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MOTIVATION ALTERS RESPONSE BIAS AND NEURAL ACTIVATION PATTERNS IN A PERCEPTUAL DECISION-MAKING TASK

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Abstract—Motivation has been demonstrated to affect individuals' response strategies in economic decision-making, however, little is known about how motivation influences perceptual decision-making behavior or its related neural activity. Given the important role motivation plays in shaping our behavior, a better understanding of this relationship is needed. A block-design, continuous performance, perceptual decision-making task where participants were asked to detect a picture of an animal among distractors was used during functional magnetic resonance imaging (fMRI). The effect of positive and negative motivation on sustained activity within regions of the brain thought to underlie decision-making was examined by altering the monetary contingency associated with the task. In addition, signal detection theory was used to investigate the effect of motivation on detection sensitivity, response bias and response time. While both positive and negative motivation resulted in increased sustained activation in the ventral striatum, fusiform gyrus, left dorsolateral prefrontal cortex (DLPFC) and ventromedial prefrontal cortex, only negative motivation resulted in the adoption of a more liberal, closer to optimal response bias. This shift toward a liberal response bias correlated with increased activation in the left DLPFC, but did not result in improved task performance. The present findings suggest that motivation alters aspects of the way perceptual decisions are made. Further, this altered response behavior is reflected in a change in left DLPFC activation, a region involved in the computation of perceptual decisions.

Key words: perceptual decision-making, strategy, fMRI, signal detection theory, motivation.

INTRODUCTION

Perceptual decision-making involves the accumulation and comparison of sensory evidence gathered from the environment. Based on this information decisions are made about the presence (detection) or type of stimuli (discrimination) encountered. Motivation, in turn, influences our decisions by orienting us toward goals and away from danger. In economic decision-making it has been well established that when motivated to avoid a financial loss, individuals make riskier decisions than when motivated to obtain a financial gain (Tversky and Kahneman, 1981; Levin and Hart, 2003). While perceptual decision-making can be subject to the same motivational influences as economic decision-making, this relationship has not been thoroughly investigated.

Human imaging studies suggest that different brain regions mediate the accumulation and comparison processes. Evidence *accumulation* appears to involve different brain regions depending on the modality of the sensory stimuli. For instance, tactile sensory evidence has been found to accumulate in the primary somatosensory cortex (Pleger et al., 2006a), while auditory evidence accumulation occurs in the primary auditory cortex (Binder et al., 2004). The accumulation of visual stimuli appears to be further refined with accumulation recruiting regions specific to the type of stimuli. For example, using a face-house discrimination task, Heekeren and colleagues found that accumulated evidence for faces was encoded in the fusiform face area while evidence for houses was accumulated in the parahippocampal place area (Heekeren et al., 2004). The left dorsolateral prefrontal cortex (DLPFC) is thought to *compare* the accumulated sensory evidence. Animal electrophysiological studies have demonstrated that neuronal response in the left DLPFC is a function of the subtraction of the activity of neurons coding sensory evidence for two possible choices (Kim and Shadlen, 1999). Similarly, human imaging studies have shown that the left DLPFC integrates the signal from sensory evidence regions and uses a subtraction operation to compute perceptual decisions (Heekeren et al., 2004, 2006; Pleger et al., 2006b), and that disruption of this region affects the accuracy of perceptual decisions (Philiastides et al., 2011).

Motivation is a mechanism which orients us toward a goal whether that goal requires us to approach a reward

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Abbreviations: BOLD, blood-oxygen level dependent; DLPFC, dorsolateral prefrontal cortex; FFG, fusiform gyrus; fMRI, functional magnetic resonance imaging; FWE, family-wise error correction; IFG, inferior frontal gyrus; IPL, inferior parietal lobule; MFG, middle frontal gyrus; ROI, region of interest; SD, standard deviation; VMPFC, ventromedial prefrontal cortex; VS, ventral striatum; VTA, ventral tegmental area.

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or to avoid a punishment. Substantial evidence shows that the ventral striatum (VS) mediates aspects of motivation (Salamone, 1994; Ikemoto and Panksepp, 1999; Volkow et al., 2002; Cooper and Knutson, 2008; Berridge et al., 2009; Clithero et al., 2011). Sensitivity (d') and response bias (c), two measures from signal detection theory (Green and Swets, 1966; MacMillan and Creelman, 2009), can be used to assess the effect of motivation on perceptual decision-making. Sensitivity measures how well a target stimulus can be identified. Response bias indexes how likely one is to say a target is present and reflects the decision criterion underlying perceptual choices. Studies using visual discrimination tasks have found that increased motivation, regardless of whether motivation is positive or negative, results in improved sensitivity (Brandtstadter et al., 2004; Engelmann and Pessoa, 2007; Engelmann et al., 2009). The relationship between motivation and response bias, however, is not as clear. Many studies which combine motivation with perceptual tasks either do not investigate potential changes in response bias (Engelmann and Pessoa, 2007; Engelmann et al., 2009), or manipulate response bias itself by changing the payoff matrix between conditions (Taylor et al., 2004). Further complicating the picture are perceptual decision-making studies that report changes in response bias in the absence of motivational change. These studies often explicitly manipulate response bias by using a non-neutral payoff matrix which favors one response over another (Fleming et al., 2010; Summerfield and Koechlin, 2010), manipulate the prior expectation associated with a response (Rahnev et al., 2011), or both (Bohil and Maddox, 2001; Mulder et al., 2012). The effect of motivation alone on perceptual decision-making, therefore, remains unclear. There is some suggestion, however, that motivation may induce a shift to a more liberal response bias. In a visual recognition-memory task, Henriques and colleagues found that when responding to receive a financial reward or avoid a financial punishment, individuals adopted a more liberal response bias, i.e. they were more likely to say a target was present (Henriques et al., 1994).

Motivation has been demonstrated to alter economic decision-making strategy. Different strategies, in turn, have been associated with different patterns of activation across the brain, including the VS (Tom et al., 2007; Venkatraman et al., 2009). It is unclear, however, whether motivation similarly affects the criterion used in perceptual decision-making and whether changes in response bias, representative of this criterion, are associated with different patterns of activation.

The aim of the present study was to investigate the effect of motivation on the detection dimension of perceptual decision-making. To this effect, three levels of motivation (positive, negative and neutral) were created by altering the financial contingency of a block-design, continuous performance, perceptual decision-making task where participants were asked to detect if a picture of an animal was present among distractors. In keeping with previous findings, we hypothesized that individuals will have increased sensitivity (Engelmann and Pessoa, 2007; Engelmann et al., 2009) and adopt a more liberal response bias, i.e. saying, ‘‘yes’’ a target is present more often (Henriques et al., 1994), in the positive and negative motivational conditions than in the neutral condition. The VS, fusiform gyrus (FFG), left DLPFC, and ventromedial prefrontal cortex (VMPFC) were chosen *a priori* as regions of interest (ROIs) based on their involvement in, respectively, motivational, perceptual decision-making, and task switching processes. As activation in the VS has previously been shown to increase with increasing financial motivation (Knutson et al., 2001, 2005; Engelmann et al., 2009), it was hypothesized that it would exhibit greater sustained activation in the positive and negative compared to the neutral motivation conditions. Further, given the finding by Taylor and colleagues (Taylor et al., 2004) that motivation enhanced activation in working memory regions during a working memory task, it was hypothesized that motivation would similarly increase sustained activation in perceptual decision-making regions – the FFG and left DLPFC. Since the VMPFC has previously been implicated in flexible choice behavior (Bechara et al., 2000; Fellows and Farah, 2003) we further hypothesized that the predicted change in response bias would be associated with increased VMPFC activation.

EXPERIMENTAL PROCEDURES

Ethics statement

The study was approved by the Regional Ethics Committee for the South-East Norwegian Health Authority. Participants provided written, informed consent.

Participants

Eighteen right-handed, healthy participants (mean age ± standard deviation (SD) = 24.8 ± 1.9 years; seven females) were recruited for the study. All subjects were screened for neurological, psychiatric and substance abuse problems. They did not have a history of problem gambling, medical problems, nor were they undergoing any medical treatment that could affect cerebral blood metabolism and blood flow. Subjects were paid 300Kr ($50) for their participation (150Kr for the screening interview and 150Kr for participating in the MRI session conducted on a separate day) and kept any additional money they won in the task described below.

Questionnaire

The Behavioral Inhibition/Behavioral Activation scale (BIS/BAS) was administered to measure individual differences in the two motivational systems thought to underlie approach and avoidance behavior (Gray, 1972; Carver and White, 1994).

Procedure

Experimental paradigm. The paradigm was programed and controlled using E-Prime software (version 1.2; Psychology Software Tools, Inc., Pittsburgh, PA, USA). Stimuli were presented to the participants in the scanner using VisualSystem