarding the amount of money spent. The money amount was displayed only to deter participants from viewing all 20 information in every scenario.

One example of a scenario is: "You want to invest part of your paycheck. Your manager at the bank offers you a stock that she says has a 60% chance of profiting this year. You must decide if you: buy the stock, do not buy the stock or rather not decide now." Figure 3 provides an example of this scenario.

Scenarios will differ in the presence or not of the stated probability, type and valence of the consequence. That means that the example above might be presented in another form like: "...offers you a stock that she says has a good chance of not profiting this year". In the first form, the scenario would be a stated probability (or risky scenario), high positive consequence (60% chance of profiting). In the second form, the scenario would be an unstated probability (or uncertain) low negative consequence (good chance of not profiting).

Participants were allowed to make a decision at any point in time even if no information was bought. The information was organized in a pseudorandom order. They follow the stopping rules of fixed sample size and runs (Fifić & Buckmann, 2013) and for this experiment the conditions will be fixed sample positive or negative and runs positive or negative. In the scenario example aforementioned, if the arrangement is the fixed samples positive, then within the first five information displayed, three of them (pseudorandomly displayed) will appear as positive and the other 2 negative, so in this case the decision maker should decide positively, in other words to buy the stock, if following the fixed sample rule. If the scenario pertains to a runs negative stopping rule then somewhere within the first five information bought there will be three consecutive negative information. In this case, the decision maker, if following the runs stopping rule, must decide not to buy the stock.

```
Amount available: $476


        You are thinking about buying a bicycle.
There is model that is 35% better than the alternative. You
   don't know what the avarage maintanence costs might be.
              You must decide if you:




   Buy the          Don't buy         Rather not
   bicycle          the bicycle       decide now
     (y)               (n)               (d)
```

Figure 3. Example of a decision scenario in study 1

If the decision maker chooses the "rather not decide now" button, participants will have procrastinated the decision either because they were not convinced by the information purchased or because they did not have enough knowledge to make a decision or because the information bought was overwhelming and they could not arrive at a particular decision. In any case it will be regarded that the participant did not follow any stopping rule.

Procedure

The experiment took place in a quiet room. It lasted around 45 minutes to 1 hour per participant. EEG and ECG data was recorded by Acknowledge 4.4 software (Biopac Systems, Inc, California, USA), eye tracking data was recorded via Tobii Studio (Tobii AB, Stockholm, Sweden) and behavioral data and stimulus presentation was made via PST E-Prime Professional 2.0 (Psychology Software Tools, Inc., Pennsylvania, USA). Linked acquisition of data was possible using BIOPAC MP 150 (Biopac Systems, Inc, California, USA) with wi-fi modular attachments and Acqknowledge 4.4 (Biopac Systems, Inc, California, USA). Upon arrival, each participant received information about the study and read and signed the informed consent form. Once the consent form was signed, participants started equipment calibration. The first step was to place the EEG and ECG electrodes. The EEG and ECG data acquisition was made through BIOPAC ABM B-Alert X10 (Biopac Systems, Inc, California, USA). The EEG cap is composed of 9 electrodes (Fz, Cz, Poz, F3, F4, C3, C4, P3 and P4) with linked mastoids as reference and the ECG is composed of two electrodes, one positioned on the right collarbone and the other on the lower left rib of the participant. Once electrodes were placed, the EEG impedance test was realized via Acqknowledge 4.4. When the desired impedance is achieved (below 5 kΩ), the participant was escorted to the experiment room for eye tracking calibration. A Tobii TX300 (Tobii AB, Stockholm, Sweden) equipment was used to calibrate and collect gaze data. At the end of the eye tracking calibration process, the participant was ready to start the training scenario and the actual task.

The experiment room was isolated from other rooms for privacy, temperature was controlled via air conditioning system. The experiment room was adjacent to the control room where the researchers controlled the experiment. Participants were instructed to knock on the wall if the had any doubts or discomfort. Height and distance of the chair in relation to the computer screen was adjusted if needed. Participants were in a sitting position during all the duration of the experiment, thus diminishing the occurrence of movement artifacts and increases in heart rate due to alternating positions.

The first screen presented details and instructions of the experiment. At this time, participants were informed that they would be presented with different financial scenarios and that they would have to make a decision. They were also informed that they had at their disposal 20 information pieces (or advices) that they may or may not buy in order to help them decide. They were informed that there would be a fixed fictional amount of $480 in order to complete the experiment. The next screen presented a test scenario in which participants were able to get familiarized with the way the experiment worked. While participants viewed the first screens, the researcher would be next to them explaining how the experiment worked,

should participants have any doubts. After the training screen, the researcher would leave the room and the experiment would begin. A total of 24 financial scenarios were presented. Each scenario would bring a situation involving aspects of financial decisions such as investments, purchases, asset management, losses, etc. After reading the description of the situation, participants could or could not choose to obtain information regarding the scenario. Participants were required to make a decision for each scenario. They could decide to buy/invest/pay (Positive decision), not to buy/invest/pay (Negative decision) or they could choose not to decide at the moment (Procrastination decision) and go to the next scenario without making a positive or negative choice. There was not a new attempt at that scenario, if participants chose to procrastinate. Although the time spent on each scenario until a decision was reached or procrastinated was recorded, participants would not receive any instructions regarding a maximum period of time for each scenario. They were free to use as much time as they wanted to read the scenario description, seek information and make a decision.

Each scenario had 20 information pieces that participants could buy in order to get an advice regarding the scenario at hand. All information was presented in a crescent and pseudorandom order. The order of information appearance was made to resemble the stopping rules according to Fifić and Buckmann (2013).

The 24 scenarios was divided as such: 1) 12 scenarios with stated probabilities in the description, composed of 3 scenarios with low negative consequences, 3 with high negative consequences, 3 with low positive consequences and 3 with high positive consequences; 2) 12 scenarios with unstated probabilities in the description, composed of 3 scenarios with low negative consequences, 3 with high negative consequences, 3 with low positive consequences and 3 with high positive consequences.

Psychophysiological measures

EEG data was acquired using a 9 electrode cap using BIOPAC ABM B-Alert X10 (Biopac Systems, Inc, California, USA). Impedance check respected the thresholds provided by Acqknowledge 4.4 (under 5 kΩ). Data collection occurred at 2000 Hz along all 9 channels, later at data cleaning the EEG signal was resampled down to 256 Hz. Linked mastoid (two electrodes placed on the mastoid bone behind the ears) references was used. A saline solution provided by Biopac was used as conductive mean for the electrodes. After collection, data was cleaned and filtered using the ERPLAB MATLAB (MathWorks, Massachusetts, USA) extension (Lopez-Calderon & Luck, 2014). Artifact removal used the moving window peak-to-peak algorithm provided by ERPLAB. Filters were used both for low and high pass (0.1 and

30 Hz, respectively). Epoch size was set at -2000 ms until 200 ms after a decision is made for each scenario. After all the regular data cleaning steps, the ERPs were averaged and visually inspected. The mean amplitude method was used to test for ERPs differences.

ECG data was acquired using a two electrode setting using BIOPAC ABM B-Alert X10 (Biopac Systems, Inc, California, USA). There was no need for impedance check, it was only needed that the participant had the electrodes placed for about five minutes before data collection. That was achieved by placing the ECG electrodes first, after the consent form was signed. After the ECG electrodes were placed, the participant had the EEG cap placed and the impedance check made, providing the five minutes necessary for gel adherence and optimal data collection. Collection occurred at 2000 Hz. A saline solution provided by Biopac was used as a conductive mean for the electrodes. Disposable electrodes were used. After collection, data was opened in EDF Browser in order to isolate the ECG signal. After that, the automated heart rate algorithm imbedded in the software (Christov, 2014) was used to calculate the R-R intervals. The filters applied were the ones setup during data collection in Acqknowledge 4.4. No additional filtering was used offline. R-R interval analysis was used in place of Heart Rate Variance (HRV) due to the epoch time delimited. In a 2 second window there is not sufficient amount of R-R interval observations to aptly calculate HRV. However, mean R-R interval during the epoch was analyzed. It is assumed that the scenario types could elicit differences in mean R-R interval that would be measured in the 2 seconds before a decision was made.

Eye gaze data was collected using a Tobi TX300 (Tobii AB, Stockholm, Sweden) mounted display. Data collection occurred at 300 Hz. Calibration was made using a 9 point setting. Stimulus presentation was linked with gaze data collection via Tobii extension for E-Prime (Psychology Software Tools, Inc., Pennsylvania, USA). In order to calculate fixation time, areas of interest (AOI) were created. The AOIs regarded the main aspects of this study, that of the statement or not of probability (probability AOIs), the decisions (decision AOIs), and the purchase of information pieces (information AOIs). So, for every scenario, each individual decision (positive, negative and procrastination) were marked as AOI. It is important to register that the AOI regarding information was only active as long as the information was purchased and appeared on screen for that particular scenario. Lastly, in the scenario description, the parts of the phrases that contained the statement or not of probability, the valence and type of consequences were marked as an AOI. Every other text in the scenario description was not part of the AOI.

Data Analysis

The main dependent variables were the psychophysiological measures (EEG, ECG and eye tracking), the quantity of information accessed and the choice made by each participant. The independent variables were the different conditions of scenario presentation. For each scenario condition, participants could access no more than 20 information pieces, decide positive/negative or procrastinate, all the while having brain, heart waves and eye gaze measured. Statistical analysis used the lme function in R for Repeated Measures ANOVA. The analysis was made as follows:

EEG data: As previously stated, epochs have a range of -2000 ms until 200 ms of the time each participant makes a decision. The decisions (positive, negative or procrastination) and the types of scenarios (as previously described) were compared with the ERPs using Repeated Measures ANOVA. It is important to state that the EEG data was not analyzed in the two time frames discussed above (the ERP epoch and whole scenario duration) due to the fact that the most appropriate analysis for the latter time frame is power spectrum analysis. Given that duration of each scenario varied across participants and scenarios there is no way to aptly synchronize time frames in order to produce a reliable power spectrum analysis.

ECG data: Using the same epochs as the EEG data, mean R-R Interval values were compared decisions and type of scenarios using Repeated Measures ANOVA. The ECG data could also provide a different time frame in order to analyze the results. Mean R-R Interval may vary during the whole scenario duration (from scenario onset to decision). In order to explore if there would be differences using a larger time frame Repeated Measures ANOVA was performed contrasting mean R-R Interval with scenario decision, and type of scenario.

Eyetracking data: Fixation data was calculated using the AOIs created. Mean fixation time for each AOI group was calculated and compared to the decisions made and type of scenario using Repeated Measures ANOVA. The analysis was made in the same two time frames as the ECG data. The AOIs created for this analysis were: decision AOI (the three decision as they appeared on screen), probability AOI (just the exerts from the scenario descriptions that pertained to the probability statements), and information AOI (each piece of information as they appeared on screen).

Information purchase: The information purchase behavior was analyzed by the information quantity and the balance of information. Information quantity is the mean amount of information pieces that each individual bought during each scenario. The balance is, just as Fifić and Buckmann (2013) proposed, one of the stopping rules, the Bayesian calculation of the valences for each information bought. That is, if information is positive, then the value considered is +1, if information is negative, then the value considered is -1. At the end of a

given scenario, for example, if the pieces of information acquired were 3 positives and 2 negatives (independent of order of appearance), balance will be +1. Those measures will be analyzed with the decisions made and the type of scenarios using Repeated Measures ANOVA.

Time synchronization: In order to integrate all psychophysiological measures some measures needed to be taken. As it was show above, EEG and ECG data was collected with the same equipment and software. Gaze data was collected with Tobii Studio. Both acquisition software were automatically initiated by a signal from E-prime (via connection with Biopac and the Tobii Extension for E-prime). Still, there is an issue of time synchronization with the EEG, ECG and eyetracking data. By the order in which E-prime would send the signals to start data collection, Tobii Studio began recording after EEG and ECG. Using the triggers recorded by Acqknowledge and the AOIs created in Tobii Studio it was possible to measure the time difference and synchronize the timeline of the data acquired. This measures was made for all participants in the raw data provided by Tobii Studio. The time difference was subtracted in the raw data file and then it was uploaded to R for data cleaning and analysis.

Results

In order to determine the use of stopping rules and strategies for information acquisition we focus our analyses on two measures: information quantity (QTY) and balance (BAL). Information quantity is the mean amount of information pieces that each individual bought during each scenario. The balance is, just as Fifić and Buckmann (2013) proposed, one of the stopping rules, the Bayesian calculation of the valences for each information bought. That is, if an information is positive, then the value considered is +1, if an information is negative, then the value considered is -1. At the end of a given scenario, for example, if the pieces of information acquired were 3 positives and 2 negatives (independent of order of appearance), the balance will be +1. The conditions compared to the two measures were: decision (positive, negative and procrastination), probability (risk and uncertainty), and the combination of consequences (high or low) and valence of consequences (positive or negative) in risky and uncertainty.

Behavioral

Of the total of possible scenarios, 40.63% were decided without any kind of information acquisition, thus without the use of stopping rules. This behavior might emerge given the objects of the scenarios at hand. In order to better control the conditions, the objects of decision (car, bicycle, motorcycle purchase, student financial aid, home and car repair,

investments) were less complicated. That might have made the decisions easier based on each individual set of preferences. However, there is no data to back this hypothesis. Next, there were 44.88% of the scenarios that were decided using 1 through 5 information pieces. The 14.50% of cases left used 6 through 20 information pieces.

Decision

Regarding the decisions available for the participants, the mean information quantity gathered when a decision was positive was 2.75 (SD=3.90), when a decision was negative 2.10 (SD=3.60) and when participants decided to procrastinate the mean quantity was 3.32 (SD=4.60). That shows that, despite the fact that participants had up to 20 information pieces available they sought only a small amount. Also it shows that the procrastination behavior was observed with more acquisition of information, while positive and negative decisions demanded practically the same amount of information pieces. On the other hand, when the balance is considered, a positive decision was made with a mean BAL of +1.12 (SD=1.72), negative decisions -0.72 (SD=1.41) and procrastination decisions 0.05 (SD=1.58). That suggests that the information acquisition stopping point behavior is more influenced by the so called balance of the valences, regardless of the quantity of information acquired. A Repeated Measures ANOVA (lme function in R) was conducted to test for differences between each decision and QTY and BAL. The test revealed that there is a significant difference between the decisions for BAL, $\chi^2(2)=88.73$, $p<0.0001$. Post hoc Tukey test revealed significant differences between negative and procrastination decisions (p=0.0002), positive and procrastination decisions (p<0.0001), and positive and negative decisions (p<0.001). There was no statistically significant difference for decisions and QTY (p=0.197)

Probability

Analyzing only if the scenario presented risk or uncertainty, there was no statistically significant difference for mean QTY for risk (M=2.46, SD=3.82) and for uncertainty (M=2.47, SD=3.81), p=0.916. There is a marginally significant difference (p=0.059) for mean BAL for risk (M=0.003, SD=1.78) and for uncertainty (M=0.259, SD=1.82).

Combining the conditions

The conditions were not presented isolated to the participants. Combining the conditions yielded 8 possible scenarios, as it was previously explained, that were randomly presented three times each for the participants. If all conditions are analyzed there is a significant difference for QTY ($\chi^2(7)=23.26$, p=0.001). A post hoc Tukey test revealed significant

differences between risky scenario with low positive consequences (M=2.69, SD=3.70) and risky scenario with high negative consequences (M=1.61, SD=3.19) (p=0.02) and between risky scenario with high positive consequence (M=3.04, SD=4.50) and risky scenario with high negative consequence (M=1.60, SD=3.18) (p<0.0001). There was no significant differences for BAL (p=0.260)

Electroencephalography

EEG analysis focused on risky and uncertain scenarios and both of the combined conditions highlighted previously. As was discussed earlier SCP might emerge in a situation where there might be prolonged use of cognitive control and resources in fronto-medial electrodes (Oswald & Sailer, 2013). As it was seen, BAL has significant differences in risky and uncertain scenarios and also in scenarios with different valences and consequences. That might point to the fact that prior to a decision individuals may exert more thought and allocate more cognitive resources to decide given the conditions presented.

The comparison between risky and uncertain conditions showed SCP negativity for the uncertain condition and a positivity for the risk condition in F4 between -886 ms and -574 ms, with statistically significant difference (main effect for probability statement $\chi^2(1)=6.27$, p=0.02, post hoc: risk vs uncertainty, p=0.001) as shown in figure 4. A similar shaped SCP was also observed within the same time frame in Fz, however there was no statistically significant difference between mean amplitudes (p=0.13).
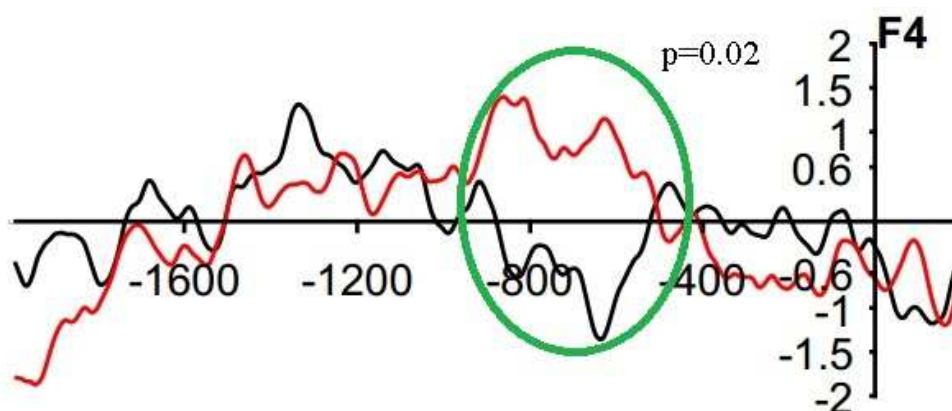
Figure 4. SCPs in risk x uncertain condition in F4

Black line represents uncertain condition, red line risk condition. The ellipsis shows the point of the significant difference. Y axis represents micro voltages, X axis represents the epoch in milliseconds.

As for the comparison between risky and uncertain scenarios in a low consequence condition, we found a SCP negativity for the uncertain condition and a positivity for the risky condition in Fz and F4 between -1290 ms and -490 ms, with statistically significant differences for both electrodes (main effect for probability statement $\chi^2(1)=5.20$, p=0.02, post hoc: risk vs uncertainty, low consequence, p=0.02) and (main effect for probability statement $\chi^2(1)=4.90$, p=0.03, post hoc: risk vs uncertainty, low consequence, p=0.02), respectively, as shown in figure 5.
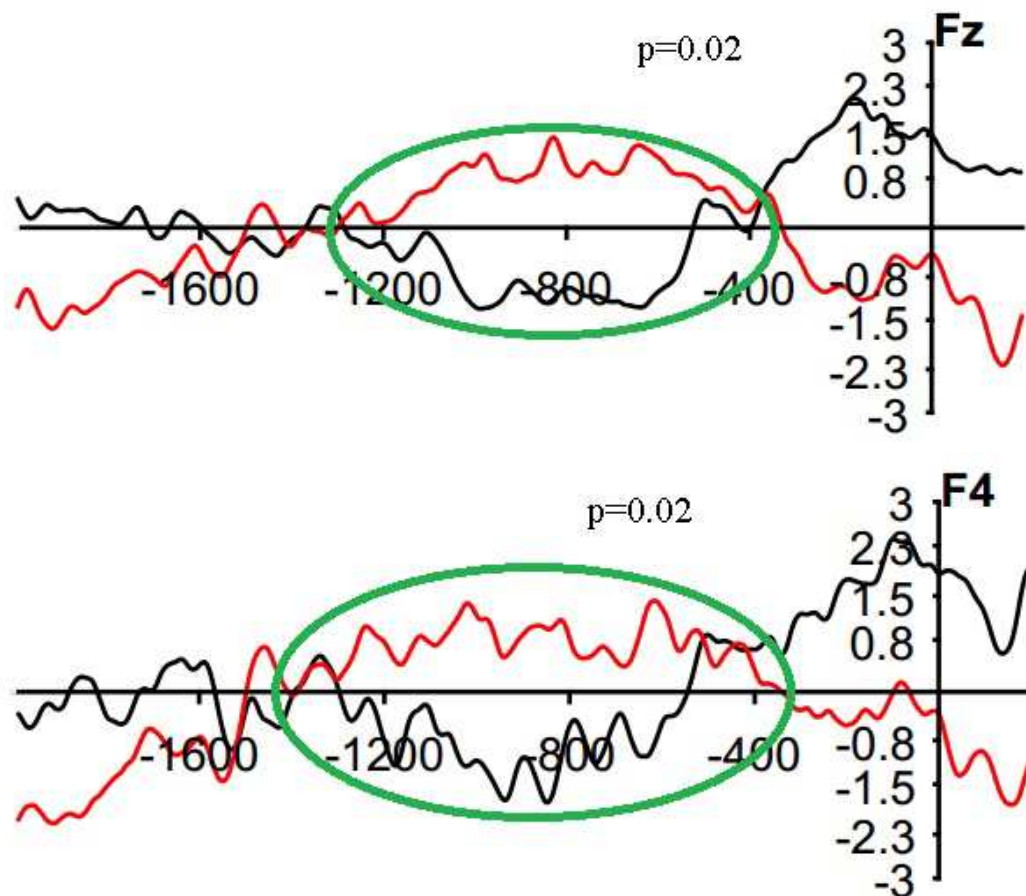
Figure 5. SCPs in risk x uncertain, low consequence condition.

Top part represents Fz electrode. The bottom panel depicts microvoltages in F4 electrode. Black line is uncertain condition, red line is risk condition. The ellipsis shows the point of the significant difference. Y axis represents micro voltages, X axis represents the epoch in milliseconds.

When high consequences are observed, there is a noteworthy shift. There is statistical significance between a SCP positivity in uncertain conditions and a negativity in risky conditions in F3 between -1226 ms and -835 ms (main effect for probability statement $\chi^2(1)=5.71$, p=0.02, post hoc: risk vs uncertainty, high consequence, p=0.01) as shown in

figure 6. A similar SCP was observed in Fz, however there was no significant statistical difference between mean amplitudes (p=0.10). As seen above, both time frame and localization of the electrodes (frontal) are similar to SCPs for low consequences. However, in high consequence scenarios the uncertain conditions positivity when in low consequences it presents negativity. There is also a shift in electrodes. High consequence scenarios present significance in F3 against F4 in low consequence scenarios.
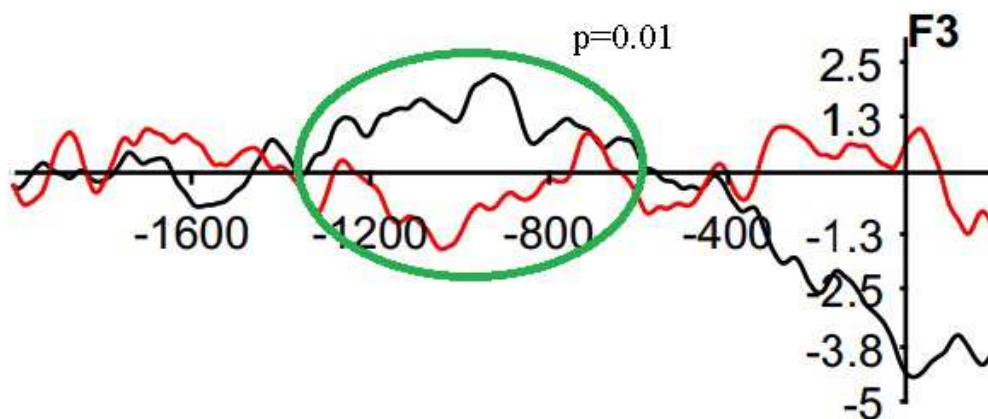
Figure 6. SCPs in risk x uncertain, high consequence condition in F3

Black line represents uncertain condition, red line risk condition. The ellipsis shows the point of the significant difference. Y axis represents micro voltages, X axis represents the epoch in milliseconds.

Electrocardiography

The ECG analysis focused on two different time frames, as previously stated. Mean R-R interval was analyzed using repeated measures ANOVA (lme function in R) against i) general type of scenario (risk or uncertainty), ii) type of scenario and consequences (high and low risk x high and low consequences and high and low uncertainty x high and low consequences).

No significant statistical differences or interactions were found; moreover mean R-R intervals were very similar in all type of comparisons, as will be reported below. The reasons pertaining to the lack of statistical significant differences in the analysis will be explored during the discussion and conclusion sections.

Epoch time frame

Mean R-R interval for risk and uncertainty are practically the same, as shown in Table 2.

Table 2. Mean R-R interval for type of scenario for epoch time frame

Type	Mean R-R interval	SD
Risk	0.761	0.140
Uncertainty	0.765	0.130

The same result is seen when consequences are analyzed, as show in Table 3.

Table 3. Mean R-R interval for type of scenario and consequences for epoch time frame

Type	Mean R-R interval	SD
Risk and high consequences	0.758	0.133
Risk and low consequences	0.764	0.147
Uncertainty and high consequences	0.766	0.134
Uncertainty and low consequences	0.763	0.127

Whole scenario time frame

Results considering the whole scenario are similar to those obtained in the epoch time frame, as show in Tables 4 and 5.

Table 4. Mean R-R interval for type of scenario for whole scenario time frame

Type	Mean R-R interval	SD
Risk	0.748	0.143
Uncertainty	0.750	0.128

Table 5. Mean R-R interval for type of scenario and consequences for whole scenario time frame

Type	Mean R-R interval	SD
Risk and high consequences	0.753	0.152
Risk and low consequences	0.744	0.134
Uncertainty and high consequences	0.747	0.128
Uncertainty and low consequences	0.753	0.129

Eyetracking

The main eyetracking measure that was analyzed was the mean fixation time on the AOIs. They were analyzed using repeated measures ANOVA (lme function in R) against i) general type of scenario (risk or uncertainty), and ii) type of scenario and consequences (high and low risk x high and low consequences and high and low uncertainty x high and low consequences). Moreover, two time frames were observed: the epoch time frame (-2000 ms until decision time) and the whole scenario duration (from scenario onset until decision time).

No significant statistical differences or interactions were found, however there are differences in mean fixation time that will be reported below. The reasons pertaining to the lack of statistical significant differences in the analysis will be explored during the discussion and conclusion sections.

Epoch time frame

As Table 6 show, participants generally fixate more on the AOIs in a risky scenario. Decision AOIs are the most fixated, followed by information AOIs and later the probability AOIs. That suggests that participants tend to spend more time looking at the decision buttons and the information (when acquired) than the statement of the probabilities.

Table 6. Mean fixation time for type of scenario for epoch time frame

Type	Mean fixation - Decision AOIs	SD – Decision AOIs	Mean fixation - Information AOIs	SD – Information AOIs	Mean fixation - Probability AOIs	SD – Probability AOIs
Risk	555.02	402.14	470.79	403.92	319.98	206.47
Uncertainty	517.32	367.78	431.09	386.95	278.96	165.76

When the consequences are inserted in the analysis, table demonstrates the same differences as shown above for risk and uncertainty. Both low and high consequences for risk demanded more fixation time than low and high consequences for uncertainty. However, there is an interesting result when the low and high consequences are observed within risk and uncertainty. While in risky scenarios, low consequences demanded more fixation time in all AOIs than high consequences, in uncertain scenarios high consequences demanded more fixation time than low consequences. Repeated measures ANOVA did not result in statistical significant differences nor interactions, but this result might suggest that consequences can play a role in the decision and information seeking behavior in risky/uncertain scenarios.

Table 7. Mean fixation time for type of scenario and consequence for epoch time frame

Type	Mean fixation - Decision AOIs	SD – Decision AOIs	Mean fixation - Information AOIs	SD – Information AOIs	Mean fixation - Probability AOIs	SD – Probability AOIs
Risk and high consequences	475.40	368.68	381.72	263.09	286.56	199.21
Risk and low consequences	486.28	359.45	520.05	482.15	328.06	181.26
Uncertainty and high consequences	451.40	330.58	379.95	326.59	284.45	145.89
Uncertainty and low consequences	445.83	334.70	441.51	404.26	261.96	162.47

Whole scenario time frame

As in the epoch time frame, risk demanded more fixation time than uncertainty in all but the probability AOIs. However, in this time frame the information AOIs were more fixated than the other AOIs, when in the epoch time frame the most fixated AOIs were decision AOIs. This suggests that participants were reading the information acquired.

Table 8. Mean fixation time for type of scenario for whole scenario time frame

Type	Mean fixation - Decision AOIs	SD – Decision AOIs	Mean fixation - Information AOIs	SD – Information AOIs	Mean fixation - Probability AOIs	SD – Probability AOIs
Risk	539.85	443.08	931.54	791.24	533.01	377.70
Uncertainty	690.56	622.59	913.76	831.93	514.00	343.64

When the consequences are analyzed there is a difference as to the epoch time frame. Both risk and uncertainty demanded more fixation time for high consequences than low consequences.

Table 9. Mean fixation time for type of scenario and consequences for whole scenario frame

Type	Mean fixation - Decision AOIs	SD – Decision AOIs	Mean fixation - Information AOIs	SD – Information AOIs	Mean fixation - Probability AOIs	SD – Probability AOIs
Risk and high consequences	576.87	423.53	789.18	770.31	455.73	342.67
Risk and low consequences	554.82	376.79	774.14	657.72	477.82	328.34
Uncertainty and high consequences	578.96	416.89	775.50	709.58	457.09	332.90
Uncertainty and low consequences	617.40	620.82	771.01	762.60	441.00	287.66

Discussion

Behavioral data suggests that the balance of acquired information (BAL), according to Bayesian calculations (Fifić & Buckmann, 2013), is a preferred stopping rule. EEG data supports this conclusion given the fact that where BAL represented significant differences, there was the emergence of SCPs. According to Oswald and Sailer (2013), the SCPs are task-related components and the negativity might mean conflict processing and the usage of cognitive resources to resolve such conflicts. Even though there was also a significant difference for the quantity of information bought and the decisions, consciously or not participants behave according to Bayesian calculation in order to determine the end of the information acquisition process. By consciously we mean that participants might not be aware of the Bayes' equation but they do act by updating their choices according to the amount of information that is acquired.

This holds up even if the conditions are considered (combined or isolated). This means that the participants will take into account the valences of the information pieces acquired and when they reach a particular threshold (depending on the scenario characteristics and their personal preferences), the decision is made. That becomes clearer when the threshold is approximately +1 for a positive decision, approximately -1 for a negative decision and approximately zero for a procrastination decision. Procrastination decisions show that even though there are more pieces of information acquired, participants often would feel more uncertain and would rather skip the decision. This means that that particular scenario and the set of information acquired would not diminish the residual uncertainty acknowledged by the participant, thus making it harder to assess which decision is better given the probabilities and consequences.

Uncertain scenarios needed higher BAL in order to reach a decision than risk scenarios. That means that sometimes the information acquisition needs to be higher and thus the sum of valences is also more demanding. The appearance of the SCP negativity for uncertain scenarios can reflect a higher conflict and cognitive effort in this condition given that, even though participants seek few information pieces, they need higher valences to resolve the conflict. The SCP showed negativity for uncertain scenarios and positivity for risky scenario in F4. The difference between the waves might suggest that the way participants processed the information acquisition alongside the scenario description in order to resolve the conflict generated by ambiguity can be different. This conflict may arise due to the difficulty to assign a value to the unstated probability described in the scenarios. As in Stern et al. (2010) each new information can change the subjective probability that the participant assigns to the outcome. These changes can require more BAL and result in more use of cognitive resources in order to decide and make sense of the information acquired and the uncertainty depicted in the scenario. This might be further explained by the difference in R-R interval for the procrastination behavior and the higher fixation time for uncertain scenarios, especially in the decision AOIs. Participants were fixating their gaze on one of the decision and calculating - devoting more cognitive capacity -, based on the information acquired, if that particular decision is suited.

When considering low and high consequences for risk and uncertainty, similar effects are also present. Risky scenarios with low consequences demanded more fixation time in all AOIs, especially the decision AOIs for the epoch time frame (2000 ms before decision was made) and information AOIs for the whole scenario time frame. There was also an SCP found in the epoch time frame in Fz and F4 where risky scenarios presented positivity and uncertainty presented negativity. This, according to Oswald and Sailer (2013), mean that there is an expanded cognitive effort in resolving the conflict that the valences and the condition might imply. These results suggest that participants where indeed reading the information pieces acquired during the scenario, but that attention is later focused on the decision buttons prior to the decision. Seconds before the decision is made there is an increase in cognitive efforts in order to resolve ambiguity generated by the probability statements and/or by the information pieces acquired. Lack of differences in R-R interval suggests that there is no increased emotional engagement in the scenarios. Leaving us with the perception that the phenomena occurring both during the whole scenario time frame and the seconds before a decision is made is primarily a straightforward cognitive effort in resolving conflicts and ambiguity.

Lastly, in high consequence scenarios, there is an interesting shift. Risk in high consequence scenarios yielded SCP negativity in F3 and differences in gaze fixation, especially for decision and information AOIs. This represents an inversion both in laterality and in microvoltages as from the ones seen in the low consequence scenarios. In this condition, risk presents the negativity located in the left frontal electrode, alongside with the predominance of gaze fixation. We hypothesize that the lack of stated probability in a high consequence scenario might mean that the information has more weight for the participants, compensating the lack of some level of certainty, and therefore there is no need to allocate as much cognitive effort as with risky conditions. That might happen due to the fact that decisions in this type of scenario might occur more visually than computationally, when participants have to weigh in the values of the information with the risk and consequences proposed. In this case, a stated probability might introduce some level of ambiguity given that the risk is apparent and the consequences can be large. That is further supported by the lack of differences in the R-R interval which, again, mean that there is no evidence of emotional engagement in the task at hand. Further studies need to be conducted in order to better understand this shift of cognitive effort, especially the shift between medial-frontal right electrodes in low consequences and left frontal electrodes for high consequences.

Integrated measures

Regarding a general picture, the analysis sought to synchronize all the collected psychophysiological measures. This approach represents an attempt to integrate and use different measures in the same time frame in order to analyze the decision making behavior in the depicted scenarios. As it was seen above, the proposed manipulations (the types of scenarios and information acquisition) did not result in statistically significant differences within all the psychophysiological measures.

Be that as it may, some of the differences in the means suggest possible effects. For example, EEG shows differences between risk and uncertain scenarios. Eyetracking also portrays that difference within the mean fixation time for all AOI groups (decision, information and probability), being that risky scenarios present a higher mean fixation in every group, but more for decisions and information AOIs. The only measure that does not present difference is the mean R-R interval for both types of scenario. That can be explained largely due to time frame of the epoch. Within a 2000 ms window it is only possible to obtain around two observations of R-R interval, which hinders the possibility of significant variance within the measure. However, when the whole scenario duration is observed, the same behavior of eyetracking measures and R-R interval is presented (EEG data is not available for the whole

scenario duration due to technical issues involving both ERP and power spectrum analysis, as previously discussed in the Method section).

The integration of the measures seeks to shed new light into the observations of the experiment. Higher amplitude in SCPs, higher time fixating in the AOI means that the participant is somewhat engaged in the task proposed. The lack of difference in the R-R interval means that the attention paid to the task is not sufficiently meaningful in order to elicit an emotional engagement in the task, one that would produce an increase in R-R interval (and thus in the beats per minute).

The results of the integrated measures observed all point to failure in the experimental design to elicit emotional engagement in the participants, which was something hypothesized with the introduction of the consequences and their valences. That can be a result of lack of feedback, lack of monetary incentive (real and/or imaginary), the products or services offered or the presentation of the scenarios. Still, even though there was no interaction between the psychophysiological measures and no statistically significant differences between gaze fixation and heart activity, the integration of the measures gave us important and complementing information about the study. The results allow us to perceive that the cognitive effort was indeed related to calculations (objective or subjective) regarding the probabilities and information available for each scenario. The lack of emotional engagement (be that by the faulty experimental design or by the sheer lack of emotions in this type of decision) tells us that the decision behavior was most likely free of any emotional entanglement, which can in fact hinder the decision process. We would have not been able to conclude in a such a manner if it was not for the integration of all psychophysiological measures.

Concluding remarks

We developed an experiment aiming to observe different strategies, or stopping rules, that individuals might use in order to cease information acquisition and make a decision in a given scenario. Departing from the stopping rules proposed by Fifić and Buckmann (2013), we manipulated scenarios in order to show or not show probabilities, high or low consequences and positive or negative consequences. We also acquired three separate psychophysiological measures (aside from behavioral data): EEG, ECG and eyetracking. The data suggests that individuals do not actually follow a particular stopping rule, rather they tend to use, consciously or not, Bayesian calculations in order to consider all the information that was bought in a scenario, when considering the decisions participants made. Moreover we found SCP waves for different conditions in the experiment, sustained gaze fixation for decision buttons and information pieces. We found no significant differences for heart rate activity. That can mean that for those conditions there was an expanded allocation of cognitive

resources in order to solve conflicts that emerged from the information acquisition and the scenario description without emotional engagement.

This study has several limitations that need to be regarded. The main limitation might be corroborated by the data presented, the experimental design. It is possible that, although showing significant differences, the lack of incentive for the participants might not have elicited a sufficient amount of emotional engagement. Changes in the experimental design incorporating rewards and/or feedback have to be tested. Another limitation is the objects of decision scenarios (cars, insurance, stocks, repairs, etc.) that were purposefully constructed to be quite general in order to avoid biases and to be suitable for a wider array of personalities (given that most of them are decisions that participant might already have made in their lives). That also could have contributed to a lack of engagement and general information seeking behavior. There is also a need to further explore the scenario conditions in different ways. This exploratory design sought to combine probability statements, consequences and valences of consequences in order to more closely relate to ecological conditions. New studies need to be conducted in order to test for these conditions alone in order to confirm or refute some of the findings reported here.

There is also a limitation regarding the data analysis. As it was explained, there was a need to synchronize the times of the data acquired in order to integrate the psychophysiological measures. This synchronization had to be handmade and it is probable that the synchronization was off by less than 50 milliseconds in average. Although that does not represent a critical problem to the data analysis effort (for the purposes of this experiment alone), this is a limitation that needs to be addressed. It is more than a procedural or experimental issue, but rather a technological matter. The details on this fact exceed the scope of this paper but, so far, very few software permit full integration for psychophysiological measures.

Finally, there is a need to grasp the experimental nature of the study. Results must not be regarded as definite proof or causal relation. They must be seen as indications of effects that still require further studies in order to be confirmed. New studies seeking to replicate the main results of this study are being constructed and will soon be applied.

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CHAPTER 2 – STUDY 2

Study 2 – Belief updating in decision making: EEG, ECG and Eyetracking correlates

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Abstract

The evidence accumulation part of a decision making process is a vital endeavor. Information may change individual preferences as to the scenario at hand. A replication of the study conducted by Stern et al. (2010) was proposed. The experiment aimed to assess the neural correlates of belief updating using functional magnetic resonance imaging (fMRI). This study aims at replicating the first using the same experimental paradigm adapted to integrated psychophysiological measures (EEG, ECG, and Eyetracker). The task is made of 72 sequences of card draws aimed to assess belief updating given by sequential evidence accumulation and a posterior decision. Each new piece of information served to update uncertainty as to which deck may have supplied the card draws. 47 healthy college students participated in the task. Results show that greater uncertainty presented higher response time and inaccuracy in the final decision. The results were associated with P400 in central right electrode for the pick in uncertainty, P300 in frontal left electrode for the last draw in a less uncertain sequence, and a N100 and posterior slow cortical potential (SCP) for the last draw in a more uncertain sequence. Eyetracker data shows more fixation time on the decks and heart rate did not present any differences regarding sequence types. Results point to higher usage of cognitive effort and task engagement in order to resolve conflicts and process the sequential information presentation. That is more so for uncertain sequences. Integration of psychophysiological measures was of great support to the findings.

Keywords: belief updating; uncertainty; EEG; ECG; Eyetracker; P300; P400 N100; SCP; integrated psychophysiological measures.

Introduction

This study aims to replicate the fMRI study conducted by Stern, Gonzalez, Welsh and Taylor (2010) where they tested the belief updating issue in a card draw task. When facing a decision, it is customary that individuals seek advice and information from other people or other means in order to satisfy any doubts or know more about the subject of the decision. This process can be called information cascade (Huber, Klucharev & Rieskamp, 2015). It is

the sequential updating of information when in a decision making situation. After acquiring or receiving each piece of information, individuals tend to recalculate their beliefs as to the decision. That is, let's assume that an individual is thinking about buying a car. Given her own preferences she finds herself narrowing the list down to two sports utility vehicles (SUV). She then proceeds to collect more information about those cars. During this process, each information that is received will make her lean more towards one of the SUVs. Upon receiving new information, each individual will update their beliefs about an outcome or a choice (Stern et al., 2010). Information acquisition and belief updating is thought to be an important measure in adaptive behavior (Bennet, Murawski & Bode, 2015).

Psychophysiological measures are associated with the underlying processes in evidence accumulation and belief updating. It appears that both Central Nervous System (CNS) and Autonomic Nervous System (ANS) can be correlated to uncertainty and belief updating behavior. Most studies seek to identify CNS influences through neuroimaging techniques. Stern el al. (2010) performed an fMRI study with a belief updating paradigm in order to analyze the effects of different information on subjective and objective uncertainty. They found that increasing objective uncertainty was associated with dorsal anterior cingulated cortex (dACC) and precuneus activity. They also suggested autonomic arousal due to ventromedial prefrontal cortex (VMPFC) activation. Similar results were found by Paul, Smith, Valentin, Turner, Barbey and Ashby (2015) for uncertainty where they discuss the possibility of a cognitive control network between prefrontal cortex (PFC), anterior and posterior cingulated cortex (ACC and PCC). Hoeks, Stowe, Hendriks, and Brouwer (2013) studied participants' responses to partially given information. They found differences in event related potentials (ERP) in an electroencephalography (EEG) study where amplitudes for positivity around 600 milliseconds (ms) in scenarios where information was given partially. Supposedly, this late difference would point to an effort to piece together missing information. Gole, Schäfer, and Schienle (2012) found that, during evidence accumulation, uncertainty is modulated by P200, N200 and late positive potential. Lin, Gao, You, Liang, Ma, Yang, Xu, and Jin (2014) also found differences in N200 for certain and uncertain cues. They conclude that uncertain cues elicited larger negativity around 200 ms after cue presentation in medial electrodes, representing greater anxiety when faced with uncertainty. Still in the subject of uncertainty regarding outcomes, Schienle, Köchel, Ebner, Reishofer, and Schäfer (2010) found posterior frontomedial cortex (PFMC), dorsolateral prefrontal cortex and anterior cingulated cortex activation in their fMRI study to represent uncertainty processing. Bennet, Murawski and Bode (2015) found P3 components associated with higher belief updating and a stimulus-preceding negativity for uncertainty. Different levels of uncertainty elicited N2 and N400

components for feedback validity and late positive complex (LPC) for volatility (Bland & Schaefer, 2011).

As far as the ANS is concerned the main focus is on emotional traits that may surface with the uncertainty entailed in a decision making scenario. Berker, Rutledge, Mathys, Marshall, Cross, Dolan, and Bestmann (2016) found that uncertainty correlated with stress responses measured by saliva, subjective uncertainty ratings, changes in pupil size and electrodermal activity. Ramírez, Ortega and Del Paso (2015) found distinctive heart rate variability (HRV) in influencing both anxiety and risk aversion. Heart rate can decisively hinder the decision making process, even resulting in procrastination behavior (Gluth, Rieskamp & Büchel, 2013). There is also evidence that deceleration in heart rate is a predictor of picture stimuli (Poli, Sarlo, Bortoletto, Buodo & Palomba, 2007), similar to the card draws that compose this experiment. Eyetracker was also used to test information acquisition and movement prediction with experts and non-experts in soccer (Bishop, Kuhn & Maton, 2014).

Given the studies outlined above, it is possible to suggest that different psychophysiological measures can shed light on underlying processes and/or better explain belief updating in risky or uncertain scenarios. However, to the best of our knowledge, little was done so far as to using psychophysiological measures in an integrated way in this line of study. The study conducted by Poli et al. (2007) is an example, however their focus was on anticipation of affective pictures and not belief updating per se. By integrated we mean two or more psychophysiological measures being acquired at the same time. Although some studies aforementioned did use heart rate and eyetracker, the measures focused only on ANS. CNS was not measured in those studies. Engelke, Darcy, Mulliken, Bosse, Martini, Arndt, Antons, Chan, Ramzan, and Brunnström (2017) discuss the importance and propose that researchers make use of integrated (or multimodal, in their words) psychophysiological measures. According to the authors, exploring integrated measures can better explain and provide a wider understanding of constructs.

As it was previously stated, the objective of this study is to replicate the study used in Stern et al. (2010). Their results found evidence of both cognitive and autonomic phenomena. Thus, this study will rely on integrated psychophysiological measures (EEG, ECG and Eyetracking) in order to achieve two main goals. The first is to reliably replicate the findings made by Stern et al. (2010), and the second is to advance the study of belief updating and the psychophysiological correlates that seem to underlie it. We expect to find similar cognitive control components as the ones described above and autonomic responses in light of time and decision accuracy manipulation.

Participants

In this experiment 25 individuals (from the University of Michigan PsychPool) of both sexes without self-reported diagnosis of psychiatric or neurological disorders performed an information acquisition task. Of those, one was excluded for asking to go to the bathroom during the experiment (there was no possibility to pause the experiment), one was excluded for drinking coffee 2 hours before data collection, two were excluded due to problems in the ECG waves, one was excluded due to software problem (at the end of data collection the software froze and all data was lost), and lastly, three were excluded due to problems with EEG data (impedance issue, flatline waves and outlier waves). After exclusions 17 individuals were part of the data analysis. All participants were aged between 18 and 45 years of age with normal or corrected-to-normal vision and they were right-handed. Participants were instructed not to consume coffee or alcohol up to 4 hours before data collection.

Instruments

The task is a replication of the fMRI study performed by Stern et al. (2010), adapted for EEG, ECG and Eyetracking recording. The task is made of 72 sequences of card draws. At the beginning of each sequence two decks (Deck A and Deck B) containing red and blue cards were displayed at the top of the screen. Deck A was made of 80% red cards and 20% blue cards, represented at the top left part of the screen. Deck B was made of 80% blue cards and 20% red cards, represented at the top right part of the screen. The composition of each color is represented by the quantity of the color in each deck, as figure 7 depicts.

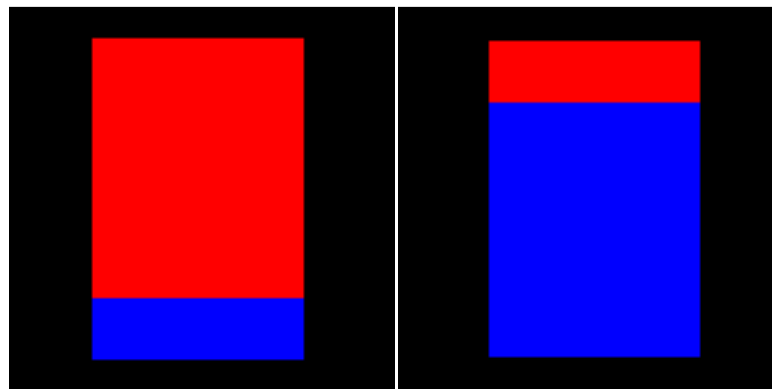Figure 7. Example of the decks (reproduced from Stern et al., 2010)

Left part of the figure represents deck A and its proportion of red and blue cards. Right part of the figure represents Deck B and its proportion of red and blue cards.

Each sequence was comprised of four sequential draws of red or blue cards, the evidence accumulation part of the sequence. At each draw, participants had up to two seconds to rate

how certain they were as to which deck supplied the card that was drawn using a 9-point scale that had "certain" at each extremity, and "uncertain" at the center. If the participant would choose 1, for example, it meant that the participant was rating Deck A as the source of the draw. If the participant chose 9, it meant that the participant was rating Deck B as the source of the draw. So the 9-point scale means evenly distributed categories between certain and uncertain. No feedback was given during the evidence accumulation part. This part aimed to diminish objective uncertainty (a similar concept as residual uncertainty) by the establishing an update of the likelihood that each deck would supply the draws.

After the four draws, participants were requested to make a choice as to which deck supplied the four consecutive draws, also with a time frame of two seconds to decide. They were also able to decline to choose. After the choice, participants received a feedback in order to associate the choices with incentives, given that a correct answer would result in the gain of 50 points and an incorrect answer resulted in the loss of 50 points. If the participant chose to decline, no points were given nor taken. In all parts (evidence accumulation or decision) failure to respond within the given time frame would result in a message saying "Please decide faster" and the decision was classified as an omission.

There were three types of card draw sequences: 1) Type 2:2, where 2 of the draws were blue cards and 2 of the draws were red cards, representing high objective uncertainty; 2) Type 3:1, where 3 of the draws represented one color and the remaining draw represented the other color, this sequence represents a middle point, of some sort, between high and low objective uncertainty. This is so because the order of card draws were randomly presented, thus it could come in any of the combinations allowed; and 3) Type 4:0, where all cards drawn are from the same color, representing the lowest in objective uncertainty. There were also 18 control sequences where Deck A contained only red cards and Deck B contained only blue card. The goal with this sequence was to avoid automatic responses and fatigue. The task was setup so that Deck A supplies the cards on half of the sequences and Deck B on the other half.

The whole experiment was divided into 6 blocks. At the end of each block, a partial score was given to the participant. This interval would take as much time as the participant felt needed, as it is by the participant's key pressing that the experiment moved on.

Procedure

The experiment took place in a quiet room. The experiment lasted around 45 minutes to 1 hour to be completed. EEG and ECG data was recorded by Acknowledge 4.4 software (Biopac Systems, Inc, California, USA), eye tracking data was recorded via Tobii Studio (Tobii AB, Stockholm, Sweden) and behavioral data and stimulus presentation was made via

PST E-Prime Professional 2.0 (Psychology Software Tools, Inc., Pennsylvania, USA). Linked acquisition of data was possible using BIOPAC MP 150 (Biopac Systems, Inc, California, USA) with wi-fi modular attachments and Acqknowledge 4.4. Upon arrival, each participant received information about the study and read and signed the informed consent form. Once the consent form was signed, participants started equipment calibration. The first step was to place the EEG and ECG electrodes. The EEG and ECG data acquisition was made through BIOPAC ABM B-Alert X10 (Biopac Systems, Inc, California, USA). The EEG cap is composed of 9 electrodes (Fz, Cz, Poz, F3, F4, C3, C4, P3 and P4) with linked mastoids as reference and the ECG is composed of two electrodes, one positioned on the right collarbone and the other on the lower left rib of the participant. Once electrodes were placed, the EEG impedance test was realized via Acqknowledge 4.4. When the desired impedance is achieved (below 5 kΩ), the participant was escorted to the experiment room for eye tracking calibration. A Tobii TX300 (Tobii AB, Stockholm, Sweden) equipment was used to calibrate and collect gaze data. At the end of the eye tracking calibration process, the participant was ready to start the training sequences and the actual task.

The experiment room was isolated from other rooms for privacy, temperature was controlled via air conditioning system. The experiment room was adjacent to the control room where the researchers controlled the experiment. Participants were instructed to knock on the wall if the had any doubts or discomfort. Height and distance of the chair in relation to the computer screen was adjusted if needed. Participants were in a sitting position during all the duration of the experiment, thus diminishing the occurrence of movement artifacts and increases in heart rate due to alternating positions.

Psychophysiological measures

EEG data was acquired using a 9 electrode cap using BIOPAC ABM B-Alert X10 (Biopac Systems, Inc, California, USA). Impedance check respected the thresholds provided by Acqknowledge 4.4 (under 5 kΩ). Data collection occurred at 2000 Hz along all 9 channels, later at the data cleaning the EEG signal was resampled down to 256 Hz. Linked mastoid (two electrodes placed on the mastoid bone behind the ears) references was used. A saline solution provided by Biopac was used as conductive mean for the electrodes. After collection, data was cleaned and filtered using the ERPLAB MATLAB (MathWorks, Massachusetts, USA) extension (Lopez-Calderon & Luck, 2014). Artifact removal used the moving window peak-to-peak algorithm provided by ERPLAB. Filters were used both for low and high pass (0.1 and 30 Hz, respectively). Epoch size was set at -200 ms and 2000 ms after a card draw or a decision was made for each draw or pick. After all the regular data cleaning steps, the ERPs

were averaged and visually inspected. The mean amplitude method was used to calculate differences in ERPs.

ECG data was acquired using a two electrode setting using BIOPAC ABM B-Alert X10 (Biopac Systems, Inc, California, USA). There was no need for impedance check. It was only needed that the participant had the electrodes placed for about five minutes before data collection. That was achieved by placing the ECG electrodes first. After the ECG electrodes were placed, the participant had the EEG cap placed and the impedance check made, providing the five minutes necessary for gel adherence and optimal data collection. Collection occurred at 2000 Hz. A saline solution provided by Biopac was used as a conductive mean for the electrodes. Disposable electrodes were used. After collection, data was opened in EDF Browser in order to isolate the ECG signal. After that, the automated heart rate algorithm imbedded in the software (Christov, 2014) was used to calculate the R-R interval. The filters applied were the ones setup during data collection in Acqknowledge 4.4. No additional filtering was used offline. R-R interval analysis was used in place of Heart Rate Variance (HRV) due to the epoch time delimited. In a 2 second window there is not sufficient amount of R-R interval observations to aptly calculate HRV. However, mean R-R interval during the epoch was analyzed. It is assumed that the scenario types could elicit differences in mean R-R interval that would be measured in the 2 seconds before a decision was made.

Eye gaze data was collected using a Tobi TX300 (Tobii AB, Stockholm, Sweden) mounted display. Data collection occurred at 300 Hz. Calibration was made using a 9 point setting. Stimulus presentation was linked with gaze data collection via Tobii extension for E-Prime. In order to calculate fixation time, areas of interest (AOI) were created. The AOIs created were localized on the decks (A, B and Feedback), the card drawn and the scales used to choose the certainty levels and decisions.

Data Analysis

The main dependent variables are the psychophysiological measures (EEG, ECG and eye tracking), the uncertainty ratings, mean reaction time (RT), correct and incorrect answers and declination to choose a deck.

Behavioral data: As in Stern et al. (2010), mean subjective uncertainty ratings in draws 1 and 4 and the sequence types was be analyzed using Repeated Measures ANOVA (lme function in R). Mean RT for draws 1 and 4, the decision and the types of sequence was also analyzed via Repeated Measures ANOVA (lme function in R). Percentage of correct and incorrect answers and types of sequence were analyzed.

EEG data: The EEG analysis was separated into three parts. The first one will analyze all 4 draws. The epoch, as described earlier, was set at the presentation of the card drawn. Each draw was analyzed by each type of sequence in order to determine if there was any effect on the increase or decrease of objective uncertainty. The second part analyzed only draws 1 and 4 and the sequence types in order. Finally, the third part analyzed the feedback of the decisions made. Every analysis was made using Repeated Measures ANOVA (lme function in R).

ECG data: Using the same epochs as the EEG data, mean R-R Interval values will be compared with the draws 1 and 4, sequence types, decision and feedback using Repeated Measures ANOVA (lme function in R).

Eyetracking data: Fixation data will be calculated using the AOIs created. Mean fixation on each AOI will be analyzed against the types of sequence using Repeated Measures ANOVA (lme function in R).

Time synchronization: In order to integrate all psychophysiological measures some measures needed to be taken. As it was show above, EEG and ECG data was collected with the same equipment and software. Gaze data was collected with Tobii Studio. Both acquisition software were automatically initiated by a signal from E-prime (via connection with Biopac and the Tobii Extension for E-prime). Still, there is an issue of time synchronization with the EEG, ECG and eyetracking data. Given the order in which E-prime would send the signals to start data collection, Tobii Studio began recording after Biopac. Using the triggers recorded by Acqknowledge and the AOIs created in Tobii Studio it was possible to measure the time difference and synchronize the timeline of the data acquired. This measure was made for all participants in the raw data provided by Tobii Studio. The time difference was subtracted in the raw data file and then it was uploaded to R for data cleaning and analysis.

Results

Results were computed by cleaning and organizing behavioral and psychophysiological data in contrast with the conditions of draw distribution, picks and feedback. Psychophysiological data was time synchronized with the behavioral data frame in order to analyze effects of experimental conditions on the measures. In general form the results found in this study replicate and confirm the results demonstrated by Stern et al. (2010), as will be exposed next.

Behavioral

Subjective uncertainty ratings showed significant effects and interactions (main effect $\chi^2(5)=154.89$, $p<0.0001$) between draw (1 and 4) and sequence type (1:3, 2:2 and 4:0). Post

hoc Tukey revealed significant differences for draw 4 and 1 in sequence type 1:3 (p<0.0001), for draw 4 and 1 in sequence type 4:0 (p=0.005), however there were no significant differences for draw 4 and 1 in sequence type 2:2 (p=0.960). Draw 4 in comparison with all sequence types revealed significant differences (2:2 vs 1:3, 4:0 vs 1:3; and 4:0 vs 2:2, all p<0.001). The same effect appears for Draw 1 (2:2 vs 1:3, 4:0 vs 1:3; and 4:0 vs 2:2, all p<0.001).

Response time (RT) presented significant effects and interactions (main effect $\chi^2(5)=16.36$, p=0.006) between draw (1 and 4) and the sequence types (1:3, 2:2 and 4:0). Post hoc Tukey revealed that RT was significantly higher only in Draw 4 for sequence type 2:2 than for sequence type 4:0 (p<0.0001).

As for the deck choice and choice accuracy, participants demonstrated higher accuracy for sequence types 3:1and 4:0 with lower decline rate than sequence type 2:2. Table 10 depicts the results.

Table 10. Percentage of omission, accuracy and declination to choose by sequence type.

Type	Omission	Correct	Error	Decline
1_3	8.61%	83.33%	5.56%	2.50%
2_2	6.48%	24.07%	22.22%	47.22%
4_0	1.23%	98.15%	0.62%	0.00%

Values depict percentage of frequency of all trials per sequence type. It is possible to see from Table 10 that the overall percentage of omission was low for all scenario. Moreover, sequence types 1:3 and 4:0 presented extremely low decline percentages, quite different from sequence type 2:2.

Electroencephalography

EEG data showed significant statistical difference for the picks in the sequence types (1:3, 2:2 and 4:0) in electrodes C4 (main effect $\chi^2(2)=7.80$, p=0.02) around the P400 component. Post hoc Tukey revealed that there was significant difference between sequence 1:3 vs sequence 2:2 (p=0.02) and a marginal significant difference between sequence 1:3 and sequence 4:0 (p=0.068).
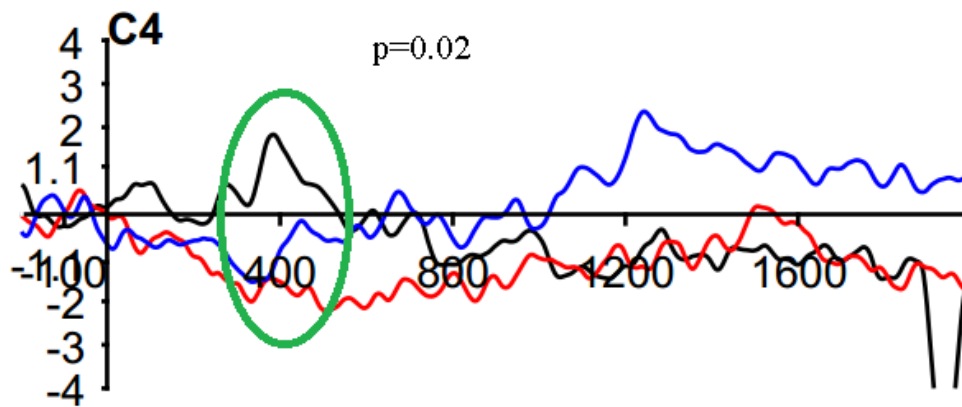
Figure 8. P400 for C4 electrodes when picking the deck

Black line represents 1:3 condition, red line 2:2 condition, and blue line 4:0 condition. The ellipsis shows the point of the significant difference. Y axis represents micro voltages, X axis represents the epoch in milliseconds.

Comparing only draws 1 and 4 for condition 1:3, there was a significant main effect around the P300 component (main effect $\chi^2(3)=16.96$, $p<0.0001$). Post hoc Tukey revealed a significant difference for draw 1 and 4 in F3 ($p<0.0001$) as shown in Figure 9. It was observed a similar wave configuration around 300 ms for F4, however the difference was not significant ($p=0.096$).
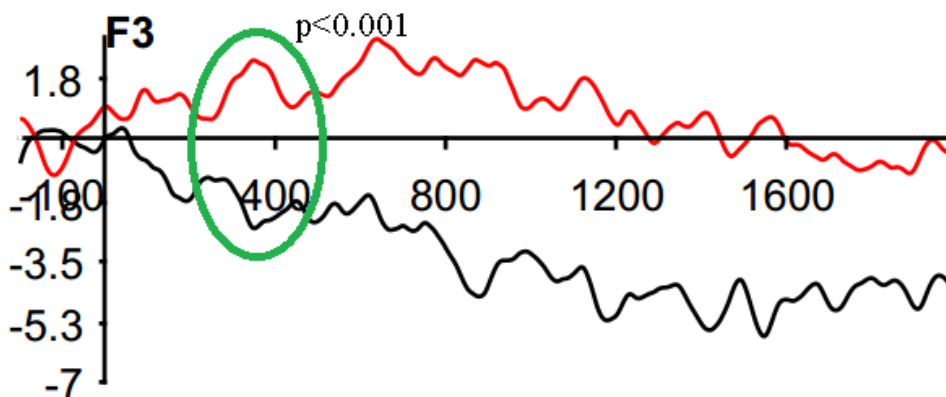
Figure 9. P300 in F3 in Draw 4 for sequence type 1:3

Black line represents draw 1 and red line draw 4. The ellipsis shows the point of the significant difference. Y axis represents micro voltages, X axis represents the epoch in milliseconds.

The last comparison was made between draws 1 and 4 and sequence type 2:2. A N100 component is seen on F4 and P4 for draw 4. A repeated measure ANOVA for each electrode show significant differences between the draws. The ANOVAs results are as follows: F4: main effects $\chi^2(1)=4.62$, p=0.03, post hoc Tukey: draw 1 presents significant difference from draw 4 (p=0.02); P4: main effects $\chi^2(1)=6.57$, p=0.01, post hoc Tukey: draw 1 presents significant difference from draw 4 (p=0.006). Moreover there is a significant difference in F4 and Fz for draw 4 around 1167 ms and 1351 ms, characterizing as a late slow cortical potential, after the draw. Electrode F4 presented main effects $\chi^2(1)=5.77$, p=0.01, post hoc Tukey: draw 1 presents significant difference from draw 4 (p=0.01). Electrode Fz presented main effects $\chi^2(1)=4.26$, p=0.03, post hoc Tukey: draw 1 presents significant difference from draw 4 (p=0.03). Similar differences were also observer in F3, however there was no significant differences (p=0.08). Figures 10 and 11 show the ERPs.
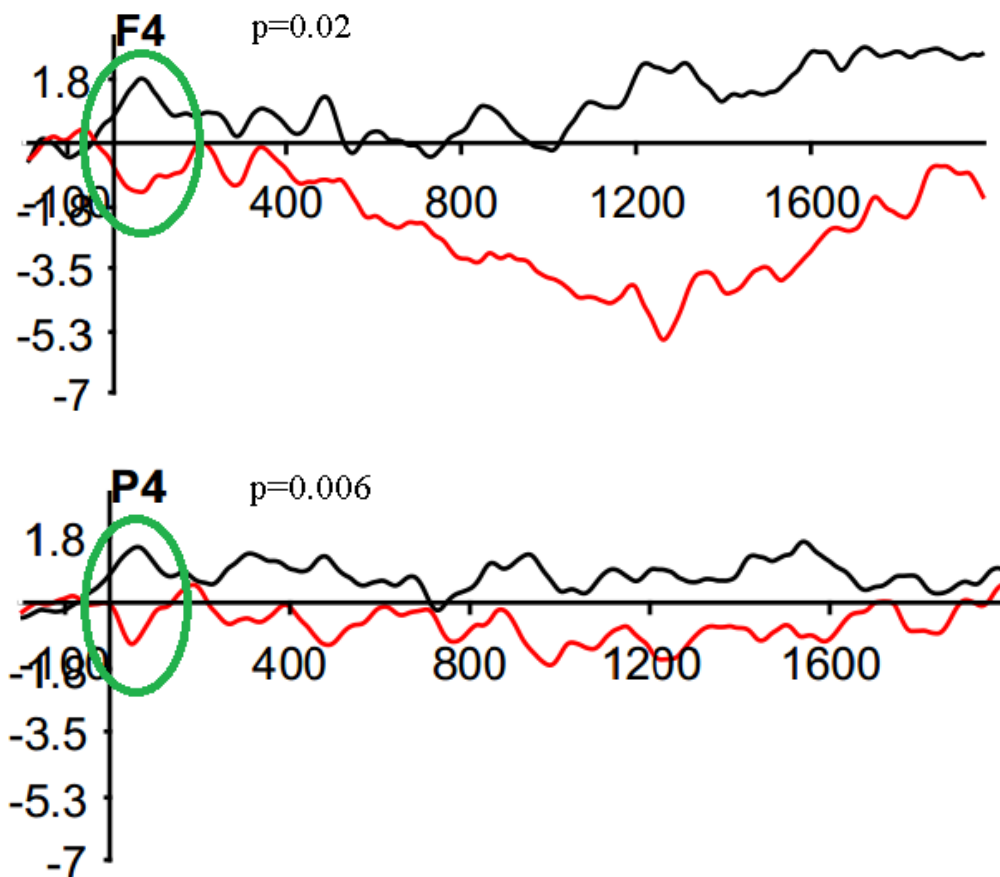
Figure 10. N100 for electrodes F4 and P4 in Draw 4 for sequence type 2:2

Top panel represents F4 electrode. Bottom panel represents P4 electrode. Black line represents draw 1 and red line draw 4. The ellipsis shows the point of the significant difference. Y axis represents micro voltages, X axis represents the epoch in milliseconds.
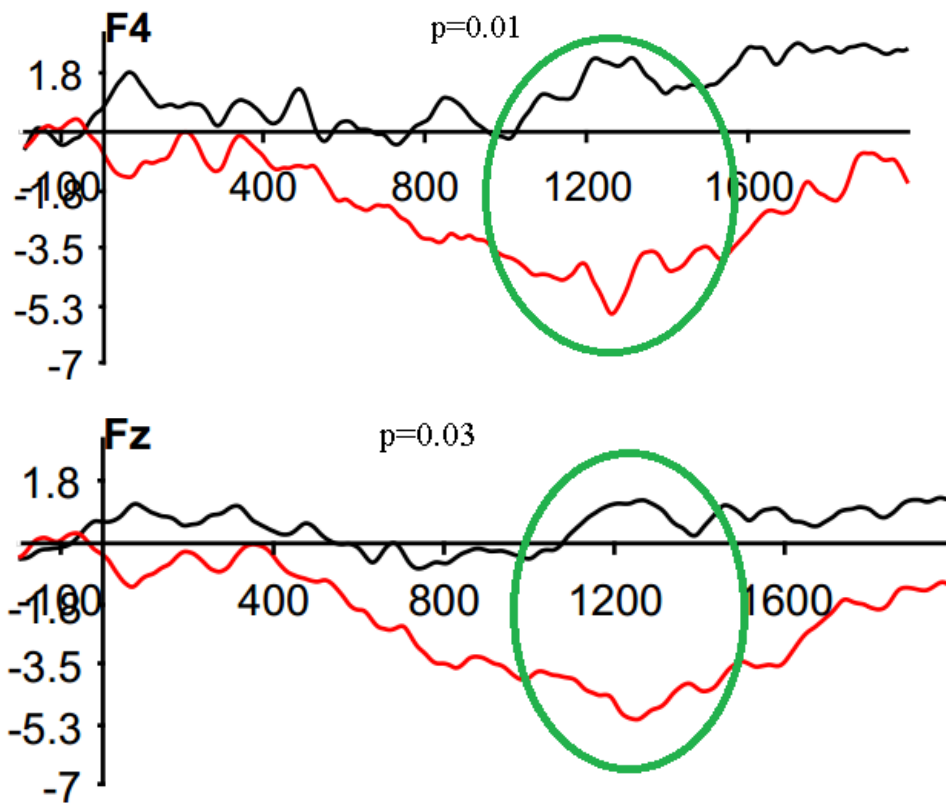
Figure 11. SCP for electrodes F4 and Fz in Draw 4 for sequence type 2:2

Top panel represents F4 electrode. Bottom panel represents Fz electrode. Black line represents draw 1 and red line draw 4. The ellipsis shows the point of the significant difference. Y axis represents micro voltages, X axis represents the epoch in milliseconds.

Electrocardiography

Mean R-R interval was compared to the draws, decision and feedback for sequence types 3:1, 2:2 and 4:0. No statistically significant results were found for any of the tests, nor were any differences between means found. Tables 11, 12 and 13 show the results for mean R-R interval for the comparisons abovementioned.

Table 11. Mean R-R Interval for draw 1 and 4 by sequence type

Draw - Type	Mean R-R interval	SD
1 – 1:3	0.747	0.143
4 – 1:3	0.759	0.138
1 – 2:2	0.762	0.124
4 – 2:2	0.764	0.134
1 – 4:0	0.749	0.134
4 – 4:0	0.761	0.129

Table 12. Mean R-R Interval for pick by sequence type

Pick - Type	Mean R-R interval	SD
Pick – 1:3	0.751	0.144
Pick – 2:2	0.755	0.139
Pick – 4:0	0.758	0.136

Table 13. Mean R-R Interval for feedback by sequence type

Feedback - Type	Mean R-R interval	SD
Feedback – 1:3	0.754	0.150
Feedback – 2:2	0.753	0.150
Feedback – 4:0	0.759	0.131

Eyetracking

The main comparisons analyzed in this study were the mean fixation time on two separate AOI groups and moments of the sequences. AOI groups are the decks and card (deck A, deck B, and the card drawn) and the scale of the certainty ratings (1, 2, spacebar, 8, and 9). Two distinct moments of the sequences were analyzed: the draws and the pick (after all four draws). In this sense, the Repeated Measures ANOVAs contrasted draws 1 and 4 and the sequence types regarding the decks and card AOIs, draws 1 and 4 and the sequence types regarding the scale AOIs, the picks and sequence types regarding decks and card AOIs, and the picks and sequence types regarding scale AOIs.

There was only one significant difference found in the ANOVAs. During the draw part of the sequence there is significant effect for sequence type and mean fixation in the decks and

card AOIs, $\chi^2(5)=12.36$, p=0,03 However, post hoc Tukey test showed significant differences only for draw 4 in sequence type 4:0 and draw 1 in sequence type 1:3 (p=0.02) and draw 4 in sequence type 4:0 and draw 1 in sequence type 2:2 (p=0.02). Although significant, those results do not constitute meaningful results for this analysis. Tables 14 and 15 show the mean fixation time for each AOI and moments.

Table 14. Mean fixation time for draw 1 and 4 by sequence type

Draw - Type	Mean fixation – Deck AOI	SD	Mean fixation – Scale AOI	SD
1 – 1:3	438.76	527.51	413.73	668.29
4 – 1:3	514.68	683.05	311.60	301.41
1 – 2:2	428.29	519.93	395.60	386.80
4 – 2:2	528.47	615.51	323.74	235.54
1 – 4:0	470.90	975.05	853.47	1871.77
4 – 4:0	588.50	1069.54	385.95	523.43

Table 15. Mean R-R Interval for pick by sequence type

Pick - Type	Mean fixation – Deck AOI	SD	Mean fixation – Scale AOI	SD
Pick – 1:3	271.65	199.94	339.10	336.80
Pick – 2:2	255.50	155.05	347.75	509.68
Pick – 4:0	336.17	277.09	443.65	714.86

Discussion

This study aimed at replicating the fMRI study conducted be Stern et al. (2010). Instead of the fMRI we adapted the experimental paradigm to have multiple psychophysiological measures (EEG, ECG and Eyetracker), in order to attempt a full replication of their findings. The results obtained mostly confirm the results presented by Stern et al. (2010). Behavioral data shows that in sequence types that elicit greater uncertainty (type 2:2) there is an increase in RT and procrastination (declining to choose), and a decrease in pick accuracy. RT is greater for sequence type 2:2 than 4:0 (which is related to the highest level of objective certainty). Lack of accuracy in sequence type 2:2 is 47% which is close to chance levels, suggesting that uncertainty was successfully elicited. Moreover, there was no significant difference in subjective uncertainty levels in sequence type 2:2 for draws 1 and 4, whereas there was a significant difference for sequence types 1:3 and 4:0.

Electroencephalographic data can be said to corroborate the results obtained by Stern el al. (2010). In moments of evidence accumulation there were significant results in medio-frontal electrodes and right frontal electrodes. Stern et al. (2010) found increased BOLD signal in the dorsal anterior cingulated cortex (dACC) and precuneus especially for sequence types 1:3 and 2:2 (with greater increase for type 2:2). We found a P400 component in right central electrode (C4) when participants were deciding which deck supplied the cards for sequence type 1:3. Moreover, results show a N100 component for frontal and parietal right electrodes (F4 and P4) and a late slow cortical potential (SCP) in medial and right frontal electrodes (Fz and F4) for draw 4 in sequence type 2:2. Lastly, we found a P300 component in left frontal electrode (F3) for draw 4 in sequence type 1:3. Stern et al. (2010) state that this particular dACC activation may occur because there is some sort of inconsistency in sequence types 2:2 and 1:3. Sequence 1:3, depending on how the card is presented, can lead to such inconsistency, which is more obvious to happen in sequence 2:2. Participants are expecting the draw sequence to follow one pattern but the presentation of one or two different card colors can elicit the feeling of inconsistency and thus augment perceived uncertainty at later draws. Lin et al. (2014) and Liang et al. (2014) also found a fast negative component for uncertain scenarios, although later than 100 ms. Lin et al. (2014) found greater amplitude of N200 for uncertain cues of future events in Fz, Cz and FCZ. In contrast to our findings, which were predominantly in the right hemisphere, we hypothesize that the N100 found in F4 and P4, may relate to the uncertainty generated by the sequence type and given the necessity of remembering the last three draws and still sustain attention to the next card. When the fourth draw is presented and the maximum of objective uncertainty is reached there might be a general sensation of ambiguity and uncertainty that might be related to the activation of the dACC and precuneus as seen in Stern et al. (2010). The N100 can be linked to selective attention in auditory and visual attention paradigms (Luck & Kappenman, 2012). This result points to the fact that there is a significant response to the uncertainty elicited by sequence type 2:2 on the fourth draw. That response is preceded by sustained attention since participants might be in a greater state of expectation for the last draw. This last draw will convey the information that the sequence is either 1:3 or 2:2. As the participants might still be expecting the sequence type to be 3:1, the reveal of the last draw bringing up the objective uncertainty will elicit some sort of uncertainty intolerance behavior. That behavior, we hypothesize, is the moment of realization that the fourth draw is a color that determines the 2:2 sequence. Interestingly, after this realization participants seem to sustain higher cognitive efforts in order to arrive at a decision of which deck supplied the cards. This suggestion is made given the late SCPs that were observed in Fz and F4. According to Oswald and Sailer (2013), a SCP can be

correlated to conflict processing. The experimental design was made to leave a 2000 ms window after the last draw before a decision was requested. Being that the SCP occurred at around 1167 ms and 1351 ms after the onset of the draw, it is possible to suggest that this negativity in medial frontal electrodes can be related to the cognitive efforts participants are engaging in order to resolve which deck supplied the cards. That is more evident given that it was not a component observed in other epochs for sequences 1:3 and 4:0. Bland and Schaefer (2011) found a similar late component (although earlier than ours) that seem to correlate with changes in the information that was already given to the individuals. Behavioral and gaze data also seem to corroborate this particular behavior. There is a large difference in errors and omission between all sequence types (especially for type 2:2). Gaze data showed significant differences for mean fixation time in the decks and card AOIs in the occasion of draw 4, sustaining the assumption that participants were indeed looking at the cards as they were drawn.

In addition, we found a P400 for sequence type 1:3 during the pick phase of the sequence. A similar later positivity was found by Hoeks et al. (2013), in a study investigating partial answers to questions. They found positivity around 600 ms after stimulus presentation representing, according to them, an update in the representation of what was trying to be communicated by the sentences. Most P400 studies converge to understanding effects of differentiation of incongruent stimuli as in Du, Hitchman, Zhang and Qiu (2014). The fact that we found the P400 in the pick phase for sequence type 1:3 might suggest that, when faced with a decision, participants might have a greater level of cognitive conflict in choosing the decks given that one incongruent information, which is not seen in the 4:0 sequence type. That seems to be the case, especially due to the fact that the effects were found in C4. It is noteworthy that this P400 for sequence type 1:3 was contrasted with a N400 for sequence type 2:2 in the pick phase, as shown in figure 8, which according to Bland and Schaefer (2011) and Kutas and Federmeier (2014), might correlate with perception, attention, memory and language. All of which (perhaps aside from language) can be a suitable explanation for the negativity in sequence type 2:2.

Lastly, we found a P300 component in F4 for draw 4 in sequence type 1:3. That particular draw and sequence need to be further explained in order to better understand the emergence of the P300. In any given trial, from draw 1 until draw 3, the sequence of draws can be: i) red-blue-blue; ii) blue-red-blue, or iii) blue-blue-red, if the forth draw is to be a blue card. The reverse is also true if the fourth draw is a red card. As it was seen before, the P300 component in a risky/ambiguity task (Wang, Zheng, Huang, & Sun, 2015) was linked to higher usage of memory load, especially for ambiguity scenarios. Although not the higher

ambiguity elicited in this task, sequence type 1:3 might be the one that takes a higher toll in memory load. As it was demonstrated above, there are a few possible combinations in which a sequence type 1:3 can be formed. Participants, when confronted with the fourth draw, would have to accurately remember the last 3 draws (whichever the prior sequence) in order to determine their decisions.

Taking the results together, they converge to corroborate the findings by Stern et al. (2010). They found significant differences in greater uncertain linking this fact to incongruent cues in the evidence accumulation phase. Our study further explains this result in the fact that there where early negative deflections for uncertain sequences and a later positivity in the choice phase, all related to the cognitive effort of conflict control (Du et al., 2014; Wang et al., 2015)). There is, however, on difference between our study and the study by Stern et al. (2010). They found a possibility of autonomic arousal in the evidence accumulation phase (given the VMPFC activation). Our study did not find evidence for autonomic arousal given that we did not find significant differences for mean R-R interval during evidence accumulation, pick or feedback phases. A further study using electrodermal activity analysis should be performed in order to confirm this finding. This confirmation is needed given that this study proposed a fixed time period in order to make a decision (and if the decision was not made, a message would appear asking participants to decide faster) and also, there were correct and incorrect choices with point tally (which appeared at the end of each block). All those experimental manipulations should have sufficed for emotional engagement and autonomic arousal. That, however, was not observed in the ECG data.

Integrated measures

The aim of the integration of the psychophysiological measures was to attempt to analyze different physiological responses to the stimuli that was presented. Moreover, this fact was of particular importance in order to better replicate the results found by Stern et al. (2010). As proposed by Engelke et al. (2017), there is a niche that needs to be explored. This niche is made possible through the advances in technology within the equipments used for psychophysiological measures. They produce a great opportunity to complement the tools and analysis the science community has in order to observe phenomena, especially psychological and behavioral.

Our study showed that the use of integrated psychophysiological measures can come to aid and complement the findings. Case in hand is the corroboration of the gaze data with the EEG data. Although it might be a logical hypothesis to assume that gaze fixation would be on the decks, a confirmation of this fact helped support the EEG data that there was greater

attention paid to the decks in an effort to solve a cognitive conflict that arose from the card draws. In this case we had cooperation from central nervous system and eye inputs as delimited by Engelke et al. (2017). Moreover, the integration of the psychophysiological measures brought forth a result that did not corroborate the fMRI findings of Stern et al. (2010). As it was discussed above the VMPFC activation linked with autonomic responses was not seen with the measurement of ECG. That does not mean that the effect seen in Stern et al. (2010) is disproven, however that raises an opportunity of confirmation with the use of electrodermal activity and/or heart rate variability (HRV) analysis using the whole sequence as a time frame. The reason that the HRV analysis was not performed was due to the short epoch time (2000 ms). That time is no sufficient to obtain enough data to properly calculate HRV.

The integration of psychophysiological measures was of great value to this study. Through this process, it was possible to further understand the process of belief updating and the physiological correlates that stem from the task. It is needed to state that such integration is still in its infancy. As such, some issues emerge that limits our capacity to better understand and analyze the data. Those issues will be regarded in the next section. Be that as it may, the result obtained in this study echoes the proposition made by Engelke et al. (2017), in that psychophysiological measures, when integrated, will be a source of great achievements for understanding behavior in general. It is a much needed advance and one that is surely happening fast.

Conclusion

This study aimed at replicating the fMRI paradigm performed by Stern et al. (2010). It presents a belief updating experiment that is composed of four card draws and after those four draws, participants had to choose which of the decks provided the cards for the draws. The decks varied in proportion of colors (red and blue), being that one of the decks had 80% blue and 20% red and the other deck had the opposite. Three main manipulations were presented, all of them regarding the distribution of the draws. The card could be drawn in a 1:3 (one card of one color and three of the other color), 2:2 (two cards of color and two cards of the other) and 4:0 (all cards of one of the colors) fashion. In this study, the same experimental design was used, however, instead of fMRI, three psychophysiological measures were utilized: EEG, ECG and Eyetracker.

Behavioral and psychophysiological data largely corroborate the results found by Stern et al. (2010). This is so especially for the EEG data. Much of the results obtained in the fMRI data was corroborated by the ERPs found. In general, the findings suggest that there is greater cognitive effort when in a situation where uncertain is higher than others. That is suggested by

the P400 for the picks, the N100 and late SCPs for draw 4 in a 2:2 sequence type, and the P300 for draw 4 in a 1:3 sequence type. We assume, as did Stern et al. (2010), that this effect might come from an attempt in integrate incongruent information, with higher cognitive load to perform the uncertainty update and memory retrieval. This incongruence can emerge from the fact that participants are expecting one type of distribution, but when the draws where made, that distribution did not follow what was expected. They then had to summon past information regarding the prior draws in order to form and possibly recalculate their assumption of subjective uncertainty as to which deck supplied the cards.

Further studies should focus on confirming the ERP results, especially the results of high uncertainty found in sequence type 2:2 and the picks for sequence type 1:3. Also, there is a need to further investigate the role of cardiac influence in a belief updating experiment. Data found in this experiment showed no significant differences for any of the sequence types, draws, pick or feedback. That autonomic effect was seen by Stern et al. (2010). This inconsistency in the result demonstrates the need to further explore and understand the role of autonomic arousal in the belief updating process. There is a need to explore if the lack of autonomic arousal found in this study was an issue that pertains to the experimental design, the data analysis or if it is a physiological trait – meaning that activation in the VMPFC does not generate changes in cardiac activity. Berntson, Quigley, Lozano (2007) further add to this question when they say that it is not possible to fully relate cardiac activity to autonomic arousal.

The limitations of this study comprehend both experimental and methodological sides. In regard to the experiment itself, the main limitations are the same as stated by Stern et al. (2010), the use of categorical scale for uncertainty and the fact that the uncertainty ratings might have hindered participants' emotional involvement (although not observed in the ECG). We did not seek to mitigate those limitations because the goal of this study was to fully replicate the experimental design with the addition of integrated psychophysiological measures. Any changes in experimental design would have impaired our ability to contrast our results with those of Stern el al. (2010). Still, our study resulted in a technological limitation that has to be addressed.

It regards the off line work that had to be done in order to synchronize the psychophysiological data. As it was explained, there was a difference in time between EEG, ECG and Eyetracking data, mainly because two different software were used to collect data (EEG and ECG data used Acqknowledge and Eyetracking used Tobii Studio). It was required to manually subtract this time difference in order to synchronize the data. Although the effort was made for each particular participant difference, there might be a risk of resulting in about

50 millisecond difference, which should not be a significant problem regarding data analysis. This is rather a technological issue and not an experimental or methodological one. As it was discussed above, technology in integrated psychophysiological measures is in full development and those issues are quite likely to be mitigated in the near future.

Future studies should engage in an attempt to replicate this experimental design correcting the experimental limitations proposed by Stern et al. (2010) in order to test if that will produce an autonomic response to the uncertainty in the sequences. They should also incorporate the use of electrodermal activity measures to serve as a complementary data source for autonomic response analysis.

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CHAPTER 3 – CONSIDERATIONS ABOUT INTEGRATED PSYCHOPHYSIOLOGICAL MEARUES

According to Cacioppo, Tassinary and Berntson (2007), the interdisciplinary field of psychophysiology crosses multiple levels of analysis in dealing with the relationships between physiological events and psychological events or states in a physical, biological, and social context. Psychological events and states become scientifically tractable as behavior, emotion and cognition are operationalized in order to be measured and/or manipulated as variables. On the physiological domain, besides two essential Nervous Systems, Central and Autonomic, there are multiple subsystems such as the musculoskeletal or the electrocortical. Each subsystem carries phenomena in many forms of physical energy, such as electricity, that generate events that unfold through time. Thus, physiological events, whether internal to the body or externally accessible, can be measured through physical instrumentation. Nevertheless, functional analysis and the interpretation of events it entails at both fields, the psychological and the physiological, is crucial. Functional analysis is also fundamental toward integral psychophysiological explanations for phenomena that necessarily cross the environment-body-mind-behavior pathway.

Cacioppo, Tassinary and Berntson also point out that fruitful experimental work can only be achieved in the field psychophysiology as long as the aforementioned measures are logically implicated in a hypothetic-deductive method of inquiry. Only thus, with exhaustive and cumulative hypothesis formulation and testing, would a sound, encompassing model of psychophysiological relationships be obtained. However, the myriad of different physiological systems and structures, and the diversity of human behavior in its ever-changing contexts, add to a practically intractable number of permutations. Moreover, the complexity and dynamics inherent to the nature of physiological and psychological events, as well as to the relations of the latter to the social, biological and physical environments, might render objectionable the effort to serially test each possible permutation of physiological to psychological systems and events. One promising alternative for psychophysiological research to take steps toward addressing such obstacles as multitudinous hypothesis testing and not accounting for complexity is the simultaneous use of multiple physiological measures. Nonetheless, integrating multiple measures will take careful technical advances in time synchronization and theoretically sound functional analyses that factor complexity as a contributor to psychophysiological interactions. This chapter of the thesis focuses on the technical challenges and promises to using multimodal physiological measurements in experimental and applied approaches to psychological processes, with special attention to decision making.

Engelke et al. (2017) discussed the case of multimodal psychophysiological assessment. In Figure 12, they show a collection of methods that may be used, whether separately or conjointly, in psychophysiological experiments.
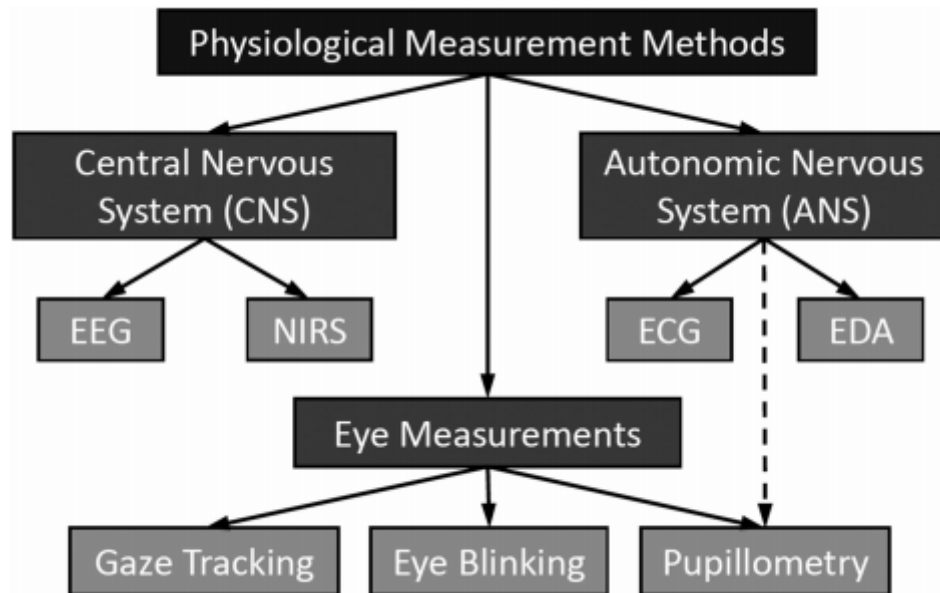
Figure 12. Classification of physiological measurement methods (reproduced from Engelke et al., 2017)

The separation and the equipment were already discussed in previous sections of this thesis. Moreover, there are more equipment and techniques available for psychophysiological research, and new technological solutions are presented at a fast pace. Figure 12 proposes a wide array of measures that can be obtained. It is possible, with these measures, to adapt experimental paradigms in order to assess multiple psychophysiological results (when possible). Of great value is the fact of having measures from both Central Nervous System (CSN) and Autonomic Nervous System (ANS). The possibility of focusing on different specific subsystems, such as muscular, electrodermal, amongst others, present ever growing possibilities. Some examples of studies using EEG (Bland & Schaefer, 2011; Liang, Ma, Yang, Xu & Jin, 2014; Bennet, Murawski & Bode, 2015; Slagter, Prinssen, Reteig & Mazaheri, 2016, amongst others), Eyetracker (Mitterer-Daltoé, Queiroz, Fiszman & Varela, 2014; Benn, Webb, Chang & Reidy, 2015, amongst others) and ECG (Clark, Li, Wright, Rome, Fairchild, Dunn & Aitken, 2012; Studer, Scheibehenne & Clark, 2016, and others), can be given. Especially, the area of decision making is, with each passing year, more involved and beneficiating from the use of psychophysiological research.

Zhang et al. (2013) used event-related potentials (ERP) and principal component analysis (PCA) to investigate the experience of outcomes and risk behaviors in an economic decision. As the results of the choices were presented, they found significant activation of frontopolar cortices and sensorimotor connected attention to the presentation of results and behavior change strategy. Horská and Berčík (2014) investigated the effects of beta and alpha waves in the consumer choice process given differences in lighting, finding that lamps of different colors produced different emotional effects on consumers. Using both EDA and ECG, Danner, Haindl, Joechl and Duerrschmid (2014) verified the effects produced by the experimentation of different types of juice. The use of eyetracker is more widespread in label analysis studies and discrete choices. Benn, Webb, Chang and Reidy (2015) conducted an experiment measuring eye tracking in an online shopping process. Bialkova, Grunert, Juhl, Wasowic-Kirylo, Stysko-Kunkowska and Trijp (2014) and evaluated the customer's attention process when observing nutritional information in packages.

Obviously the examples cited above did not seek to exhaust all studies and / or focuses of studies that use psychophysiology as a method. However, it should be emphasized here, as Engelke et al. (2017) comment that psychophysiological measures serve as complementary techniques to the process of behavioral and self-report measurement. The authors even demonstrate how the integration between psychophysiological measures can leverage the understanding of psychological and behavioral variables. With technological advancement, allowing equipment to become more accessible and easier to use, a great opportunity is emerging for the integration of multiple psychophysiological measures in the decision-making studies. Nonohay, Casalinho, Gauer and Gonzalez (in preparation) carried out a review of articles whose theme was consumer decision and which reported some psychophysiological tool. Of the reviewed articles only eight actually used integrated measures in their methodology. By integrated measures, we mean the use of two or more techniques or equipments at the same time. From the examples cited above, Danner et al. (2014) was one of the few studies that used integrated measures. So the question that remains is, why, given recent technological advances and the growing interest in psychophysiological measure, there are not more research using integrated psychophysiological measures?

As per the integration of psychophysiological measures, it became clear with the execution of the experiments that there is indeed a great opportunity to use said measures to grasp a wider understanding of the phenomena that is at hand. As much as it represents a tremendous opportunity, it is also necessary to admit that full integration still needs more work. That is true in light of issues that are still not fully resolved. Those issues will be explored in the following sections.

Issues in integrating psychophysiological measures

As with any technology in its infancy it is common to observe several issues regarding applicability and usage of the psychophysiological instruments. They can be sorted into three different main issues: technological, experimental, and cost. The physical arrangement of the laboratory, the purchase of computers, trained personnel to connect computers, programmers, physical space and thermal, acoustic and electrical insulation to avoid noise and artifacts in the data should be taken into account. In addition to this, the equipment has proprietary software that can vary in parameters and especially in how the output files are formatted for analysis (since in many cases the data analysis is done in other software, such as Matlab). Finally, there is the concern with the temporal synchronization between the sending of the stimulus and the registration by the software.

Technological issues

From a technological point of view, there are a growing number of sensors and equipments being developed and marketed. Such movement is beneficial because that will force down the prices that are practiced today (although prices are still fairly elevated). In order for a laboratory setup to work with more than one psychophysiological measure the costs are sometimes impractical. More so if the laboratory wishes to count with three or more of the different psychophysiological equipment. There are low-cost (a discussion on costs will be made in the cost issues section) equipment in the market, however, they still face difficulties in acceptance by the academic community. Some reasons for that are quite valid. Sampling rate might be too low and equipment pieces might not have proper quality, for example. However, that is not true for all equipment. There is an upside in low-cost technology, open access. Most codes in low-cost technology equipment are open source or at least facilitate access to programming, and there is a wide support community that grows each day, quite different from proprietary software.

Equipments consolidated in the market seldom use open source codes. Rather, they have proprietary software that mostly do not permit the level of flexibility needed to run novel or even replicate modified psychophysiological experiments. Some experimental designs might require features that are not present on proprietary software, be that for stimuli presentation or for data extraction and analysis. On the other hand, open source software might not have a reliable code. This is not due to ill will by the support community or programmers. Novel code can be built for one purpose and, if applied to another, it might not function properly. In that sense, laboratories would have to retain personnel with the necessary programming skills to

properly apply the measure to the experiment. This discussion is not aimed at the battle between proprietary and open source codes. However, psychological research needs the best of what both have to offer. Robust software works well with the equipment and has enough reliability and also flexibility and transparency. By flexibility we mean the necessary options to produce different types of psychological research and fully integrate it with single or multiple physiological measures. By transparency we mean that the algorithms used for data collection, event markers, online filtering, file encryption and data analysis (when featured), have to be clear for researchers. This is due to the fact that there are a vast number of different algorithms and techniques used to analyze psychophysiological research. As is demanded by scientific journals, we need to have enough information as to what was done to the raw data.

That, however, poses one further question, one of measurement reliability. Different companies, different equipment and different software might obtain divergent measures for the same equipment running the same experiment, even with the same subjects. That is true regarding different statistical packages used to analyze data. If one uses SPSS, it will have a set of parameters that are different in R for the same test, for example (and that does not mean that one is wrong, just that there are indeed different parameters). This is particularly true with the data export in the software used for psychophysiological measures. Different software (proprietary or open source) will provide a different type of file with the raw data. Not all software comes with built-in algorithms that are fit to analyze the data. Sometimes, those algorithms do not fully identify the necessary parameter for data analysis (identification of R peaks in ECG for example).

Even though those difficulties are true, there is the possibility of integrating psychophysiological measures. A minimally acceptable lab setting that wishes to collect two measures (EEG and Eyetracking for example) would have to count with at least three computers plus the psychophysiological equipment: one computer for stimuli presentation, one to run the EEG software and one to run the Eyetracking software. Although that is feasible, there is a concern with the proper synchronization and event triggers. Some psychological experiments depend on very accurate millisecond measurement for all data. Psychophysiological data depends fully on event triggers in order to perform proper analysis.

If, as Cacioppo, Tassinary and Berntson (2007) suggest, psychophysiology is about identifying the relations between the psychological and physiological domains, one needs to reliably know the exact time when the desired stimuli (image, sound, behavior, etc.) was presented. In a setting as described above (three computers) the computer presenting the stimuli is the one controlling when the main stimuli is going to be shown. The other two computers (EEG and Eyetracker software) are most likely not synchronized with the stimuli

computer. Alas, the EEG and Eyetracker computers must know and mark whenever that stimuli was shown. Doing this after data collection has a hazard of lack o proper synchronization.

In an average experiment, the triggers will be sent form the stimuli computer (it is possible that the collection software inputs triggers based on data acquisition, a voltage peak above 100 mV in F3 electrode for example, but that is not the case for most psychological experiments). The signal has to go from one computer to the other (EEG computer) using physical means (cable). That signal has to be received and marked on the timeline of the data acquisition software. If possible, the same signal also has to be sent to the other computer (Eyetracking computer) in order for the stimuli to be marked on both data sets. Different software running on the same configuration (if that is the case, because it is possible that the computers differ in configuration) will take a different toll on computer memory and thus time marking can be lagged due to bus and memory issues. That alone might be a source of lack of synchronization. Stimuli presentation and multiple data acquisition cannot be performed on the same computer using different software at the same time. That will most likely impair the system.

There are, recently, software that propose to acquire data from different psychophysiological equipment. Although of great aid to integrated psychophysiological research, they still do not accept all equipment offered in the market and sometimes they require additional hardware and do not yet reliably integrate the data. There is also a proposed solution for some computer synchronization. The Lab Streaming Layer (LSL) package permits synchronization and collection of psychophysiological measures in the same computer with an accuracy of up to 1 millisecond (ms). Still, not all equipment are accounted for by that package. The upside is that LSL is based on Python, which is fairly easy to learn and relies on a wide support community. Most of the synchronization is made either via parallel port, serial cable and/or TTL pulses. Differences between computers and the transmission of data via the logical cable can impair temporal synchronization and macroscopic data analysis.

Experimental issues

As Cacioppo, Tassinary and Berntson (2007) propose, there is a need to clearly propose an experimental design that will be able to answer the question as to which domain relations are being observed. One need to create or adapt an experimental design that is fit to answer the research question and also that enables proper data acquisition and analysis. That may pose a challenge due to some critical differences in experimental design and / or psychophysiological measures.

Although the technology is rapidly evolving, there are simply some measures that depend on higher inter trial intervals (ITI). Others enable only a brief moment of inspection, meaning that they cannot provide continuous data collection. On the other hand, there are experimental setups and psychological phenomena that simply are not adaptable to the use of psychophysiological measures. Extremely intricate psychological phenomena are somewhat difficult to measure, especially if there are several factors that may play a role in its emergence. Emotions are a suitable example. It is widely known that emotions are one of the most complicated psychological and behavioral phenomena. It is still debated what they actually are and how indeed they are visualized as a physiological phenomena. The existing psychophysiological measure technologies, even if combined, still will not result in one single answer (it is happiness or sadness, for example). An experimental design must successfully elicit an emotional response, which in it and by itself is already a difficult approach. Later, it must be able to create very stable neutral or opposite stimuli in order to tone down that emotion and compare it with other conditions (if that is the case). The same is true for every other psychological and behavioral phenomenon. Be that uncertainty and risk in decision making, information acquisition, discounted temporal decision making, etc.

The other part of the experimental design issue is to correctly choose which psychophysiological measure is to be taken. In order for that to happen, as with any equipment, one must know what it can deliver. To date the most commonly used psychophysiological measures are EEG, Eyetracker, ECG, EMG (and here we also consider EoG), fNIRS, fMRI, and EDA. As seen in Figure 12 they are mostly divided into measures of CNS and ANS. The list below summarizes what each kind of equipment can offer in terms action potential and data analysis.

EEG (Luck, 2014): Measuring electrical differences in different scalp sites. It is not possible to measure single neuron data or subcortical regions. Furthermore, it will measure a few inches of cortical area. It possesses great temporal resolution and can be used for continuous data collection and analysis. The most commonly used data analysis techniques are Event-Related Potentials and Power Spectrum Analysis. Both techniques differ in the results and can offer complementary analysis.

fNIRS (Ferrari & Quaresima, 2012): Its range of action is similar to the EEG. It will measure only cortical regions and will not measure single neuron activity, even though it can penetrate a few inches more into the cortical area than the EEG. It provides a measure of activity in specific regions of the brain and can be used jointly with EEG. It also has great temporal resolution, allowing for continuous readings.

fMRI (Wager, Hernandez, Jonides, Lindquist, 2007): It measures the concentration of oxygenated hemoglobin in certain areas of the brain. It has great spatial resolution. It can focus on a very specific brain region, even in subcortical areas. However, it has poor temporal resolution, requiring larger ITI in order to perform its measurements.

Eyetracker (Holmqvist, Nyström, Andersson, Dewhurst, Jaordzka and van de Weijer, 2011): Main focus of action is eye movement and pupil reaction. It can be used both in a fixed or wearable setup. Care must be taken as to which is the objective of data collection. Reading analysis using a wearable setup might not be possible. It has great temporal and spatial resolution being able to perform continuous analysis. Data analysis techniques include fixation time, visits, scanpaths, heatmaps, pupil dilation and contraction, etc. It can serve both as a primary source of data (attentional processes, reading, etc.) or as secondary source of data (complementary analysis for other psychophysiological measures).

ECG (Berntson, Quigley & Lozano, 2007): Measures electrical changes due to heart functioning. It can be a reliable source of emotional or task engagement, and challenge or threat (Blascovich, Seery, Mugridge, Norris & Weisnuch, 2004). Although it possesses great temporal resolution (it can measure continuous data), experimental setups must account for ITI that will allow time for sufficient heart rate (HR) recovery and/or permit enough data samples to analyze. A cardiac cycle takes around 600 to 800 ms. Therefore the epoch of analysis must comprehend over five seconds in order to reliably analyze hear rate variability (HRV).

EMG (Tassinary, Cacioppo & Vanman, 2007): Measuring the electrical activity of muscles, the main concern with this equipment is proper electrode placement and extreme care with the experimental design. Any type of movement of any neighboring muscles will be captured and will be a source of artifacts. This equipment will provide measures of muscle contraction and relaxation. It is largely used in medical, rehabilitation and physical therapy studies.

EDA (Dawson, Schell & Filion, 2007): It measures the electrical current flow between two electrodes placed normally on participants' fingers. It is a reliable measure of autonomic arousal and emotional effects. It has great temporal resolution, being able to perform continuous measurements. It will provide measures of microvoltages peaks and valleys as to baseline.

There are other possibilities of measuring different psychophysiological data such as MEG, SPECT, PET, TMS, body temperature, respiration, saliva analysis, and blood analysis, which are beyond what detail can be here presented. Measures such as psychological

instruments, surveys, interviews, facial expression analysis, etc., are also important, however out of the scope of this work.

The purpose with this list was not to exhaust every detail or possibility, rather it is meant to serve as baseline knowledge of basic differences in the main psychophysiological measures available.

Cost issues

Currently there are several technical and financial issues that still prevent the integration between psychophysiological measures. The cost of acquiring equipment accepted by the academic community is still high. For a laboratory to have at least three different equipment of psychophysiological measures the cost will be no less than $ 100,000.00. As an example we will consider an EEG, an Eyetracker, and an ECG. A quick research will reveal that EEG sets can range from US$700.000 (without the data collection software) up to several hundred thousands of dollars (a geodesic set). Eyetracker equipment range from EU$500,00 up to more than US$50,000.00. ECG will range from EU$300.00 up to US$4,000.00. Prices may vary and may or may not include data acquisition software. Cheaper equipment may present problems with reliability when trying to publish results. Also, brands and specifications are purposefully omitted because this comparison is not the scope of this work. Let us assume, now, that the software that comes with the equipment is a basic one (with the option of purchasing the more elaborate version). That poses the issue of not having built-in algorithms to analyze the data. In this case, researchers have to export raw data and analyze it using MATLAB, R, Python or any other kind of software. Although that is not a severe issue, it might pose an additional cost of staff with programming skills. Once the psychophysiological equipment and software are purchased the work is not yet finished. There is the need to purchase computers and to prepare a fit space for data collection.

Computers should be in the number needed for adequate data collection. That might mean the number of measures intended plus the stimuli presentation computer. To the best of our knowledge there is not a single computer configuration that is the best. It will largely depend upon specifications given by the psychophysiological equipment manufacturer and the intended setup of the laboratory. It is recommended that all computers share the same configuration, especially motherboard, processor, and memory due to synchronization issues. There is also the need to purchase auxiliary equipment such as cables, adapters, monitors, etc., that, although fairly low cost, are sometimes of vital importance to data collection. It is true

that some equipment already come with one or more possibilities of measures. That is, however, still somewhat rare.

The physical space provided for data collection should have a number of concerns when being setup. Lighting, temperature, noise and electrical insulation, furniture, privacy, etc., are all important factors that need to be addressed. Light may be a source of artifacts for EEG, Eyetracker and fNIRS, for example. Excess brightness may hinder participants' visual capability and hinder visual stimuli response. It can also interfere with the infrared diodes that track eye gaze and the reception of the light in fNIRS. Finally, fluorescent light may be a source for electromagnetic fields which can interfere with electrode readings. Temperature may also hinder electrode adherence and reading. Alongside with temperature, noise can be a disturbing effect on participants' concentration and may elicit a wave pattern that is not due to the experimental design. Proximity to electrical sources may be a way to introduce noise to the data collected. If possible, the space where data collection will be performed should be as insulated as possible. Power outlets, electrical wires, other equipment must be as far as possible from electrodes or amplifiers used in the equipment. Luck (2014) devoted an entire chapter for laboratory setup. Although very detailed, readers must be advised that Luck's book is focused on event related potentials acquired via EEG equipment so it may not be applicable for all measures.

Conclusions

Although there are several issues with the integrated psychophysiological measures, it is of great importance that new studies make the effort to engage in the advance of multiple psychophysiological measures. It is a critical tool to complement psychological research and shed light on the underlying processes that occur in the human body and behavior. It is a tool that is in its infancy in methodological and technical terms, but it is one that is growing fast within academia and will certainly bring many advances. The main conclusion of this chapter is that further studies have to be undertaken in integrated psychophysiological measures, not only on the psychophysiological aspects but on the hardware, software and methodological aspects of it. There is a great opportunity to advance data collection and analysis methods within integrated psychophysiological measures.

As it was seen there are many concerns e preparations that need to be addressed when conducting a psychophysiological research. Table 16 below provides a summary of the main concerns one should address.

Table 16. Main concerns regarding integrated psychophysiological research

Equipment	Unit of Measure	Psychophysiological measure	Temporal resolution	Spatial Resolution	Range of action	Need for ITI	Purchase cost	Operational Cost
EEG	Microvoltages	Electrical differences from cortical areas, mainly measuring cognitive processes	Good	Poor	Continuous	Dependent on type of analysis	Ranges from low to high	Medium
fNIRS	BOLD signal	Activity in cortical regions, mainly measuring cognitive processes	Good	Poor	Continuous	Dependent on type of analysis	High	Low
fMRI	BOLD signal	Activity in brain regions, measuring cognitive and emotional processes	Poor	Good	Epoched	At least a 2 second window	Extremely high	High
ECG	Microvoltages	Electrical activity from heart cycles, measuring emotional and task engagement	Good	Not applicable	Continuous	At least a 5 second window	Ranges from low to medium	Low
EDA	Microvoltages	Electrical impedance, measuring autonomic processes.	Good	Not applicable	Continuous	At least a 2 second window	Ranges from low to medium	Low
EMG	Microvoltages	Electrical measures from muscles, measuring contraction and relaxation	Good	Not applicable	Continuous	Dependent on type of analysis	Ranges from low to medium	Low
Eyetracker	Eye movement and pupil dilation	Measure eye movement and fixation. Mainly attentional and automatic processes.	Good	Good	Continuous	There is only the need for fixation cross or baseline	Ranges from low to high	Low

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General conclusion

This thesis aimed at understanding the decision making process in risky, uncertain and complex scenarios. The approach taken to do so was focused in the information acquisition and belief updating behaviors when in a decision scenario such as described above. In order to do that, two experiments were conducted. The first was an adaptation of three different experimental paradigms with the intention to analyze the decision making process and the information acquisition behavior in financial scenarios with varying levels of uncertainty and risk. The second was a replication of a study by Stern et al. (2010) that aimed at analyzing the belief updating behavior in a four draw card task. Both studies took advantage of the technological advances that permitted the integrated collection of psychophysiological measures.

After conducting and analyzing said experiments it is possible to reach some general conclusions regarding the work performed. Firstly, there is the main conclusion regarding the studies, from an empirical and theoretical point. Secondly, it is necessary to comment on the integration of psychophysiological measures and how it can help the research effort on decision making and other fields.

As per the studies conducted it was clear that in both of them there was a significant influence of uncertainty, both in the evidence accumulation and in the decision making behaviors. Uncertainty seemed to modulate response time, pattern of information acquisition and decisions. Study 1 showed significant difference for uncertainty when the BAL measure was concerned. It also showed significant difference for uncertainty in low and high consequences scenarios. Both results had more BAL than risk scenarios. That is an indication that uncertain scenarios needed more collection of information in order to reach a decision (be that a positive, negative or procrastination). The results obtained on Study 2 also points to same conclusion. When uncertainty was greater, participants would incur in more omissions and misses when determining which decks provided the cards. Larger response times were also verified for sequences with greater uncertainty. Taking both studies into consideration it is possible do infer that uncertainty leads to more time, the necessity of more information, and higher cognitive effort in order to reach a decision.

Psychophysiological measures were collected in order to aid the understanding of the underlying physiological and behavioral processes in those experiments. Data was collected from EEG, ECG, and Eyetracker. EEG data proposes main effects for uncertainty on Study 1 located in fronto central electrodes with predominance on the right hemisphere, specifically a SCP before the decision was made. As it was seen, a SCP can represent the use of cognitive

effort to resolve conflicting information in the scenario and information pieces acquired. Data in Study 2 also presented significant differences in frontal and central electrodes, again with predominance on the right hemisphere. The effects were seen both at the pick and the evidence accumulation phase of the study. In the pick phase there was the appearance of a P400 for sequence type 1:3, which can be related to the processes of piecing conflicting information together in order to make sense of what was presented. This phenomenon might also have been observed give the P300 component found for draw 4 in the same sequence.

There was also a N100 and SCPs after the fourth draw on sequence type 2:2. This early component can be linked to receiving incongruent information. This is especially true for said sequence type. At the time of the fourth draw, participants would be expecting to find themselves in either a 1:3 or a 2:2 sequence type and thus facilitate or hinder the objective uncertainty and the choice. When the fourth draw is shown and it is established that it is indeed a 2:2 sequence type, participants are left with inconsistent evidence and that might cause difficulties in reaching a decision, as show by the omissions, errors and response time discussed above. The late component can suggest higher usage of cognitive effort in order to solve the greater uncertainty presented by the 2:2 sequence.

Moreover there is the eyetracking data which confirms that participants were in fact fixating their gaze at the decision and information AOIs (Study 1) and the decks and card AOIs (Study 2). The fixation on decision AOIs in the epoch time frame supports the inference that participants would consider the decisions itself rather than going back at the information pieces in order to resolve the conflict generated by the uncertainty that might have not been sufficiently resolved by the information acquired. Fixation on the information AOIs during scenario duration points to the fact that the information acquired was indeed read and there was an attempt to interpret them. The fixation on the decks and card AOIs provide more data to support the fact that it was indeed the new information that resulted in the conflict.

Electrocardiography results did not provide significant results in either experiments. However, this fact brought forward a necessity to further explore the emotional and autonomic aspects of uncertainty in evidence accumulation and decision making. This is so given the results obtained by Stern et al. (2010), where they found VMPFC activation that was linked to autonomic arousal. This result was not corroborated by Study 2. Moreover, eliciting emotional responses is not an easy task. The experimental setup must be carefully designed and executed. Engelke et al. (2017), revising several studies that used integrated psychophysiological measures show that none of those studies revealed significant difference in ECG measures. Bernston, Quigley and Lozano (2007) discuss that difficulty by stating that it is still not clear what processes will elicit changes in heart rate activity. That might pose a

reason as to the results obtained by both studies. Also, this can corroborate the difference of autonomic arousal in Stern et al. (2010) and the results sustained in Study 2.

In general terms, the main conclusion that this thesis can arrive is that the uncertainty aspect inherent in the decision making process might not be the effect of lack of information but rather a cause of conflictions of information gathered by the scenario or task description and also by the pieces of information acquired during the decision process. Taking the liberty of analyzing the results from both studies in one timeline, it can be seen, especially in the EEG and behavioral data, that in uncertain scenarios participants might receive incongruent information eliciting a electrophysiological indication of that conflict (N100). After that, participants had to make the cognitive effort to try and resolve this conflict (P400, N400, P300, and SCPs) in order to reach a decision that would take more response time and is indeed more error prone. The cognitive effort might arise from subjective/objective uncertainty update calculation, information processing and memory retrieval.

Obviously, such relation between the two studies is a mere hypothesis, no confirmation or certainty should be taken from this given that studies had different aims, experimental designs and population. However, it is a hypothesis that deserves further studies in order to asses if the uncertainty issue does actually elicit this tremendous cognitive effort. To further analyze this hypothesis, there is the fact that so far there still is an open debate as to how much information is necessary to diminish residual uncertainty in order to make an optimal decision. It might not be a question of amount of information, but rather how that set of information resonates cognitively and in which order it is presented.

Ethical considerations

The studies followed all ethical guidelines and were approved by both the University of Michigan Internal Review Board (IRB) and the Ethics Committee at *Universidade Federal do Rio Grande do Sul* Psychology Institute. All participants were informed of all aspects of each study including possible hazards. In this case the main hazards that may have occurred were emotional and perceptual discomforts. Each participant was assured that they could withdraw from the study at any time without suffering any kind of prejudice. Moreover, all participants read and signed an Informed Consent Form prior to the beginning of data collection. All data collected will remain anonymous and will be kept by the researchers for 7 years after data collection. At that time, data will be erased.

<div align="center">

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INSTITUTO DE PSICOLOGIA - UFRGS

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Tomada de decisão em tarefas complexas com alta incerteza
Pesquisador: Gustavo Gauer
Área Temática:
Versão: 1
CAAE: 59059216.2.0000.5334
Instituição Proponente: Instituto de Psicologia - UFRGS
Patrocinador Principal: MINISTERIO DA CIENCIA, TECNOLOGIA E INOVACAO

DADOS DO PARECER

Número do Parecer: 1.732.951

Apresentação do Projeto:

Trata-se de um projeto de tese de doutorado focado no tema de Tomada de Decisão. Parte-se do princípio que toda a decisão ocorre em cenários com variados graus de risco, incerteza e complexidade. Ainda que os temas sejam amplamente estudados, nota-se que sua análise é normalmente feita separadamente. Portanto, o projeto visa a entender as estratégias para a tomada de decisão em ambientes com altos graus de risco, incerteza e complexidade, levando em conta que: i) o processo de tomada de decisão pode ocorrer individualmente ou em uma situação de interação, em

díades ou grupos; e ii) essas interações e estratégias podem ser afetadas pela incerteza, risco e complexidade. Então chega-se a três questões que irão nortear este projeto: 1) Como os indivíduos buscam e decidem quando parar de buscas informações para tomar uma decisão?; 2) Quais tipos de estratégias os indivíduos utilizam para decidir em cenários dinâmicos com variados graus de incerteza, risco e complexidade?; e 3) Quais estratégias as díades e grupos de indivíduos utilizam para interagir e decidir em cenários dinâmicos com variados graus de incerteza, risco e complexidade?Para responder às questões, serão utilizados quatro experimentos inter-relacionados: 1) Um experimento baseado nos trabalhos de Fific e Buckman (2013), Stern et al. (2010) e Söllner et al. (2014) que analisa o uso de regras de parada para aquisição de informação e acúmulo de evidência em cenários com variações de risco e incerteza. É composto de 24 cenários

Continuação do Parecer: 1.732.951

econômico/financeiros onde cada indivíduo deverá decidir se

aceita, rejeita ou prefere não decidir sobre o cenário apresentado. Para cada cenário o indivíduo poderá comprar até 20 informações referente à decisão em questão. Medidas psicofisiológicas (EEG, ECG e Eyetracker) serão auferidas. Participantes irão responder 5 instrumentos (Big Five, BAI, BIS, Regret e Maximization Scale e Need For Cognition). 2) O estudo 2 é uma adaptação do estudo de Stern et al. (2010). O estudo tem por objetivo analisar a atualização da crença baseada em acúmulo de evidências. Os participantes deverão passar por 72 sequencias de 4 saques de carta.

Cada carta será da cor vermelha ou azul. Após cada saque, o participante deverá dizer qual de dois baralhos (Baralho A ou Baralho B) ele acha que as cartas foram retiradas. Ao final dos quatro saques, o participante deverá dizer qual dos baralhos foi o utilizado. O baralho A é composto de 80% de cartas vermelhas e 20% de azuis. O baralho B tem composição inversa ao baralho A. Medidas psicofisiológicas (EEG, ECG e Eyetracker) serão auferidas. 3) O terceiro estudo tem por objetivo analisar o comportamento decisório em cenários com variações de graus de complexidade. Baseado

no estudo de Venkatraman et al. (2009), o experimento irá apresentar cenários com 5 opções de escolha de recompensas. As probabilidades de ganho de cada cenário serão apresentadas de variadas maneiras, assumindo-se as condições de baixa, média e alta complexidade. Medidas psicofisiológicas (EEG, ECG e Eyetracker) serão auferidas. Participantes irão responder 5 instrumentos (Big Five, BAI, BIS, Regret e Maximization Scale e Need For Cognition). 4) O último estudo irá utilizar dados dos três primeiros, em especial a manipulação de risco, incerteza e complexidade e

seus resultados no processo decisório, de aquisição de informação e acurácia baseada em complexidade de informação. O experimento será composto de cenários criados com manipulação nos níveis de incerteza, risco e complexidade. Cada cenário terá uma resposta correta e uma estratégia que levará até o resultado. Medidas psicofisiológicas (EEG, ECG e Eyetracker) serão auferidas. Participantes irão responder 5 instrumentos (Big Five, BAI, BIS, Regret e Maximization Scale e Need For Cognition).

Objetivo da Pesquisa:

Objetivo Primário:

Investigar como os indivíduos reagem e utilizam-se de diferentes estratégias quando deparados com as variações nos níveis destes elementos por meio da manipulação e mensuração dos níveis de incerteza, risco e complexidade em problemas que deve ser resolvidos por indivíduos, díades ou grupos.

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Página 02 de 04

Continuação do Parecer: 1.732.951

Objetivo Secundário:

Compreender o processo de aquisição de informação em cenários de variados níveis de incerteza, risco e complexidade; compreender o processo de atualização de crença baseado em acúmulo de evidência; avaliar o efeito de variados níveis de complexidade no processo decisório; e analisar como indivíduos utilizam-se de estratégias para resolução de problemas em cenários com variados níveis de incerteza, risco e complexidade, e como eles interagem em díades diante destes cenários.

Avaliação dos Riscos e Benefícios:

Riscos:

Ainda que as técnicas utilizadas sejam totalmente não invasivas, os principais riscos são: desconforto pelo uso dos equipamentos em razão do desconhecimento deles, desconforto pelo tempo de cada experimento, desconforto pela necessidade de mínima movimentação durante o estudo.

Também deve-se considerar um possível desconforto por responder os instrumentos. Não se prevê nenhum tipo de dano sério a saúde física ou psicológica dos participantes.

Benefícios:

Auxílio e contribuição inestimável ao avanço da ciência e da pesquisa em tomada de decisão. Os participantes poderão conhecer melhor sobre o processo de tomada de decisão e suas estratégias.

Comentários e Considerações sobre a Pesquisa:

Trata-se de uma pesquisa relevante que contempla todos os aspectos éticos e metodológicos necessários.

Considerações sobre os Termos de apresentação obrigatória:

Os termos estão presentes e estão adequados.

Recomendações:

Não há.

Conclusões ou Pendências e Lista de Inadequações:

Não há pendências ou inadequações.

Considerações Finais a critério do CEP:

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Endereço: Rua Ramiro Barcelos, 2600
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INSTITUTO DE PSICOLOGIA - UFRGS

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_745554.pdf	24/08/2016 11:54:37		Aceito
Outros	AtaRGN.pdf	24/08/2016 11:50:45	Gustavo Gauer	Aceito
Folha de Rosto	FRrgn.pdf	23/08/2016 16:06:47	Gustavo Gauer	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE_Estudo_4_2.pdf	21/08/2016 23:32:14	Roberto Guedes de Nonohay	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE_Estudo_4_1.pdf	21/08/2016 23:31:50	Roberto Guedes de Nonohay	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE_Estudo_3.pdf	21/08/2016 23:30:30	Roberto Guedes de Nonohay	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE_Estudo_2.pdf	21/08/2016 23:30:12	Roberto Guedes de Nonohay	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE_Estudo_1.pdf	21/08/2016 23:29:50	Roberto Guedes de Nonohay	Aceito
Projeto Detalhado / Brochura Investigador	projeto_tese_RGN_CEP.pdf	21/08/2016 15:53:02	Gustavo Gauer	Aceito

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

PORTO ALEGRE, 18 de Setembro de 2016

_____

Assinado por:
Clarissa Marceli Trentini
(Coordenador)

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Página 04 de 04

eResearch M REGULATORY MANAGEMENT

Date: 16/09/2015 14:43:43

Print   Close

01. General Study Information

All questions marked with a red asterisk (*) require a response. Questions without a red asterisk may or may not require a response, depending on those questions' applicability to this study.

1.1* Study Title:
Information Acquisition: Stopping rules for varying levels of probabilities and consequences

1.1.1 Full Study Title:
Information Acquisition: Stopping rules for varying levels of probabilities and consequences

1.1.2 If there are other U-M studies related to this project, enter the eResearch ID number (HUM#) or IRBMED Legacy study number. Examples of related projects include, but are not limited to:

- Projects funded under the same grant
- IRBMED Legacy study being migrated into eResearch
- Previously approved Umbrella applications (such as Center Grants or approvals for release of funding)
- Previously approved projects for which this is a follow up study

1.2* Principal Investigator:
Roberto Guedes de Nonohay
Note: If the user is not in the system, you may Create A New User Account...

1.3 Study Team Members:

Study Team Member	Study Team Role	Appointment Dept	Appointment Selection Complete?	Student	Friend Account	COI Review Required	Edit Rights	Accepted Role?	PEERRS Human Subjects?
Roberto Guedes de Nonohay	PI		N/A	no	No	no	yes	N/A	yes
Richard Gonzalez	Faculty Advisor	RCGD - Rsrch Cntr for Grp Dyn	Yes	no	No	no	yes	Yes	yes
Alicia Carmichael	Research Staff	RCGD - Rsrch Cntr for Grp Dyn	Yes	no	No	no	yes	Yes	yes
Donna Walter	Research Staff	RCGD - Rsrch Cntr for Grp Dyn	Yes	no	No	no	yes	Yes	yes

1.8* Project Summary:
When making decisions individuals often conduct a search for information regarding the problem at hand in all forms and dimensions. They can seek advice from professionals, relatives, friends or even online. When risk and uncertainty come into play the search for information becomes even more important.

Individuals may have different strategies for information acquisition; they may use different information acquisition stopping rules. The main question is How do individuals search and stop searching for information in order to decide?

The objective of this study is to analyze how individuals will or will not search for information to aid decision in financial/economic scenarios and how scenario and information presentation may interfere with the process. Each scenario will differ in its presentation regarding probabilities (shown and not shown), consequences (positive and negative) and valence of consequences (high and low).

EEG, ECG, eyetracking and behavioral data will be recorded for each participant. Individuals will respond to the Big Five Personality Test (Short version), Beck Anxiety Inventory, Barratt Impulsiveness Scale, Need for Cognition scale and Maximization and Regret Scales instruments.

1.9* Select the appropriate IRB:
Health Sciences and Behavioral Sciences

1.10* *Estimated* Study Start Date (Not required for IRBMED): *(mm/dd/yyyy)*
8/24/2015

1.11* *Estimated* Duration of Study:
12 months

01-1. Application Type

1-1.1* Select the appropriate application type.
Standard, non-exempt, research project

Date: 16/09/2015 14:43:43

01-2. Standard Study Information

1-2.1* Who initiated this study?
Student investigator or faculty member on behalf of a student

If other, please specify:

1-2.2* Are you or any students working on this project being paid from a federally funded training grant?
  ○ Yes   ● **No**

1-2.3 This study is currently associated with the following department. To associate this research with a different department, click Select. If the department has defaulted to "student", click select to specify the department through which this application is being submitted.
RCGD - Rsrch Cntr for Grp Dyn

1-2.4 Will the study utilize resources from the following centers?
Select all that apply:
There are no items to display

1-2.6* Has the scientific merit of this study already been peer reviewed (i.e., reviewed by one or more recognized authorities on the subject)?
  ● **Yes**   ○ No

1-2.6.1* List the peer-review organization(s).
Peer Review Organization
Faculty advisor, thesis committee, other student review

1-2.7* Is this a clinical trial?
  ○ Yes   ● **No**

01-7. Student Research Information

1-7.1* This application is being submitted by a:
Select all that apply:
Student for a mentored research project (e.g. K award)

1-7.2 Indicate course number here:

Study Team Detail

1.4 Team Member:
Roberto Guedes de Nonohay
Preferred email: rguedesd@umich.edu
Business phone
Business address: 426 Thompson Street 48104

1.5 Function with respect to project:
PI

1.6 Allow this person to EDIT the application, including any supporting documents/stipulations requested during the review process:
yes

1.7 Include this person on all correspondences regarding this application: *(Note: This will include all committee correspondence, decision outcomes, renewal notices, and adverse event submissions.)*

Credentials: *Required for PI, Co-Is and Faculty Advisors*

Upload or update your CV, resume, or biographical sketch.

Name	Version
CV_Roberto_Nonohay.pdf	History	0.01

Conflict of Interest Detail: *Required for all roles except Administrative Staff*

Date: 16/09/2015 14:43:43

Print   Close

Current Disclosure Status in M-Inform: *This study team member has indicated in M-inform that they do not have any outside interests to disclose.*

D1 Do you have an outside interest or relationship with a non-UM entity that relates to this research in one of the following ways:

- The entity is sponsoring this research
- The entity's products are used in this research
- The entity has licensed your invention (e.g. device, compound, drug, software, survey, evaluation or other instrument) being used in this research
- Part of the work on this project will be subcontracted to the outside entity
- Other relationship not listed above

no

D2 If "Yes" to the question above, name the entity or entities and provide a brief description of the relationship(s).

Study Team Detail

1.4 Team Member:
Richard Gonzalez
Preferred email: gonzo@umich.edu
Business phone   734-647-6785
Business address: Psychology   525 E University 48109-1109

1.5 Function with respect to project:
Faculty Advisor

1.6 Allow this person to EDIT the application, including any supporting documents/stipulations requested during the review process:
yes

1.7 Include this person on all correspondences regarding this application: *(Note: This will include all committee correspondence, decision outcomes, renewal notices, and adverse event submissions.)*

Credentials: *Required for PI, Co-Is and Faculty Advisors*

Upload or update your CV, resume, or biographical sketch.

Name	Version
Gonzalez CV 2014	History	0.01

Conflict of Interest Detail: *Required for all roles except Administrative Staff*

Current Disclosure Status in M-Inform: *This study team member has indicated in M-inform that they do not have any outside interests to disclose.*

D1 Do you have an outside interest or relationship with a non-UM entity that relates to this research in one of the following ways:

- The entity is sponsoring this research
- The entity's products are used in this research
- The entity has licensed your invention (e.g. device, compound, drug, software, survey, evaluation or other instrument) being used in this research
- Part of the work on this project will be subcontracted to the outside entity
- Other relationship not listed above

no

D2 If "Yes" to the question above, name the entity or entities and provide a brief description of the relationship(s).

Date: 16/09/2015 14:43:43

Study Team Detail

1.4 Team Member:
Alicia Carmichael
Preferred email: almagior@umich.edu
Business phone   734-764-4265
Business address: RCGD-Rsrch Cntr for Grp Dyn 5260 ISR-Thompson 48104-1248

1.5 Function with respect to project:
Research Staff

1.6 Allow this person to EDIT the application, including any supporting documents/stipulations requested during the review process:
yes

1.7 Include this person on all correspondences regarding this application: *(Note: This will include all committee correspondence, decision outcomes, renewal notices, and adverse event submissions.)*
yes

Credentials: *Required for PI, Co-Is and Faculty Advisors*

Upload or update your CV, resume, or biographical sketch.

Name	Version
AGiordimainaCV	History	0.01

Conflict of Interest Detail: *Required for all roles except Administrative Staff*

Current Disclosure Status in M-Inform: *This study team member has not yet disclosed in M-Inform.*

D1 Do you have an outside interest or relationship with a non-UM entity that relates to this research in one of the following ways:

- The entity is sponsoring this research
- The entity's products are used in this research
- The entity has licensed your invention (e.g. device, compound, drug, software, survey, evaluation or other instrument) being used in this research
- Part of the work on this project will be subcontracted to the outside entity
- Other relationship not listed above

no

D2 If "Yes" to the question above, name the entity or entities and provide a brief description of the relationship(s).

Study Team Detail

1.4 Team Member:
Donna Walter
Preferred email: drwalt@umich.edu
Business phone   734-763-5325
Business address: Res Ctr for Group Dynamics 5253 ISR 48109-1248

1.5 Function with respect to project:
Research Staff

1.6 Allow this person to EDIT the application, including any supporting documents/stipulations requested during the review process:
yes

Date: 16/09/2015 14:43:43

`Print` `Close`

1.7 Include this person on all correspondences regarding this application: *(Note: This will include all committee correspondence, decision outcomes, renewal notices, and adverse event submissions.)*
yes

Credentials: *Required for PI, Co-Is and Faculty Advisors*

Upload or update your CV, resume, or biographical sketch.

Name   Version

There are no items to display

Conflict of Interest Detail: *Required for all roles except Administrative Staff*

Current Disclosure Status in M-Inform: *This study team member has not yet disclosed in M-Inform.*

D1 Do you have an outside interest or relationship with a non-UM entity that relates to this research in one of the following ways:

- The entity is sponsoring this research
- The entity's products are used in this research
- The entity has licensed your invention (e.g. device, compound, drug, software, survey, evaluation or other instrument) being used in this research
- Part of the work on this project will be subcontracted to the outside entity
- Other relationship not listed above

no

D2 If "Yes" to the question above, name the entity or entities and provide a brief description of the relationship(s).

02. Sponsor/Support Information

The following sections request details about the current or pending sponsorship/support of this study. Consider all of the choices below and complete the appropriate sections.

* Note: At least one of the following sections must be answered. Multiple sponsors or sources of support must be added one at a time.

2.1 External Sponsor(s)/Support:

Type	Name	Other Direct Sponsor/Support	Support Type	Has PAF?

There are no items to display

2.5 Internal UM Sponsor(s)/Support: [Including department or PI discretionary funding]

Type	Department Sponsor	Support Type
View UM Institutional - Department, Pilot Grant Program, or other Institutional funding source	RCGD - Rsrch Cntr for Grp Dyn	Both Financial and Non-financial

2.8 Check here if the proposed study does not require external or internal sponsorship or support:
☐

Internal Sponsor Detail

2.6* Department Sponsor/Support:
RCGD - Rsrch Cntr for Grp Dyn

2.6.1* Sponsor Type:
UM Institutional - Department, Pilot Grant Program, or other Institutional funding source

If other, please specify:

2.6.2* Support Type:
Both Financial and Non-financial

2.6.3* Is the support confirmed?

◉ **Yes** ○ No

2.7 Upload Supporting Documentation

Name   Version

There are no items to display

03. UM Study Functions

3.1* Indicate all functions that will be performed at University of Michigan locations.

Select all that apply:

Recruitment (including screening)

Interaction (e.g., information gathering, survey, interview, focus groups, etc.)

Intervention (e.g., use of drug or device, medical procedures, educational intervention, group intervention, social/psychological intervention etc.)

Observation of behavior (direct or indirect)

Qualitative research (e.g., 'member checking', open-ended questions, etc.)

Primary or secondary analysis (data/specimen)

Storage (data/specimen)

If other, please specify.

03-1. Performance Sites

3-1.1* Performance Sites:

Location	Country	"Engaged" in the research?	Site Function
University of Michigan	USA	yes	Qualitative research,Intervention,Storage,Interaction,Analysis,Observation,Recruitment

Performance Site Detail

3-1.2* Location or Institution:

University of Michigan

3-1.3 Address:

City
State
Country*****USA

3-1.4* Function of this location with respect to this study:

Select all that apply:

Recruitment (including screening)

Interaction (e.g., information gathering, survey, interview, focus groups, etc.)

Intervention (e.g., use of drug or device, medical procedures, educational intervention, group intervention, social/psychological intervention etc.)

Observation of behavior (direct or indirect)

Qualitative research (e.g., 'member checking', open-ended questions, etc.)

Primary or secondary analysis (data/specimen)

Storage (data/specimen)

If other, please specify:

3-1.5* Will this site be "engaged" in the conduct of the research?

◉ **Yes** ○ No

3-1.6 If known, provide the Federalwide Assurance (FWA) number for this location.
FWA00004969

3-1.7 If applicable, indicate what organization, agency or government office has reviewed this research and provided its approval (e.g., IRB, ethics committee, school district office, prison official, nursing home administrator).

3-1.8 Upload any location site approval documentation here:

Name   Version

There are no items to display

05. Research Design

5.1* Is there a stand-alone scientific protocol document and/or research plan associated with this application?

○ Yes ◉ **No**

5.2* Will the involvement of ANY subjects in this study be limited to analysis of their existing data or specimens?

○ Yes ◉ **No**

5.3* Will the study involve recruitment and/or participation of subjects in order to

produce new data *(e.g., surveys, interaction, intervention)*? *[Require sections 8-1 and 11-3]*

◉ Yes ◯ No

5.4* List the inclusion and exclusion criteria for this study population and/or data set. *(If covered in attached protocol, indicate section)*

All participants must be between 18 and 45 years of age with normal or corrected-to-normal vision and they must be right-handed.

No exclusion criterias will be implemented for eyetracking and ecg data collection.

5.5 Identify any racial, ethnic, or gender group(s) that will be specifically excluded from participation in this research study and provide a compelling justification for such exclusion:

No exclusion criteria on race, ethnicity or gender.

5.6* Indicate the age range (in years) of the subject population in this study.
Minimum Age: 18
Maximum Age: 45 If no upper limit, enter "999"

05-1. Research Design

In its review of research applications, the IRB considers whether research procedures are consistent with sound research design in order to yield the expected results. Scientific merit is examined in relationship to the risks and benefits of the research. This section covers the overall research design of the project. Later sections will ask more specific questions about benefits, risks, special review considerations, targeted populations, recruitment strategies, and experimental methodologies/procedures.

5-1.1* Objective: What is the overall purpose of this research study?

The objective of this study is to analyze how individuals will or will not search for information to aid decision in financial/economic scenarios and how scenario and information presentation may influence this process.

5-1.2* Specific Aim(s): What is (are) the specific aim(s) of this study and/or what hypothesis (hypotheses) is (are) to be tested?

Analyze if different scenario and information presentantion will influence the information acquisition and decision processes.

EEG: Scenario and information presentation will produce different components at different times within the epoch

ECG: Scenario and information presentation will produce differences in heart rate variability

Eyetracking: Individuals will tend to fixate more on information pieces and probabilities/consequences presentation.

Behavioral data: Individuals with different scores for the instruments will use different strategies for information acquisition and decision. Strategies will be compared with four models: Sensitivity to base rates, Negative Binomial, Random Walk and Ignore the Base Rates.

5-1.3* Background: What prior information or knowledge exists to support the conduct of this study?

Fifić and Buckmann (2013) discuss an integrative vision to determine a set of selection rules (stopping rules) in order to cease the search for information where the individual would access a storage of rules that he/she could use adaptively and according to her needs. They contrast rules that would be optimal by calculating bayesian probabilities factoring advices retrieved that are positive or negative contained in a space of n opinions, with greater cognitive demand. Fifić and Buckmann (2013) propose that individuals might use multiple rules aiming the maximization of the right moment to stop searching. Those rules, differently from the bayesian calculation, require less cognitive effort and thus makes it easier for the decision maker to decide when to stop. Assuming that individuals do search for information to help them in the decision process, when they do so each opinion will change or reinforce the individuals belief regarding the subjective probabilities of the occurrence of events or outcomes (Stern et al., 2010) and the expected returns of the decision (Pitz, 1968).

5-1.4* *Briefly* outline the special expertise and qualifications of the PI, Co-Investigators, and/or Faculty Advisors to conduct and/or oversee the particular procedures or activities involved in *this particular study*. This will supplement information provided in the study team CVs.

Judgment and Decision Making
Statistical Analysis
Probability modeling
Psychophysiological Measures

PI's affiliation with UM is Visiting Scholar.

5-1.5* Methodology: Describe the design and procedures to be used to accomplish the specific aims of the study. Describe the advantages of any innovative methodologies.

The experiment will take place in a quiet room. It is expected that the experiment will take around 45 minutes to 1 hour. EEG and ECG data will be recorded by Acknowledge 4.4 software, eye tracking data will be recorded via Tobii Studio and behavioral data and stimulus presentation will be made via PST E-Prime Professional 2.0. Linked acquisition of data will be possible using BIOPAC MP 150 with wi-fi modular attachments and Acqknowledge 4.4. Upon arrival, each participant will receive information about the study and be asked to read and sign the informed consent form. Once completed, participants will start equipment calibration. The first step is to place the EEG and ECG electrodes. The EEG and ECG data acquisition is made through BIOPAC ABM B-Alert X10. The EEG cap is composed of 9 electrodes and the ECG is composed of two electrodes, one positioned on the right collarbone and the other on the lower left rib of the participant. Once electrodes are placed, the EEG impedance test is realized via Acqknowledge 4.4. When the desired impedance is achieved, the participant will be escorted to the experiment room for eye tracking calibration. A Tobii TX300 equipment will be used to calibrate and collect gaze data. At the end of the eye tracking calibration process, the participant is ready to start the training scenario and the actual task. The PI or research

staff will be responsible for electrode placing and calibration.
The first screen will present details and instructions of the experiment. At this time, the participants will be informed that they will be presented with different economic/financial scenarios and that they will have to make a decision. They will also be informed that they will have at their disposal 20 information pieces (or advices) that they may or may not buy in order to help them decide. There will be a fixed fictional amount of $480 in order to complete the experiment. The next screen will be a test scenario in which the participants will be able to get familiarized with the way the experiment works. While participants view the first screens, the PI will be next to them explaining how the experiment works should the participants have any doubts. After the training screen, the PI will leave the room and the experiment will begin. A total of 24 economic/financial scenarios will be presented. Each scenario will bring a situation involving aspects of economic/financial decisions such as investments, purchases, asset management, losses, etc. After reading the description of the situation, participants may or may not choose to obtain information regarding the scenario. Participants will be required to make a decision for each scenario. They can decide to buy/invest/pay (Positive), not to buy/invest/pay (Negative) or they can choose not to decide at the moment (Procrastination) and go to the next scenario without making a positive or negative choice. There will not be a new attempt at that scenario, should the participant choose to procrastinate. Although the time spent on each scenario until a decision is reached or procrastinated will be recorded, participants will not receive any instructions regarding a maximum period of time for each scenario. They will be free to use as much time as they want to read the scenario description, seek information and make a decision.
Each scenario will have 20 information pieces that the participants can access in order to get an advice regarding the scenario at hand. All information are presented in a crescent and pseudorandom order. The order of information appearance is made to resemble the stopping rules according to Fifić and Buckmann (2013).
The 24 scenarios will be divided as such: 1) 12 scenarios with stated probabilities (risk) in the description, composed of 3 scenarios with low negative consequences, 3 with high negative consequences, 3 with low positive consequences and 3 with high positive consequences; 2) 12 scenarios with unstated probabilities (uncertainty) in the description, composed of 3 scenarios with low negative consequences, 3 with high negative consequences, 3 with low positive consequences and 3 with high positive consequences.

After the task is complete, each participant will complete the psychological instruments proposed. And at the end of this part they will receive their compensation (US$10.00 for participants recruited from PPSP and Face-to-Face and course credits for IPSP).

The main advantage of this methodology, especially in the equipments used, is the chance of associating different physiological measures for the same task. There is a great possibility of complementary data amongst measures.

There are no more than minimal risks in recording EEG, ECG, eyetracking and behavioral data. All responses will be kept confidential;l data files will be coded with subject ID numbers and ID numbers will not be attached to names.

AME55672: During equipment calibration one member of the research staff will ask control questions (support document is available in survey section). These questions are meant as control for the occasion of a abnormal signal or response. For example, a different baseline heartbeat might be measured because of coffee consumption or prescription drug intake. So in the data analysis this difference can be explained by the response of coffee intake. The responses will not constitute exclusion criteria. The responses will not be linked to the identity of the participant and he or she may refuse to answer any question without prejudice or exclusion from data collection.

5-1.6* Statistical Design: Describe the statistical design of the research study, including methods used to analyze data.
There will be two windows of analysis. 1) From 2.000 milliseconds before the decision is made up to 200 milliseconds after the decision is made.; 2) The duration of the scenario, from scenario onset until decision is made.

EEG data: Repeated measure ANOVA for decisions, scenarios and decision x scenarios. All of the parameters will be analyzed grouped by instruments results. Time window 1 will be used.

ECG data: Repeated measures ANOVA using baseline BPM against decisions and scenarios using time window 1 as a parameter. Also, repeated measures ANOVA using baseline BPM against scenario using time window 2. All of the parameters will be analyzed grouped by instruments results.

Eye tracking data: Fixation duration and percentage fixation in the probability statement words of scenario presentation and decision alternatives using time windows 1 and 2. All of the parameters will be analyzed grouped by instruments results.

Behavioral data: Strategies of information acquisition will be compared with the four proposed models. Quantity of information purchased compared against scenarios and decisions. All of the parameters will be analyzed grouped by instruments results. Repeated measures ANOVA will be used to compare groups and conditions.

Overall analysis: the results of each individual analysis will be compared to associate psychophysiological measures to the strategies and decisions performed by each group of participants.

06. Benefits and Risks

6.1 * Describe the potential benefits of this research to society.
- Understand how individuals search and acquire information in order to make a decision.
- Understand psychophysiological components of information acquisition and decision under scenarios of risk and uncertainty

6.2 * Will results of the research be communicated back to the subjects?
○ Yes ◉ **No**

6.3 * Describe any direct risks to the public or community, which could result from this research?
Given that all measures are not invasive and there is no use of drugs or clinical intervention, no major risks are foreseen in this study.

6.4 * Does this project involve study arms that have differing levels of benefit or risks to subjects?

○ Yes ◉ **No**

6.5 * Benefits and Risks:

Click "Add" to begin entering the benefit and risk level detail information associated with this study.

Name	Risk Level	Direct Benefit
View HUM00104379	No more than minimal risk	no

Benefits and Risk Level Detail

If a study involves multiple arms or phases that pose different levels of risk or direct benefits to subjects, then create an entry for each arm or phase using the "OK and Add Another" option at the bottom of this page. Only one entry is necessary if the risk level and the direct benefit to subjects is the same for the entire project, even if the study involves multiple arms or phases.

6.5.1 * Name of Arm (experimental group, study wave, etc.)
HUM00104379

6.6 * Are there potential direct benefits of this research to the subjects?

○ Yes ◉ **No**

6.7 * Provide a description of the foreseeable risks to subjects. For studies involving multiple arms or phases, enter the risks for this arm or phase only.

        Provide a description of the foreseeable risks to the subjects.

        For EACH identified risk, include:

- **Likelihood of the risk,**
- **Seriousness to the subject; and**
- **What measures will be taken to minimize the risk (for example, study design includes the substitution of procedures already being performed on the subject for diagnostic or treatment purposes, or in a study of Post-Traumatic Stress Disorder, the investigator takes steps to identify, manage, or refer as appropriate, subjects for whom the study may evoke very difficult emotions)**

        If possible, please use the following categories to assess the likelihood:

- **"Common" (i.e., approximate incidence > 25%)**
- **"Likely" (i.e., approximate incidence of 10-25%)**
- **"Infrequent" (i.e., approximate incidence of 1-10%)**
- **"Rare" (i.e., approximate incidence < 1%):**

The main risk associated will be discomfort due to equipment calibration and experiment duration. Perceived likelihood of this risk is rare.

Although unlikely to happen, given the hypoallergenic condition of the conducting gel, should an allergic reaction occur during or after the experiment, the participant will be escorted to the hospital for appropriate medical procedures.

6.8 * What is the level of risk of harm to the subjects, resulting from this arm of the research? For studies involving multiple arms or phases, enter the level of risk for this arm or phase only.
No more than minimal risk

6.9 * Discuss why the risks to the subjects are reasonable in relation to the anticipated benefits.
There is minimal chance of any kind of serious risk given the anonymous and non-invasive characteristics of data collection and analysis. The benefits of advancing the understanding of the strategies used to collect information and decide in risky and uncertain scenarios using multiple psychophysiological measures at the same time far outweight the risks.

07. Special Considerations

7.1* Does this study involve human tissue or biological specimens (use, collection, or secondary analysis) *(e.g. blood, urine, bone marrow, skin, etc.)? [Require Section 18]*

○ Yes ◉ **No**

7.2* Does this study involve the secondary analysis of a pre-existing data set, including data associated with any specimens identified in response to question 7.1? *[Require Section 24]*

○ Yes ◉ **No**

7.3* Will the research involve the access, collection, use, maintenance, or disclosure of University of Michigan protected health information (PHI)? PHI is:

- **information about a subjects past, present, or future physical or mental health, the provision of healthcare to a subject, or payment for the provision of healthcare to a subject; AND**
- **maintained by a University of Michigan school, department, division, or other unit that is part of the University's HIPAA-covered component (e.g. healthcare provider, healthcare plan, or healthcare clearinghouse).**

[Require Section 25]

○ Yes ● **No**

07-1. Special Considerations - Continued

7-1.1* Will subjects receive payment or other incentives for their participation in the study? *[Require Section 13]*

● **Yes** ○ No

7-1.2* Will subjects undergo healthcare-related treatments or procedures (standard of care and/or research) as part of the study? *[Require Section 14]*

○ Yes ● **No**

7-1.3* Does this study involve the deception or concealment of subjects? *[Require Section 27]*

○ Yes ● **No**

7-1.4* Excluding routine email correspondence, does this study involve the use of the Internet or email as an integral part of the research design or will sensitive information be transmitted by e-mail? *[Require Section 28]*

○ Yes ● **No**

7-1.5* Will the study collect data using surveys, interviews, or focus groups? *[Require Section 29]*

● **Yes** ○ No

7-1.6* Does this study require subjects to listen to an audio recording or view images? *[Require Section 31]*

○ Yes ● **No**

7-1.7* Will any drugs, biologics, nutritional *(e.g., herbal or alternative medication)* **supplements or other material be administered, implanted, or applied to the subjects as the object of the study?** *[Require Section 15]*

○ Yes ● **No**

7-1.8* Will the study involve a placebo *(drug, device, procedure, intervention, surgery, etc.)* **control group?** *[Require Section 17]*

○ Yes ● **No**

7-1.9* Will the study involve human embryonic stem cells (hESCs) or induced pluripotent stem cells? *[Require Section 19]*

○ Yes ● **No**

7-1.10* Will the study have a Data and Safety Monitoring Plan (DSMP)? *[Require Section 32]*

○ Yes ● **No**

7-2. Special Consideration - Continued

7-2.1* Will any devices be used, administered, implanted, or applied to the subjects, or will human specimens be used to test in vitro diagnostic devices?
[Non-IRB HSBS and Non-IRB Dearborn Applications Require Section 16]

● **Yes** ○ No

7-2.1.1* Describe all devices that are the OBJECT of the study, or ARE RELEVANT to the study. If this study is designed to test the safety or efficacy of any of these devices, then this project is FDA-regulated and must be reviewed by IRBMED.
EEG, ECG and Eyetracking

7-2.2* Will the subjects be exposed to any ionizing radiation during the course of this study? *[Require Section 21]*

○ Yes ● **No**

7-2.3* Will any organs, tissues, or cells from other humans *(including fetal tissue)* **or animals be administered to the subjects for the purposes of this study?** *[Require Section 22]*

○ Yes ● **No**

7-2.4* Does this study involve a gene transfer intervention or an intervention based on recombinant DNA technology? *[Require Section 23]*

○ Yes ● **No**

08. Subject Participation

8.1* Please indicate the number of subjects to be enrolled from ALL study locations to achieve the goal of the study:
50

8.2* Enter the estimated number of subjects to be enrolled at each University of Michigan site:

Location Or Institution	Total
University of Michigan	
Adults	50
Children	0

Total from all University of Michigan sites: **50**

08-1. Subject Recruitment

8-1.1* At what point in the study are you planning on beginning the recruitment of subjects?
0-2 years after approval

8-1.2* Indicate which of the following established subject pools, if any, will be used for recruitment.
Select all that apply:

UM Ann Arbor Introductory Psychology Pool
Other UM subject pools (describe below)

Provide Related UM IRB Project Number or Subject Pool Description:

Paid Psychology Subject Pool (PPSP)

8-1.3* Describe the manner in which potential study subjects will be recruited. List how, when, who will recruit and where they will be recruited. Include any provisions to protect or maintain subject privacy.
E-mail contact by one of research team members from UM sites and pools;
Participants referall

Each participant will be asked to contact one single member of the research team who will be responsible for scheduling participation. Upon confirmation each participant will be given a code in order to protect its privacy.

8-1.3.1 If applicable, how will prospective subjects' healthcare providers *(e.g., physician, dentist, etc.)* **be involved in the recruitment and/or be notified of their individual patients' participation in the study?**

8-1.4* Explain how the recruitment strategy is equitable and represents the population required for the study. *If the information is covered in the attached protocol, please indicate section.*
Inclusion and exclusion criteria are flexible enough in order to attend the proposed recruitment strategies.

8-1.5* Does the recruitment strategy involve contacting individuals multiple times in an effort to secure their initial enrollment into the study?

◉ **Yes** ○ No

8-1.5.1* Describe how frequently and in what manner individuals will be contacted. *If the information is covered in the attached protocol, please indicate section.*
No more than three times.

1) Schedule participation - Contact will be made once the e-mail from participant is received
2) Schedule confirmation - one day prior to scheduled date an e-mail and/or a text message will be sent to remind participants of date and time of participation
3) Participation check - If applicable, participants will be contacted if there is any kind of technical issues that might hinder participation or if participant is more than 30 minutes late for its due start time.

8-1.6* Indicate which methods will be used for recruitment?
Check all that apply:

Face-to-face contact (e.g. during a health care visit or an interview at a home address, etc.)
Email
Telephone
Other

If other please specify:

Participant referral, Paid Psychology Subject Pool (PPSP) post

8-1.7 How will any email, address, and/or telephone lists be obtained?

8-1.8* What materials will be used for recruitment? *The IRB must approve all recruitment materials.*

See Help for important information regarding the requirements for recruitment materials
Check all that apply:

Pre-screening questions
Oral scripts

If other please specify:

Paid Psychology Subject Pool (PPSP) post

If Web pages will be used, provide the Web address (URL) for the location where the pages will be posted (also upload the content of the pages below):

Upload recruitment materials here:

See Help for more information about working with documents (e.g. uploading, downloading, and editing).

Name	Version
AME55672 IPSP post | History	0.02
AME55672 Oral Script for New study | History	0.01
AME55672 Pre-screening questions | History	0.02
Oral Script | History	0.01
PPSP post | History	0.01

☐ **Check here if any of the materials are not available electronically.**

Note: Study Teams are encouraged to scan and upload documents. See Help for a list of sites with scanning facilities

09. Survey Populations

9.1* Is the study limited to a survey of either:
- The general adult population (aged 18 or older); or
- A subgroup of the general population which does not specifically target:

    - Pregnant women and/or fetuses
    - Lactating women
    - Women of child-bearing potential
    - Prisoners
    - Cognitively impaired adults
    - College students
    - Economically or educationally disadvantaged persons
    - Patients of the study team
    - Employees, students or trainees of the study team
    - Family members of the study team

    where the survey is the sole interaction with the subject and does not pose more than minimal risk?

○ Yes ◉ **No**

09-1. Subject Populations

9-1.1* Is the research designed to include or allow the following populations?
Select all that apply

☑ **Normal, healthy subjects**

☑ **Adults** *age 18 and older*

☐ **Minors able to consent** *to treatments or procedures involved in the research, under the applicable law of the jurisdiction in which the research will be conducted (e.g. emancipated minors or minors seeking treatment for certain conditions.)*

☐ **Children and/or Viable Neonates** *(i.e. persons who have not yet reached the legal age for consent to treatments or procedures involved in the research, under the applicable law of the jurisdiction in which the research will be conducted) [Require Sections 33 and 41]*

☐ **Neonates of uncertain viability and/or nonviable neonates** *(do not check this box if the research is solely retrospective. For retrospective research regarding neonates of uncertain viability, check the box for 'Children'. See Help for additional information.) [Require Section 34]*

☐ **Individuals and/or products involving human in vitro fertilization**

☐ **Pregnant women and/or fetuses** *[Require Sections 35 and 41]*

☐ **Lactating women** *[Require Section 36]*

☐ **Women of child-bearing potential** *[Require Section 37]*

☐ **Prisoners** *(If the research includes a study population that is likely to become incarcerated during the conduct of the research, also select this category) [Require Section 38 and 41]*

☐ **Cognitively impaired adults** *[Require Sections 39 and 41]*

☑ **College students** *[Require Sections 40 and 41]*

☐ **Economically or educationally disadvantaged persons** *[Require Section 41]*

☐ **Patients of the study team** *[Require Section 41]*

☐ **Employees, students or trainees of the study team** *[Require Section 41]*

☐   **Family members of the study team** *[Require Section 41]*

☐   **Unknown, unspecified population**

10. Informed Consent - Adults

10.1*   **What type of informed consent will be obtained from adults or minors legally able to consent to treatments or procedures involved in the research?**

Select all that apply:

Comprehensive written

10.1.2*   **Describe the process to seek and obtain informed consent and/or assent from adults. If requesting a waiver of documentation of assent, provide justification here.**

Informed consent will be obtained as soon as the participant arrives for the scheduled date and time. One member of the research team will allow time for the participant to read and ask any questions and then sign the informed consent.

10.1.3*   **Is the cognitive capacity of the subjects expected to change significantly during the study?**

○ Yes   ● **No**

10-1. Informed Consent

10-1.1*   **All documents related to consent, assent, permission, and or debriefing documents, including oral scripts must be uploaded here. If you are requesting a waiver of documentation of informed consent, upload a copy of any written materials to be provided to participants, and provide a written description of any information to be provided orally.**

Name	Version
AME55672 Baseline consent for Intro Psych Pool subjects | History	0.02
AME55672 Debriefing form | History	0.01
Baseline consent | History	0.03

10-1.2*   **Will the subjects be audiotaped, videotaped, or photographed (identifiable images of subject) during the research?**

○ Yes   ● **No**

10-1.3*   **Is there a substantial likelihood that the research will be conducted among a non-English-speaking population?**

○ Yes   ● **No**

10-1.4*   **Indicate which anticipated costs could be the full or partial responsibility of the subject.**

Check all that apply:

No anticipated costs

If other, please specify:

10-1.5*   **Is the study designed to collect identifiable information from primary research subjects about other individuals, including family members?**

○ Yes   ● **No**

10-1.6*   **At the conclusion of this study, will specimens and/or data be retained for future research use?**

○ Yes   ● **No**

11. Confidentiality/Security/Privacy

11.1*   **Will the study team access any data that is linked to a subject's identity by name or other identifier or code?** *[Require Section 11-1]*

● **Yes**   ○ No

11.2*   **Explain how the subjects' privacy will be protected.**

Participants will correspond via e-mail or phone with only two members of the research team (Roberto Nonohay or Donna Walter). Once participants arrive at the lab, they will not write their names on any other documents than the Consent Form, which will be kept in a folder in a secure drawer. During their participation they will always be identified by a three digit number (e.g., 001). When prompted by the data collection software or at the beginning of each instrument participants will only write their numeric code. There will be no records linking real personal information to the numeric code.

Equipment placement and calibration will be made in a private room where only the participant and members of the research staff will be present. During data collection and instrument completion the participants will be in a private room by themselves. Members of the research team will only access the room at this point upon completion of instruments/experiment or by request of the participant.

11.3*   **How will the study team protect research records, data, and/or specimens against inappropriate use or disclosure, or malicious or accidental loss or destruction in order to protect the confidentiality of subject data?**

Select all that apply:

Destruction of source data immediately after data collection (e.g., to preserve anonymity of a vulnerable population)

Secure laptop

If other please specify:

11.4* Will the research generate information that, if revealed, might place the subjects at risk of personal safety, criminal or civil liability, or damage to their financial standing, employability, or reputation [Require Section 11-2]

   Yes   ● **No**

11.5* Will data be provided to a repository as part of a data sharing agreement?

   Yes   ● **No**

11.6* What will happen to the data and/or any specimens at the conclusion of this study?

Select all that apply:

Retain for study recordkeeping purposes

11.6.2* If the data and/or specimens will be retained for study recordkeeping purposes, provide the following information (if covered in the attached protocol, please indicate section):

- expected duration of the retention period,
- any changes in the conditions or arrangements for storage of research data/specimens during the retention period, if different from those listed above in question 11.3.

It will be kept for 7 years per conventions in the field of psychology.

11-1. Identifiable Data

Completion of this section is required based on the response provided to question 11.1.

11-1.1* Indicate how subjects are identified in the research records.

Select all that apply:

No Identifiers (De-identified, Anonymous, or Anonymized) - stored data record is stripped of all identifiers

11-1.2* Explain the necessity for collecting or maintaining data linked to subjects' identities. If the information is covered in the attached protocol, please indicate section.
There willl be no kind of data linked to subject's identities.

11-1.3* How long will the identifiers be retained?
There will be no kind of data linked to subject's identities.

11-1.4* Will individually identifiable sensitive data be accessed, collected, used, maintained, or disclosed in the study?

   Yes   ● **No**

11-3. End of Subject Participation

11-3.1* What specific criteria will be used to prematurely end a particular subject's participation in the study (If covered in attached protocol or informed consent, indicate specific location).
If the participant asks to withdraw from participating at any time, before or during data collection.

11-3.2* If a participant withdraws from the research, what is the plan to use, disclose, store, or destroy the participant's data and/or specimen?
Any kind of data or information collected will be destroyed. If participant decides to withdraw before data collection, all e-mail exchange will be permanently erased. If participant decides to withdraw during data collection, all files and/or surveys completed up until the moment will be immediately deleted or destroyed.

13. Subject Payments Or Other Incentives

Completion of this section is required based on the response provided to question 7-1.1 or 7-3.3.

13.1* Indicate all payments or other incentives provided to subjects for their participation in this study:

Select all that apply:

Cash

Course credit

If other, please specify:

13.2* If the subject is a child (under the age of 18 in Michigan), are any of the payments or incentives intended for the parent/guardian of the child?
N/A

13.3* Estimate the maximum total payment (including cash, checks, gift cards, and other cash-equivalent incentives) that an individual subject could receive for participating in this research in a single calendar year.
$0.01-$25

13.3.1* Please indicate what information you will be collecting from subjects in order to distribute their incentive or compensation.
Select all that apply:

Email
Name

13.4* Describe the frequency of the payments or incentives. If applicable, list any healthcare procedure(s) that will be provided to subjects at no charge.
Once at the end of the experiment

13.5* What is the justification for offering these payments or incentives?
As an incentive for participation.

13.6* What is the plan to compensate subjects withdrawing from the research prior to completing the entire study.
They will be paid normally.

AME55672: They will be paid normally or course credits will be given normally

29. Survey Research

Completion of this section is required based on the response provided to question 7-1.5.

29.1* Provide a list of all surveys and interviews used in the study:

Name	# of Questions	Duration	Sensitive?	Disturbing?
AME55672 Control questions	7	2 minutes	no	no
Barratt Impulsiveness Scale	30	12 minutes	no	no
Beck Anxiety Inventory	21	10 minutes	no	no
Big Five Personality Test (Short version)	10	7 minutes	no	no
Maximization Scale	13	7 minutes	no	no
Need for Cognition	18	10 minutes	no	no
Regret Scale	5	3 minutes	no	no

29.13* Will the research involve the use of focus groups?

○ Yes ◉ **No**

29.14* Is any of the material disturbing?

○ Yes ◉ **No**

Survey Detail

29.2* Survey or interview name:
AME55672 Control questions

29.3* Is the design or development of this survey instrument dependent on receipt of funding or hiring of personnel?

○ Yes ◉ **No**

29.4* In what manner will the survey or interview be conducted *(e.g., in-person, Internet, mail, telephone, etc.)***? Special Note: For electronic surveys, the eResearch ID number must be included in the informed consent document (uploaded in section 10-1) or other material that serves as the informed consent.**
In-person

29.5* What is the predicted response rate?
100 %

29.6* What is the total number of questions?
7

29.7* What is the anticipated cumulative amount of time required for each subject?
2 minutes

29.8* What is the total number of interviews/data collection interactions with an individual subject?
1

29.9* Does the survey or interview contain questions of a sensitive nature *(e.g., mental illness, sexual abuse, illicit drug use, etc.)***?**

○ Yes ◉ **No**

29.10* Is the survey or interview likely to produce psychological discomfort or negative feelings in the subjects?

○ Yes ◉ **No**

29.11* Has the survey instrument been validated or used in standard practice?

○ Yes   ● **No**

29.12* Upload the survey instrument here.

Name	Version
AME55672 Control questions	History	0.02

Survey Detail

29.2* Survey or interview name:
Barratt Impulsiveness Scale

29.3* Is the design or development of this survey instrument dependent on receipt of funding or hiring of personnel?

○ Yes   ● **No**

29.4* In what manner will the survey or interview be conducted *(e.g., in-person, Internet, mail, telephone, etc.)*? ***Special Note: For electronic surveys, the eResearch ID number must be included in the informed consent document (uploaded in section 10-1) or other material that serves as the informed consent.***
In-person

29.5* What is the predicted response rate?
100 %

29.6* What is the total number of questions?
30

29.7* What is the anticipated cumulative amount of time required for each subject?
12 minutes

29.8* What is the total number of interviews/data collection interactions with an individual subject?
1

29.9* Does the survey or interview contain questions of a sensitive nature *(e.g., mental illness, sexual abuse, illicit drug use, etc.)*?

○ Yes   ● **No**

29.10* Is the survey or interview likely to produce psychological discomfort or negative feelings in the subjects?

○ Yes   ● **No**

29.11* Has the survey instrument been validated or used in standard practice?

● **Yes**   ○ No

29.11.1* If yes, describe the origin of the instrument.
Patton JH, Stanford MS, and Barratt ES (1995)
Journal of Clinical Psychology, 51, 768-774. PubMed ID 8778124

29.12* Upload the survey instrument here.

Name	Version
Barratt Impulsiveness Scale	History	0.01

Survey Detail

29.2* Survey or interview name:
Beck Anxiety Inventory

29.3* Is the design or development of this survey instrument dependent on receipt of funding or hiring of personnel?

○ Yes   ● **No**

29.4* In what manner will the survey or interview be conducted *(e.g., in-person, Internet, mail, telephone, etc.)*? ***Special Note: For electronic surveys, the eResearch ID number must be included in the informed consent document (uploaded in section 10-1) or other material that serves as the informed consent.***
In-person

29.5* What is the predicted response rate?
100 %

29.6* What is the total number of questions?
21

29.7* What is the anticipated cumulative amount of time required for each subject?
10 minutes

29.8* What is the total number of interviews/data collection interactions with an individual subject?
1

29.9* Does the survey or interview contain questions of a sensitive nature *(e.g., mental illness, sexual abuse, illicit drug use, etc.)***?**
  ○ Yes ⦿ **No**

29.10* Is the survey or interview likely to produce psychological discomfort or negative feelings in the subjects?
  ○ Yes ⦿ **No**

29.11* Has the survey instrument been validated or used in standard practice?
  ⦿ **Yes** ○ No

29.11.1* If yes, describe the origin of the instrument.
Beck AT, Epstein N, Brown G, Steer RA (1988). "An inventory for measuring clinical anxiety: Psychometric properties". Journal of Consulting and Clinical Psychology 56: 893–897. doi:10.1037/0022-006x.56.6.893

29.12* Upload the survey instrument here.

Name	Version
Beck Anxiety Inventory	History	0.01

Survey Detail

29.2* Survey or interview name:
Big Five Personality Test (Short version)

29.3* Is the design or development of this survey instrument dependent on receipt of funding or hiring of personnel?
  ○ Yes ⦿ **No**

29.4* In what manner will the survey or interview be conducted *(e.g., in-person, Internet, mail, telephone, etc.)***? *Special Note: For electronic surveys, the eResearch ID number must be included in the informed consent document (uploaded in section 10-1) or other material that serves as the informed consent.***
In-person

29.5* What is the predicted response rate?
100 %

29.6* What is the total number of questions?
10

29.7* What is the anticipated cumulative amount of time required for each subject?
7 minutes

29.8* What is the total number of interviews/data collection interactions with an individual subject?
1

29.9* Does the survey or interview contain questions of a sensitive nature *(e.g., mental illness, sexual abuse, illicit drug use, etc.)***?**
  ○ Yes ⦿ **No**

29.10* Is the survey or interview likely to produce psychological discomfort or negative feelings in the subjects?
  ○ Yes ⦿ **No**

29.11* Has the survey instrument been validated or used in standard practice?
  ⦿ **Yes** ○ No

29.11.1* If yes, describe the origin of the instrument.
Rammstedt, B. & John, O. P. (2007). Measuring personality in one minute or less: A 10-item short version of the Big Five Inventory in English and German. Journal of Research in Personality, 41, 203-212.

29.12* Upload the survey instrument here.

Name	Version
Big Five Personality Test (Short version)	History	0.01

Survey Detail

29.2* Survey or interview name:
Maximization Scale

29.3* Is the design or development of this survey instrument dependent on receipt of funding or hiring of personnel?

  ⚪ Yes 🔘 **No**

29.4* In what manner will the survey or interview be conducted *(e.g., in-person, Internet, mail, telephone, etc.)*? *Special Note: For electronic surveys, the eResearch ID number must be included in the informed consent document (uploaded in section 10-1) or other material that serves as the informed consent.*
In-person

29.5* What is the predicted response rate?
100 %

29.6* What is the total number of questions?
13

29.7* What is the anticipated cumulative amount of time required for each subject?
7 minutes

29.8* What is the total number of interviews/data collection interactions with an individual subject?
1

29.9* Does the survey or interview contain questions of a sensitive nature *(e.g., mental illness, sexual abuse, illicit drug use, etc.)*?

  ⚪ Yes 🔘 **No**

29.10* Is the survey or interview likely to produce psychological discomfort or negative feelings in the subjects?

  ⚪ Yes 🔘 **No**

29.11* Has the survey instrument been validated or used in standard practice?

  🔘 **Yes** ⚪ No

29.11.1* If yes, describe the origin of the instrument.
Schwartz, B., Ward, A., Monterosso, J., Lyubomirsky, S., White, K., & Lehman, D. R. (2002). Maximizing versus satisficing: happiness is a matter of choice. Journal of Personality and Social Psychology, 83, 1178- 1197.

29.12* Upload the survey instrument here.

Name	Version
Maximization Scale	History	0.01

Survey Detail

29.2* Survey or interview name:
Need for Cognition

29.3* Is the design or development of this survey instrument dependent on receipt of funding or hiring of personnel?

  ⚪ Yes 🔘 **No**

29.4* In what manner will the survey or interview be conducted *(e.g., in-person, Internet, mail, telephone, etc.)*? *Special Note: For electronic surveys, the eResearch ID number must be included in the informed consent document (uploaded in section 10-1) or other material that serves as the informed consent.*
In-person

29.5* What is the predicted response rate?
100 %

29.6* What is the total number of questions?
18

29.7* What is the anticipated cumulative amount of time required for each subject?
10 minutes

29.8* What is the total number of interviews/data collection interactions with an individual subject?
1

29.9* Does the survey or interview contain questions of a sensitive nature *(e.g., mental illness, sexual abuse, illicit drug use, etc.)*?

  ⚪ Yes 🔘 **No**

29.10* Is the survey or interview likely to produce psychological discomfort or negative feelings in the subjects?

⚪ Yes ⚫ **No**

29.11* Has the survey instrument been validated or used in standard practice?

⚫ **Yes** ⚪ No

29.11.1* If yes, describe the origin of the instrument.

Cacioppo, J. T., & Petty, R. E. (1984). The need for cognition: Relationships to attitudinal processes. In R. P. McGlynn, J. E. Maddux, C. Stoltenberg, & J. H. Harvey (Eds.), Social perception in clinical and counseling psychology. Lubbock, Texas Tech University Press.

29.12* Upload the survey instrument here.

Name	Version
Need for Cognition	History	0.01

Survey Detail

29.2* Survey or interview name:
Regret Scale

29.3* Is the design or development of this survey instrument dependent on receipt of funding or hiring of personnel?

⚪ Yes ⚫ **No**

29.4* In what manner will the survey or interview be conducted (e.g., in-person, Internet, mail, telephone, etc.)**? Special Note: For electronic surveys, the eResearch ID number must be included in the informed consent document (uploaded in section 10-1) or other material that serves as the informed consent.**
In-person

29.5* What is the predicted response rate?
100 %

29.6* What is the total number of questions?
5

29.7* What is the anticipated cumulative amount of time required for each subject?
3 minutes

29.8* What is the total number of interviews/data collection interactions with an individual subject?
1

29.9* Does the survey or interview contain questions of a sensitive nature (e.g., mental illness, sexual abuse, illicit drug use, etc.)**?**

⚪ Yes ⚫ **No**

29.10* Is the survey or interview likely to produce psychological discomfort or negative feelings in the subjects?

⚪ Yes ⚫ **No**

29.11* Has the survey instrument been validated or used in standard practice?

⚫ **Yes** ⚪ No

29.11.1* If yes, describe the origin of the instrument.

Schwartz, B., Ward, A., Monterosso, J., Lyubomirsky, S., White, K., & Lehman, D. R. (2002). Maximizing versus satisficing: happiness is a matter of choice. Journal of Personality and Social Psychology, 83, 1178- 1197.

29.12* Upload the survey instrument here.

Name	Version
Regret Scale	History	0.01

41. Subjects Vulnerable to Coercion

Completion of this section is required based on the response provided to question 9-1.1, 9-2.1, or 9-3.1

The following subject populations, vulnerable to coercion or undue influence, have been identified for inclusion in the study.

College Students

41.1* What is the justification for the inclusion of these subject populations?
Availability and population fits target criteria for study

41.2* Describe the additional safeguards that have been included in this study to protect the rights and welfare of these subjects.

Participation is voluntary and anonymous. At any point if the participant wishes to withdraw he/she can do so without any kind of prejudice whatsoever. No link to the name of the participant will be made in the study.

44. Additional Supporting Documents

44.1 Please upload any additional supporting documents related to your study that have not already been uploaded. Examples include, but are not limited to, data collection sheets, newsletters, subject brochures, and instructional brochures.

Name	Version
AME55672 Debriefing form	History	0.01

45. End of Application

The form was successfully submitted. Click 'Exit' or 'Finish' to leave the form.

UNIVERSITY OF MICHIGAN   **Roberto Guedes de Nonohay <rguedesd@umich.edu>**

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eResearch Notification: HUM00106606 has been approved by the IRB.

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eresearch@umich.edu <eresearch@umich.edu>   Wed, Sep 30, 2015 at 3:32 PM
Reply-To: eresearch@umich.edu
To: gonzo@umich.edu, almagior@umich.edu, rguedesd@umich.edu, drwalt@umich.edu

UNIVERSITY OF MICHIGAN eResearch.umich.edu

Health Sciences and Behavioral Sciences Institutional Review Board (IRB-HSBS) • 2800 Plymouth Rd., Building 520, Room 1170, Ann Arbor, MI 48109-2800

• phone (734) 936-0933 • fax (734) 998-9171 • irbhsbs@umich.edu

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To: Mr. Roberto Guedes de Nonohay

From:

Thad   Polk

Cc:

Richard   Gonzalez
Alicia   Carmichael
Roberto   Guedes de Nonohay
Donna   Walter

Subject:Initial Study Approval for [HUM00106606]

SUBMISSION INFORMATION:
Study Title: Belief Updating
Full Study Title (if applicable): Belief Updating: EEG, ECG and Eyetracking correlates.
Study eResearch ID: HUM00106606
Date of this Notification from IRB:9/30/2015
Review: Expedited
Initial IRB Approval Date: 9/28/2015
Current IRB Approval Period:9/28/2015 - 9/27/2016
Expiration Date: Approval for this expires at **11:59 p.m. on 9/27/2016**
UM Federalwide Assurance (FWA): FWA00004969 (For the current FWA expiration date, please visit the
UM HRPP Webpage)
OHRP IRB Registration Number(s): IRB00000246

Approved Risk Level(s):

Name	Risk Level
HUM00106606	No more than minimal risk

NOTICE OF IRB APPROVAL AND CONDITIONS:
The IRB HSBS has reviewed and approved the study referenced above. The IRB determined that the proposed research conforms with applicable guidelines, State and federal regulations, and the University of Michigan's Federalwide Assurance (FWA) with the Department of Health and Human Services (HHS). You must conduct this study in accordance with the description and information provided in the approved application and associated

documents.

APPROVAL PERIOD AND EXPIRATION:
The approval period for this study is listed above. Please note the expiration date. If the approval lapses, you may not conduct work on this study until appropriate approval has been re-established, except as necessary to eliminate apparent immediate hazards to research subjects. Should the latter occur, you must notify the IRB Office as soon as possible.

IMPORTANT REMINDERS AND ADDITIONAL INFORMATION FOR INVESTIGATORS

APPROVED STUDY DOCUMENTS :
You must use any date-stamped versions of recruitment materials and informed consent documents available in the eResearch workspace (referenced above). Date-stamped materials are available in the "Currently Approved Documents" section on the "Documents" tab.

RENEWAL/TERMINATION:
At least two months prior to the expiration date, you should submit a continuing review application either to renew or terminate the study. Failure to allow sufficient time for IRB review may result in a lapse of approval that may also affect any funding associated with the study.

AMENDMENTS:
All proposed changes to the study (e.g., personnel, procedures, or documents), must be approved in advance by the IRB through the amendment process, except as necessary to eliminate apparent immediate hazards to research subjects. Should the latter occur, you must notify the IRB Office as soon as possible.

AEs/ORIOs:
You must inform the IRB of all unanticipated events, adverse events (AEs), and other reportable information and occurrences (ORIOs). These include but are not limited to events and/or information that may have physical, psychological, social, legal, or economic impact on the research subjects or other.

Investigators and research staff are responsible for reporting information concerning the approved research to the IRB in a timely fashion, understanding and adhering to the reporting guidance (http://medicine.umich.edu/medschool/research/office-research/institutional-review-boards/guidance/adverse-events-aes-other-reportable-information-and-occurrences-orios-and-other-required-reporting), and not implementing any changes to the research without IRB approval of the change via an amendment submission. When changes are necessary to eliminate apparent immediate hazards to the subject, implement the change and report via an ORIO and/or amendment submission within 7 days after the action is taken. This includes all information with the potential to impact the risk or benefit assessments of the research.

SUBMITTING VIA eRESEARCH:
You can access the online forms for continuing review, amendments, and AEs/ORIOs in the eResearch workspace for this approved study (referenced above).

MORE INFORMATION:
You can find additional information about UM's Human Research Protection Program (HRPP) in the Operations Manual and other documents available at: http://hrpp.umich.edu.

Thad Polk
Chair, IRB HSBS