Behavioural Brain Research 293 (2015) 217–226

Contents lists available at ScienceDirect

Behavioural Brain Research

journal homepage: www.elsevier.com/locate/bbr

Research report

Are the carrot and the stick the two sides of same coin? A neural examination of approach/avoidance motivation during cognitive performance

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HIGHLIGHTS

- We examined WM performance under approach and avoidance motivation.
- Both approach and avoidance motivation increase task-related cognitive activation.
- Approach and avoidance motivation lead to comparable brain network activation.

ARTICLE INFO

Article history:
Received 7 January 2015
Received in revised form 17 July 2015
Accepted 18 July 2015
Available online 23 July 2015

Keywords:
Approach and avoidance motivation
Working memory
Functional magnetic resonance imaging (fMRI)

ABSTRACT

The present study examined neural circuit activity in a working memory (WM) task under conditions of approach and avoidance motivation. Eighteen participants were scanned with functional MRI while they performed a 3-back WM task under three conditions: in an avoidance condition incorrect responses were punished with monetary loss; in an approach condition correct responses were rewarded with monetary gain; in a neutral control condition there was no monetary incentive. Compared with the control condition, activation in fronto–parietal areas – which are associated with WM processing – was increased in both the approach and avoidance conditions. The results suggest that both approach and avoidance motivation increase task-related cognitive activation.

1. Introduction

A basic principle of behavior is that organisms are naturally attuned toward obtaining desired and pleasant outcomes [43]. Stimuli indicating potential rewards lead people to modulate their behaviors to increase the probability of obtaining rewarding outcomes [38]. Such positive incentive effects have been widely examined in behavioral and brain imaging research [28]. The pursuit of reward is classically conceptualized in terms of approaching appetitive outcomes (e.g., gain of money) [3]. However, it is also known that the mere avoidance of an aversive outcome (e.g., preventing monetary loss) can constitute a rewarding outcome in terms of negative reinforcement [39]; see also [17]. Avoiding an aversive outcome can even be instrumental to pursue an approach-related goal, such as saving money (avoiding expenses) in order to approach a higher monetary payoff (cf. [8]. Considering this leads to the provoking idea that the neutral circuitry underlying approach and avoidance motivation may sometimes overlap.

To advance the understanding of the neural activity underlying approach and avoidance motivation, the present study used functional magnetic resonance imaging (fMRI) to investigate brain circuit activity during motivated (vs. neutral) performance on a working memory (WM) task. That task allowed comparing the effects of approach and avoidance motivation with that of a neutral cognitive performance setting.

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http://dx.doi.org/10.1016/j.bbr.2015.07.042
0166-4328/

A number of brain imaging studies on motivated performance have used monetary reward manipulations to examine how approach motivation affects high-demanding cognitive tasks (e.g., [2,15,24,29,30]. These studies found increased hemodynamic responses in regions related to task relevant cognitive processes (e.g., WM), as well as in reward-related network. In a pivotal study, [30] examined neural activation during the performance of a *n*-back working memory task in which monetary reward was contingent on correct responses—the more correct responses, the higher the monetary gain. This approach motivation setting induced increased activity in both classical WM regions (e.g., the dorsolateral prefrontal cortex) and brain areas sensitive to changes of rewarding value of an ongoing situation (e.g., cingulate gyrus, medial frontopolar areas). This suggests that approach motivation boosted the neural activity of regions that were already implicated in an ongoing task in order to improve performance together with neural areas that are activated in rewarding contexts.

Later studies have observed comparable patterns of activation in WM performance in approach motivation settings (e.g., [15,24,33,41]; see also [46]. However, much less is known about neural correlates of cognitive performance in avoidance motivation settings—i.e., when negative outcomes can be prevented by correct responses. Some studies have found regions of the ventrolateral prefrontal (VLPFC) and orbitofrontal cortex (OFC) to be involved in such avoidance settings (e.g., [7,26,41,42]. However, these studies did not examine the effects of avoidance motivation (preventing monetary loss) together with those of approach (attaining monetary gain) motivation, limiting possible conclusions about the differences or similarities of neural networks underling motivated cognitive performance.

Interestingly, an imaging study on reinforcement learning Kim et al. [17] found that the successful avoidance of an aversive outcome in terms of monetary loss recruits the same neural circuitry as that elicited by approaching an appetitive outcome in terms of monetary gain. The reason for this may be that avoidance of aversive outcomes can be rewarding in terms of negative reinforcement [38]. Avoiding the loss of money helps to approach the higher goal to attain a good monetary payoff. To our knowledge, only one study Krawczyk and D'Esposito [19] has addressed the question as to how monetary loss-aversion influences neural systems underlying motivated cognition. In this study, participants were scanned while performing an incentivized working memory delayed recognition task, in which they could lose money for wrong responses (good responses did not lead to monetary gain). This study revealed enhanced WM brain activity in trials with potential monetary loss, which is consistent with the idea that incentive, even in an avoidance context, boosts neural activity in regions involved in an ongoing cognitive task in order to improve performance [30]. The study yielded enhanced activity in the amygdala, a region that can be activated by punishment. However, this study did not examine WM performance motivated by potential monetary gain, making a direct comparison of neural networks involved in approach and avoidance motivation impossible.

The main aim of the present study was to make a direct comparison of neural regions involved in cognitive performance in both approach and avoidance motivation settings. For that purpose, we tested healthy volunteers' WM performances under a high demanding *n*-back task, with task accuracy being rewarded either by money gain or by avoidance of money loss, during fMRI scanning.

2. Methods

2.1. Participants

Twenty-one right-handed healthy volunteers (aged 18–29 years) recruited from the community participated in this fMRI study. All participants had normal or corrected to normal vision and were screened for neurological or psychiatric disorders. The present study complies with the Code of Ethics of the World Medical Association (Declaration of Helsinki, version 2004) and was approved by the Ethics Committee of the Faculty of Medicine of the University of Liège. Written informed consent was obtained from all participants following a full explanation of the experimental procedure. Data from 3 participants were removed from the analyses due to extreme head motion (>3 mm). The reported results are based on the remaining 18 participants (10 females).

2.2. Experimental task and procedure[1]

Participants performed a letter version of the *n*-back working memory task Braver et al. [49], which required them to indicate if a target letter was identical to a previously presented cue letter. This procedure requires the participant to maintain and permanently update the relevant information in WM. We used the 3-back version of the *n*-back WM task in which the target is the letter identical to the cue presented 3 trials back. This 3-back WM load is considered as a high level cognitive task since there are two distractors between the cue and the target stimuli, each distractor becoming a cue for the next trial. Each participant performed the 3-back trials under three conditions. In an *approach condition*, the 3-back trials were performed in association with potential monetary reward for correct performances, while in an *avoidance condition* incorrect responses were punished with monetary loss. Additionally, there was a *neutral control condition* in which the 3-back task was performed without any consequences (neither reward nor punishment). Participants learned that they would have to attain at least 80% of correct response to gain the monetary reward in the approach condition (without any loss for wrong responses) or to avoid the monetary loss in the avoidance condition (without any gain for correct responses). However, participants were not informed about the precise amount of money or their actual scores to avoid mental calculations of potential gains or losses. Rather, participants were only informed that their monetary gain or loss was contingent on their performance—more monetary gain based on more correct responses in the approach condition and less monetary loss based on less incorrect responses in the avoidance condition. However, at the end of the study all participants received the same amount of money (i.e., 50 Euro) for their participation. A 0-back condition, in which the target is a single pre-specified letter, was used as a baseline condition, controlling for perceptual processing, low-level WM processing and motor responses.

As presented in Fig. 1, each trial was preceded by an instruction panel delivering information during 3000 ms regarding the type of cognitive task (0 or 3-back) to be performed and information about the letter to be recognized in the 0-back condition and the type of the 3-back task (neutral, approach, avoidance). Instructions appeared in white on a black screen. To permit participants an easy differentiation between the three 3-back WM conditions, the approach and avoidance trials were announced with a colored cue: "GAIN" in green for the approach condition and "LOSS" in red for the avoidance condition (cf. [6]. The neutral 3-back trials were announced in white "without gain or loss".

[1] It should be noted that participants were also administrated the Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ) developed by [44] as well as other questionnaires unrelated to the present topic, i.e., the Behavior Identification Form [45] and the Self-Consciousness Scale [34]. These later two questionnaires assess, respectively, the tendency to construe actions regarding goal-related features and the tendency to reflect upon on private aspects of the self vs. external aspects (the SCS assesses 3 dimensions: Private SC, Public SC and Social anxiety).