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The role of prototyping in design and policy making: Visual stimuli, selective attention and decision making

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1. Overview

This is a theory paper. In this study, we integrate research on visual stimuli, selective attention and decision making to explore the role of data prototyping in design and policy making, in the context of education. The ultimate goal is to investigate a high-end, sophisticated decision-making tool that is being developed to be used in a decision theater (DT) where multiple state stakeholders come around the tool to make decisions related to education policies in the State. As an engineering research method, we explore the reciprocal relationship between "selective attention" and "emotions" as cognitive processes that serve, in the individual, as precursors to the social aspect of decision making in the setting of DT. Previous research work has tested the hypotheses of how attention can override discrimination in decision making; and studied the three executive functions (inhibiting, shifting and updating) in relation to intelligence. In this work we are investigating how attention to certain features in a data visualization affect decision making related to educational policy in a social setting. Previous research work has provided ample evidence that emotional stimuli modulates attention. In this work we are investigating the reverse relationship; more specifically, how attention to certain features in a data visualization influences affective judgement, and consequently, decision making related to educational policy. We explore how prior attentional state drives emotional state in the study of data visualization as it relates to education policy making. Implications shed light on perspectives related to the way we interact with a large set of data visualizations. Consider, for example, a situation where a decision needs to be made based on a collection of different data visualizations, representing data from different sources and through different representation media. One may wonder whether the attention to a certain "screen" or "exhibit" may drive the conclusions that one wishes to reach. Furthermore, in an educational policy making setting, the notion of "emotional states" become important, where emotion, as the studied aspect of the human behavior, is viewed as a "process" that evaluates current and future goals. It is clearly demarcated from attention which is viewed as a "brain process" that actively determines what and where objects are. This connection between, on the one hand, attention as a rational process, and, on the other hand, emotion as a consequential process, is something that needs to be explored in the context of data visualizations and decision making. Implications would affect our understanding of conventional marketing strategies of certain policy making in education.

2. Purpose of this paper

This is a theory paper submitted to the Educational Research Methods (ERM) Division providing a meta-analysis of the context of the intended topic; that is, research on visual stimuli, selective attention and decision making to explore the role of data prototyping in design and policy making. The paper aims to connect theories from different disciplines. The intention is to provide a background for a planned experimental study. We believe interested researchers might find this theory review valuable, especially within the context of growing interest in complex data systems that support decision making. While our effort continues to conduct the experiment and analyze the results, we find this synthesis valuable to the engineering education research community in many ways. More specifically, we find this review important to situate future efforts in the context of previous literature and to reveal relationships that can be used to extend existing theories.

3. Background

2.1 Selection in the context of decision making in design

Design thinking involves making decisions. The process of making decision in design is characterized by the ability of the designer to navigate ambiguity, combine multiple ideas, and going through iterative loops between divergent and convergent thinking (Dym, Agogino, Eris, Frey, & Leifer, 2005). In the context of this research design, making decisions is based on provided data that describe the system under consideration; i.e., the State educational system. In this context, designers and various stakeholders are asked to expand the boundaries of their understanding of the educational system to take into account different, displayed factors, in the form of visualized data, and their impact on system to be designed (see Hasting (2004)). There are three major attributes to selection in the context of decision making in design: (1) thinking about system dynamics; (2) reasoning about uncertainty; and (3) making estimates.

In *thinking about system dynamics*, a designer attempts to anticipate consequences, and, therefore, continuously evaluates alternatives based on interactions. The process requires to qualitatively reason about feedback and flows in the system (Sterman, 1994; Gharajedaghi & Ackoff, 1985). Previous research has attempted to understand human's ability for reasoning about system dynamics (Doyle, 1997). In *reasoning about uncertainty*, a designer makes selection within imperfect models and incomplete information. Under such situations, making selections is prone to errors (Kahnemann, Slovic, & Tversky, 1982). While most of the research in the areas develops ideas around probability and statistics (e.g., (Winkler, 1967; Wood, 2004)), making decisions under uncertainty continues to prove to involve more elements of human's ability for visual processing, long-term memory and pattern recognition (Dym et al., 2005). Finally, in *making estimates*, a designer seeks to grasp multiple details of the problem, usually in numerical formats, simultaneously. Making approximations is one way that a designer simplifies variables of the design problem (Linder, 1999), which enables making comparisons and selecting.

Overall, in light of this background on selection in design, it is valuable to replicate the study by Raymond et al. (2003) that used meaningless visual patterns. In contrast, here in this study, attentional state (attending vs. ignoring) is directed to complex and meaningful data visualizations. This replication will shed light on an important aspect of selection in human behavior and its consequential impact on decision making.

2.2 Data, visualizations and decision making

With the increase in computing capabilities, data storage and manipulation are no longer problems in using computing power (O'Leary, 2013) to support decision making (Keim et al., 2008). Challenges, however, exist in terms of creating and interacting with data visualizations that *support* decision making as a distinct demanding activity from merely *operational* decision making (Shen-Hsieh & Schindl, 2012). A major contributor to the challenge of visualizing and analyzing big data to support decision making has been old techniques that worked well with small, homogeneous data sets that either restrict the analysis (Andrienko & Andrienko, 2005) or produce confusing or illegible displays (Endsley, 2000; Kohlhammer, May, & Hoffmann, 2009). Overall, the advantages of making sense of complex data using interactive data visualizations (Janvrin, Raschke, & Dilla, 2014) is characterized by the increasing role that the relationship between data science, big data and data-driven decision making will play in the future (Provost & Fawcett, 2013), moving from data to decisions (Axson, 2003).

2.3 The Decision Theater (DT) immersive environment

The Decision Theater is an advanced, technology-enabled environment that uses visualization technologies in an immersive environment. The theater is equipped with seven screens that can interactively and simultaneously display seven dashboards, Figure 1. The goals of the Theater are to allow the use of data science for social transformation, facilitating dialogue to enable decision making, and visualizing solutions for complex problems (“DT”, 2019). There are multiple, cross-disciplinary featured projects that utilized the advantages of the Decision Theater, like the AZ Budget and the Maricopa County Community Colleges. The Decision Center for Educational Excellence (DCEdEx), the context of this study, is intended to utilize the Decision Theater capabilities.

The tool developed by the Center brings data models to impact new policies related to educational outcomes. The Center collects data, leverages Arizona State University’s (ASU) resources, and drives stakeholders to impact education policies. The tool used in this study is composed of multiple interactive dashboards and visualizations that are at the high end of a computational model that describes students’ performance. More specifics about the dashboards used in the experiment are provided in the following sections.

Figure 1. The Decision Theater at ASU. (“DT”, 2019)

4. Literature integration on the relationship between attention and emotion

3.1 Selective attention and brain activity

Attention to particular objects represented as a stimuli to an observer was recorded to activate the visual cortex of monkeys (Moran & Desimone, 1985). At the same time, ignoring of particular objects was reported to have dramatically reduced activity in the certain parts of brains of trained monkeys (Moran & Desimone, 1985). This observation led to the conclusion that the ability to filter the stimuli is not related to the visual system; instead, selective attention of the visual system is directed by information transmission from the striate cortex into the inferior temporal cortex (Moran & Desimone, 1985). According to Moran & Desimone (1985) the process of selective attention involves the two processes of *identification* and *remembering* of features or objects at a given moment. The process is combined with reduction of processing of irrelevant stimuli; that is, ignoring, and was shown psychophysically in humans (Parasuraman & Davies, 1984).

3.2 Filtering tasks and the study of the selective attention

Previous research on visual selective attention has been dominated by "filtering" tasks. As an example, a task may involve presenting a participant with multiple stimuli (e.g., letters) simultaneously, and then asking the participant to filter for the relevant attribute (e.g., location) within other irrelevant stimuli, and report other attributes of the successfully identified stimulus (e.g., identity) (for example, see Eriksen & Eriksen (1974)). However, new evidence emerged that suggested that location (i.e., where) and identity (i.e., what) may be represented separately in the study of selective attention. The new evidence was based on studies that suggested two cortical visual systems: one that codes spatial relations and another that tracks object identities but not spatial relations (Ungerleider & Mishkin, 1982; Ungerleider, 1983).

The separation between response to object location and object identity in human perception has been demonstrated in several studies (e.g., Butler (1980) and Gazzaniga (1987)). Because of the many emerging findings confirming the separation between representation of identity and location, new studies have been proposed where identity directs attention to spatial location, in contrast to the previous trend in selective attention studies that focused on the reverse case (Styles & Allport, 1986). An example experiment that reexamined how identity controls selection for spatially directed actions was conducted by Tipper, Brehaut; & Driver (1990). The authors were able to demonstrate that targets selected on the base of identity could have spatial location reported consequentially. These findings pointed to a mechanism of selective attention that involves the ignoring of distractors in the observed environment (Tipper et al., (1990)).

3.3 Selective attention and the organization of visual information

Theories of visual attention can fall under three broad classes: *object-based* theories; *discrimination-based* theories; and *space-based* theories. Object-based theories focus on the number of objects that can be studied simultaneously. As an illustrative example, Neisser (1967) proposed a theory where analysis of the visual world takes place in two stages: (1) the pre-attentive stage that segments the world into separate objects; and (2) the focal attention stage that focuses on a particular object for more details. Discrimination-based theories consider the limit on the numbers of discriminators that can be used. As an illustrative example, Allport (1971; 1980) proposed a "system of analyzers" to decompose attributes of stimuli. Based on this suggestion, humans are limited in dealing with several objects by the difficulty of handling multiple analyzers simultaneously. Finally, space-based theories suggest a limit on the spatial area from which information can be accessed and assessed. As an illustrative example, mental spotlight theories (Eriksen & Hoffman, 1973; Hoffman & Nelson, 1981; Posner, Snyder, & Davidson, 1980) proposed that focus can be made on a particular area in space where attention can be made for full perceptual analysis.

Collectively, these theories highlight the nature of selective attention as attributed to the organization of visual information. They also guide the design of experiments in terms of defining displays and identities of corresponding objects. Building on the idea of the separation of representation between the "what" is the object and "where" is the object, and in order to distinguish the views proposed by these three major streams of theories, experiments by Duncan (1984) supported the view that selective attention that focuses on one object at a time is preceded by parallel cognitive processes which take place to segment the field under study into separate objects.

3.4 Coordination between the selective attention system and the emotional system

Studies have shown that selective attention involves ignoring, or the process of suppression, of distracting objects (Moran & Desimone, 1985) as well as controlling representations of task-irrelevant objects

(Tipper, Brehaut, & Driver, 1990). As discussed before, selective attention facilitates the process of determining what and where objects are, in a reciprocal fashion. In addition, however, selective attention involves the process of evaluating objects representations in terms of current and future goals (Ortony, Clore, & Collins, 1988). The two processes of selective attention and emotional evaluation take place in coordination between the two corresponding systems; that is the fronto-parietal cortical network (Hopfinger, Buonocore, & Mangun, 2000) and the emotion network (Le Doux, 1996; Panksepp, 1998; Rolls, 1999). With regard to the selective attention system, the neural mechanisms of top-down attentional control were found to engage distinct networks. Using functional magnetic resonance imaging (fMRI), superior frontal, inferior parietal and superior temporal cortex were selectively activated by cues (Hopfinger, Buonocore, & Mangun, 2000).

Moreover, selective attention was characterized as a *top-down* process where, although competition for attention of stimuli takes place in the visual cortex, the top-down basing takes place in networks in frontal and parietal cortex (Kastner & Ungerleider, 2000). The question that Raymond et al. (2003) tried to address in their paper (being replicated here) is whether this *top-down* control "over perceptual processing is extended to include emotional processing" (p. 541). They were able to demonstrate that this *top-down* control is in fact the case "even when the attention-demanding task does not require emotional evaluation of stimuli" (p. 541).

3.5 Emotional stimulus directs selective attention

The reciprocal relationship between selective attention and emotional stimuli is of interest in this study. Research suggests that emotional stimuli guides selective attention. In four experiments where participants searched displays of schematic faces for unique face expressions, Eastwood, Smilek & Merikle (2001) concluded that emotional expression in a face guides attention to the location of the face. Similarly, Vuilleumier & Schwartz (2001) studied brain-damaged patients with unilateral inattention using neutral, happy, or angry expressions presented in right, left, or both visual fields. They concluded that emotional facial expressions influenced the spatial distribution of attention even when lying on the unattended side. In a study on threat words and angry faces, Fox et al. (2001) presented threat cues and targets subsequently in another location to participants. They found that more time was needed by high state-anxious participants to detect target relative to positive or neutral cues. They concluded that the emotional stimulus, in the form of threat related cue, affected attention, in the form of dwell time. In another study in an attentional blink task of detection of aversive words within neutral words, Anderson & Phelps (2001) examined the affective modulation of perception, and found evidence that impairment in awareness takes place in transitioning from the first identified single target stimulus to the next. In another attentional blink task study, Raymond, Shapiro, & Arnell (1992) used rapid serial visual presentation (RSVP) asking participants to identify a partially specified target and then detect the presence or absence of a fully specified probe. In this study, the authors found that interference in letter recognition takes place after the presentation of the target and while the target identification process is complete. They concluded that this interference may cause the temporary suppression of visual attention. Overall, there is abundance of evidence that emotional stimuli direct selective attention; however, the gap in this research is to systematically study if attentional state influences emotional response.

3.6 Different ways to manipulate emotional state

In order to study how selective attention influences emotional state, it is insightful to review how studies have reported the different ways to manipulate the emotional state. Bornstein (1989) provided a comprehensive overview of the research in this area, categorizing the influence of exposure-affect relationship based on "stimulus type, stimulus complexity, presentation sequence, exposure duration, stimulus recognition, age of subject, delay between exposure and ratings, and maximum number of stimulus presentation" (p. 265). He observed in the various reviewed research that all these factors influence the magnitude of the exposure effect. One way to manipulate emotion is through *repetition* Zajonc (2001). Zajonc reported that repeated exposure to an object influnces an individiual's preference to the object. The phenomeon was observed "across cultures, species, and diverse stimulus domains" (p. 224). The phenonomn has been described simply as merely presenting a stimulus and making it accessible to the senesory receptors. What is fascinating is that, accroding to Zajonc (2001), mere exposure to a stimulus, and its resulting effect on change in preference, degrades an individual's ability of awareness to the occurrence of this degradation. Early attempts of the explanation of causality provided simplistic explanations of the tendency to like familiar objects (Wilson, 1979); however this subjective explanation were rejected in favor of the emerged evidence of the objective history of exposures (Zajonc, 2000). This observation was supported by research that showed that even with subliminal exposure that is flashed infrequently, without attention from an individual, produces the same effect on the individual's preferences (Murphy, Monahan, & Zajonc, 1995; Zajonc, 1980). However, as will be described later, the notion of mere-exposure is shown to be refuted in the replicated study here of how attentional state influences emotion.

In addition to repetition, another way to manipulate emotion was achieved through perceptual fluency that used nonfigural properties such as brightness (Reber, Winkielman, & Schwarz, 1998). In their study, Reber et al. (1998) conducted three experiments to test perceptual fluency effect, beyond mere-exposure, on the emotional state. In the first experiment, participants were presented with a prime, followed by a matching target, and asked to judge the target. In the second experiment, participants were asked to compare emotional states based on the presented level of contrast of a ground figure. In the third experiment, presentation duration was used to control perceptual fluency. The authors concluded that perceptual fluency increases with liking, indicating that "preference for neutral stimuli can be enhanced by manipulation of fluency in the perceptual domain, independently of stimulus repetition" (p. 48).

A third way to manipulate emotion is through the use of affective priming by *a priori* stimulus exposure. Murphy & Zajonc (1993) studied the effect of both affective and cognitive priming under brief (suboptimal) and longer (optimal) exposure durations. In the case of suboptimal exposure, they found that participants experienced significant shifts in judgement to novel stimuli only under the conditions of affective priming, but under the conditions of cognitive priming. In the case of optimal exposure, however, the authors found that a reverse pattern resulted; that is, significant shifts in judgement to novel stimuli only under the conditions of cognitive priming, but under the conditions of affective priming. These results confirmed *the affective primary hypothesis* that is based on the work by Zajonc (1980) who asserted that positive and negative affective response can be stimulated with *minimal input and no cognitive* processing. The study by Murphy & Zajonc (1993) provided evidence that the emotional system can be manipulated with minimal stimulation and having impact on judgement without interference from preceding cognitions. In the context of decision making in a place like the Decision Theater, such results are important to understand because it undermines the notion that considerable cognitive operations are required to occur in order to produce judgement. In contrast, and according to the confirmed *affective primary hypothesis*, displays of data in the Theater and the corresponding "preferences, attitudes, impression formation, and decision making, as well as some clinical phenomena" are independent and "precede in time" the assumed cognitive operations that produce these affective judgements (Zajonc, 1980, p. 151). However, as will be described later, the notion of the effect of affective priming was refuted in the original experiment by Raymond et al. (2003) in the context of how attention influences emotional response.

Overall, while different studies have provided evidence that emotional state can be manipulated with different ways, evidence of how emotional state can be manipulated with the influence of attentional state, in particular, is lacking. The work by Raymond, Fenske, & Tavassoli (2003) has attempted to fill this gap, providing evidence that affective responses can in fact be manipulated specifically due to attentional state, elaborating on the reciprocal nature of the link between attention and emotion.

5. Summary and future work

Our goal in this study is to replicate the findings of Raymond, Fenske, & Tavassoli (2003) of the effect of prior attention on judgement and evaluation. While the original authors used complex but meaningless visual patterns, our aim is to use complex and meaningful data visualization in the context of decision making. One of the major findings by Raymond et al. (2003) is complementing the existing evidence that an emotional state influences attention in that they demonstrated that the reverse relationship holds as well as prior attention, or, more precisly, selective ignoring, impacts subsequent emotional evaluation. Their results indicated that effective ignoring persists even after attending to the ignored object under invistigation. In this sense, selective ignoring has a similar effect as negative priming, which has been demonstrated in numeros studies (e.g., Tipper, Brehaut, & Driver (1990)). Therefore, ignoring reduces emotional perception of the ignored objects, which shows a reciprocal relationship between attention and emotion.

In two different experiments in their study, Raymond et al. (2003) systematically manipulated attention to stimuli during exposure to study its effect. One of the unique aspects of their study compared to our study proposed here is that they used novel, complext but meaningless visual patterns. The authors argued against mere-exposure effects that suggested that prior expereince with a stimulus enahances evaluation regardless of the attention to or distraction by an object. In contrast to this view, their findings demonstrated that attention plays a major role in evlaution. Another aspect of their study was the conditioniong of passively viewed stimuli (Zajonc, 2001). In Experiment 1, they utilized affective primes, using positive, negative and scrambled faces, in an attempt to modulate the emotional system, and they found no effect. Overall, Raymond et al. (2003) describe their findings as running against views of mere-exposure and emphasized “the link between perceuptual experience and emotional appriaisal” (pp. 541-542). One implication of their work is that, in the advertisement industry, presenting images to which viewers are not attending to “may engender negative ratehr than positve affect” (p. 542). In the context of the Decision Theater where mutiple, complex data are presented to be disucssed and used to make decision, understanding this phenomeon becomes extremely important especially that it may have negative consequences in decision making if stakeholders do not pay attention to certain featrures in the displayed, visualized data.

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