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Multivariate pattern analysis of event-related potentials predicts the subjective relevance of everyday objects

William Francis Turner[a], Phillip Johnston[a], Kathleen de Boer[a], Carmen Morawetz[b], Stefan Bode[a,*]

[a] Melbourne School of Psychological Sciences, The University of Melbourne, Parkville 3010, Victoria, Australia
[b] Department of Education and Psychology, Freie Universität Berlin, Habelschwerdter Allee 45, 14195 Berlin, Germany

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ABSTRACT

Potentially decision-relevant stimuli have been proposed to undergo immediate semantic processing. The current study investigated whether information regarding the general desirability ('Wanting') of visually presented 'everyday' objects was rapidly and automatically processed. Participants completed a foreground task while their electroencephalogram (EEG) was recorded, and task-irrelevant images were presented in the background. Following this, participants rated the images with regards to Wanting and the potentially related attributes of Relevance, Familiarity, Aesthetic Pleasantness and Time Reference. Multivariate pattern classification was used to predict the ratings from patterns of EEG data. Prediction of Wanting and Relevance was possible between 100 and 150 ms following stimulus presentation. The other dimensions could not be predicted. Wanting and Relevance ratings were highly correlated and displayed similar feature weight maps. The current results suggest that the general desirability and subjective relevance of everyday objects is rapidly and automatically processed for a wide range of visual stimuli.

1. Introduction

There is now a large body of research suggesting that many unconscious factors can influence decision outcomes (Custers & Aarts, 2010). These factors include simple biases of previous choices in arbitrary decision scenarios (Bode et al., 2014) as well as more complex biases in financial decisions, exerted, for example, by incidental rewarding stimuli on decisions between small immediate rewards and larger delayed rewards in intertemporal choice (e.g., Kim & Zauberman, 2013; Murawski, Harris, Bode, Domínguez D, & Egan, 2012; Simmank, Murawski, Bode, & Horstmann, 2015; Van den Bergh, Dewitte, & Warlop, 2008; Wilson & Daly, 2004; Zhong & DeVoe, 2010). In general, the presence of rewards, specific social situations, and (subliminal) priming has been shown to play a role in biasing decision outcomes in a variety of situations, outside the awareness of the decision-maker (Aarts, Custers, & Holland, 2007; Custers & Aarts, 2010; Dijksterhuis & Aarts, 2010; Zedelius et al., 2014).

How these unconscious biases are generated is, however, still debated. For example, with intertemporal choices it might be plausible that any positive stimulus in the environment activates neural reward circuits, increasing the likelihood of reward seeking behaviour in a subsequent decision task. In support of this, many studies have found that images of rewarding objects, such as brand logos (Murawski et al., 2012; Zhong & DeVoe, 2010), sexual cues (Van den Bergh et al., 2008; Wilson & Daly, 2004), or food and status symbols (Simmank et al., 2015) can bias decision-makers towards immediate gratification. However, others have shown that

* Corresponding author.
E-mail address: sbode@unimelb.edu.au (S. Bode).

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decision-makers can also be biased towards delayed gratification (Benoit, Gilbert, & Burgess, 2011; Cheng, Shein, & Chiou, 2012; Peters & Büchel, 2010), suggesting a more complex mechanism.

Given the variety of cues that have been shown to bias decision-making and goals (Custers & Aarts, 2010), one possibility is that stimuli which exert such biases derive their impact from a higher-level semantic analysis. A recent study by Bode, Bennett, Stahl, and Murawski (2014) made an initial step towards testing this proposal by exposing participants to a variety of positively valenced stimuli (similar to those found to influence intertemporal decisions in previous studies) using a passive viewing paradigm with an attention-demanding foreground task. Following this task, participants were asked to rate all images with regards to whether they were felt to be subjectively related to the present or the future (a stimulus attribute termed 'Time Reference'). It was shown that these ratings could be predicted successfully from distributed patterns of event-related potentials (ERPs) recorded during passive viewing, despite the fact that, whilst initially viewing the images, the participants were unaware that they would be required to subsequently rate them. This finding supports the assumption that a fast and automatic analysis of semantic stimulus features takes place. Importantly, such an analysis might not only explain carry-over effects on incidental decision processes (e.g., intertemporal choice), but might also facilitate everyday decision-making for the analysed objects themselves by preparing unconscious shortcuts which streamline the decision-making process (Bode, Bennett et al., 2014; Creswell, Bursley, & Satpute, 2013; Dijksterhuis, Bos, Nordgren, & Van Baaren, 2006; Dijksterhuis & Nordgren, 2006).

For this to be true, several aspects of stimuli would have to be automatically processed, integrated, and made available as a general decision-related signal to the decision-maker. Several studies using functional magnetic resonance imaging (fMRI) have investigated whether categorical stimulus attributes other than Time Reference are represented in brain activity directly following stimulus presentation. For example, O'Doherty et al. (2003) demonstrated that when individuals were presented with images of faces, brain activity was predictive of subsequent attractiveness ratings, even though the experimental task was to judge gender. Others have shown that the processing of stimuli on a category level occurred rapidly following the presentation of a natural scene, even though the scene was unattended and irrelevant to the experimental task (Peelen, Fei-Fei, & Kastner, 2009). Brain activity has also been found to be systematically modulated according to individual preferences for specific stimuli, even when attention was directed away from the stimuli (Lebreton, Jorge, Michel, Thirion, & Pessiglione, 2009; Tusche, Bode, & Haynes, 2010; Tusche, Kahnt, Wisniewski, & Haynes, 2013). However, given the poor temporal resolution of fMRI, it remains unclear how rapidly the suggested processes took place. A number of studies have used electroencephalography (EEG), and its relatively superior temporal resolution, to demonstrate that semantic stimulus attributes, such as basic category information (e.g., cars vs. buildings), is rapidly reflected in brain activity following presentation of visual objects (Simanova, Van Gerven, Oostenveld, & Hagoort, 2010; Taghizadeh-Sarabi, Daliri, & Niksirat, 2015; Wang, Xiong, Hu, Yao, & Zhang, 2012).

Crucially, information regarding Time Reference as well as category membership is not necessarily directly relevant to object-related decision making. Therefore, the results from previous studies provide insufficient evidence that information of direct relevance for decision-making is rapidly and automatically processed following exposure to a visual stimulus. Notably, there is some evidence that people's choices for consumer products can be predicted from their brain activity recorded during passive viewing of the products (Levy, Lazzaro, Rutledge, & Glimcher, 2011; Telpaz, Webb, & Levy, 2015; Tusche et al., 2010). For example, an fMRI study, which measured brain activity during passive exposure to images of cars, demonstrated that hypothetical purchase decisions could be directly predicted from patterns of brain activity in decision-related brain regions such as the medial prefrontal cortex and insula (Tusche et al., 2010). However, these results were obtained in a sample of participants who indicated a high interest in cars prior to the experiment. Thus, these stimuli were highly valenced for the selected sample. Similarly, previous studies have typically used highly valenced and optimised stimuli (e.g., Bode, Bennett et al., 2014; Levy et al., 2011; Telpaz et al., 2015), which had a high likelihood of being relevant for decision-making. For example, the stimuli used by Bode, Bennett et al. (2014) were positively valenced and were selected on the basis that they strongly related to the present or the future (i.e. they were optimised for the Time Reference dimension). While this approach is valid and arguably helpful for optimising the probability of detecting the neural signatures of these processes, it also bears the danger of communicating a distorted picture of stimulus processing for decision-making. In fact, it could imply that all stimuli are unconsciously processed in great semantic depth, or that detailed purchase decisions are always prepared unconsciously for incidentally encountered objects in the environment. However, the question remains as to whether the automatic extraction of decision-relevant information also takes place for more 'everyday' objects, which have not been optimised in this manner. One possibility is that in-depth semantic processing first requires the detection of relevance or a general desire towards an object, and that any further processing is abandoned if the object does not fulfil these criteria. As suggested for early visual processing (Felsen & Dan, 2005) as well as social stimuli (Zaki & Ochsner, 2009), processing of naturalistic stimuli might indeed differ substantially from optimised stimuli.

The current study addressed this question by exposing participants to a selection of object images drawn from a novel picture set, the Nencki Affective Picture System (NAPS; Marchewka, Żurawski, Jednoróg, & Grabowska, 2014), for which normative ratings for valence, approach/avoidance and arousal were available. Notably, these images fell into a variety of categories, did not depict consumer products, and varied highly across normative valence ratings. As such, they were more representative of objects encountered in everyday life than the stimuli used in previous studies. We then asked whether the general desirability of these objects could still be predicted from brain activity shortly after stimulus presentation, despite having waived the characteristic of high valence. Moreover, following previous studies (Bode, Bennett et al., 2014; Tusche et al., 2010) we made the stimuli task-irrelevant by presenting them in the background while participants focussed on a foreground task. This corresponded closely to everyday scenarios in which objects are perceived incidentally, and are not the focus of direct attention or deliberation.

There are many ways to characterise the general desirability of, or tendency to be drawn towards, an object, including: preferences (Lebreton et al., 2009), approach motivation (Harmon-Jones & Allen, 1998), utility (Fishburn, 1970), and valence (Mogg,