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Motivation by potential gains and losses affects control processes via different mechanisms in the attentional network

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ABSTRACT

Attentional control in demanding cognitive tasks can be improved by manipulating the motivational state. Motivation to obtain gains and motivation to avoid losses both usually result in faster reaction times and stronger activation in relevant brain areas such as the prefrontal cortex, but little is known about differences in the underlying neurocognitive mechanisms of these types of motivation in an attentional control context. In the present functional magnetic resonance imaging (fMRI) study, we tested whether potential gain and loss as motivating incentives lead to overlapping or distinct neural effects in the attentional network, and whether one of these conditions is more effective than the other.

A Flanker task with word stimuli as targets and distracters was performed by 115 healthy participants. Using a mixed blocked and event-related design allowed us to investigate transient and sustained motivation-related effects. Participants could either gain money (potential gain) or avoid losing money (potential loss) in different task blocks.

Participants showed a congruency effect with increased reaction times for incongruent compared to congruent trials. Potential gain led to generally faster responses compared to the neutral condition and to stronger improvements than potential loss. Potential loss also led to shorter response times compared to the neutral condition, but participants improved mainly during incongruent and not during congruent trials. The event-related fMRI data revealed a main effect of congruency with increased activity in the left inferior frontal gyrus (IFG) and inferior frontal junction area (IFJ), the pre-supplementary motor area (pre-SMA), bilateral insula, intraparietal sulcus (IPS) and visual word form area (VWFA). While potential gain led to increased activity in a cluster of the IFJ and the VWFA only during incongruent trials, potential loss was linked to activity increases in these regions during incongruent *and* congruent trials. The block analysis revealed greater activity in gain and loss blocks compared to the neutral condition in most of these regions but no differences in the direct comparison of gain and loss blocks.

These findings show that potential monetary gain and loss rely on different mechanisms: Gain was more effective in reducing the reaction time compared to potential loss. Brain data indicate that in the gain context attentional control is executed *specifically* in incongruent trials, whereas the loss context induces an *unspecific* increase of attentional control. These findings extend previous studies by providing evidence for diverging neural mechanisms for the effects of different types of motivation on attentional control, specifying the underlying activity patterns in task- and stimulus-related regions.

Introduction

Human attentional resources are limited. Accordingly, attention needs to be allocated depending on current goals and priorities. Basically, two mechanisms are assumed to support this goal-directed allocation: On the one hand individuals selectively attend to relevant stimuli in preference to others. At the same time the inhibition of irrelevant events

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prevents individuals from distraction (Lavie, 2005; O'Connor et al., 2002). The selective attention to relevant goal related, as well as the inhibition of interfering stimuli has been shown to be realized by top-down mechanisms in the brain (Egner and Hirsch, 2005; MacDonald et al., 2000; Miller and Cohen, 2001). These processes are assumed to involve a core network composed of lateral and medial prefrontal areas, interacting with parietal and other stimulus-related regions, constituting the so-called attentional network (Engelmann et al., 2009; Hopfinger et al., 2000; Pessoa et al., 2003; Posner and Dehaene, 1994; Posner, 1994).

Successful attentional control crucially depends on the degree of motivation for a specific goal. Several studies have shown that the performance in tasks requiring top-down control can be affected by manipulating the motivational state of individuals (e.g., Chelazzi et al., 2013; Engelmann and Pessoa, 2007; Hübner and Schlösser, 2010; Watanabe, 2007). For instance, performance-based monetary incentives consistently result in improved performance, that is, faster reaction times and decreased error rates (e.g., Engelmann et al., 2009; Locke and Braver, 2008; Pochon and Levy, 2002; Sarter et al., 2006). Importantly, monetary incentives can be achieved in two dimensions: either in form of approaching a gain, or by avoiding a loss of monetary incentives.

The underlying neural mechanisms of gain-related motivational effects were previously examined by a variety of cognitive control tasks such as working memory (Jimura et al., 2010; Krawczyk et al., 2007), task switching (Shen and Chun, 2011), branching (Charron and Koechlin, 2010), visual attention (Della Libera and Chelazzi, 2006) and the Stroop task (Krebs et al., 2010, 2011, 2013; Padmala and Pessoa, 2011). Gain-related effects in these studies were associated with activation changes in task- and stimulus-related as well as control-implementing brain areas in the prefrontal cortex, indicating increased attentional top-down signals based on expected gains (Pessoa and Engelmann, 2010; see also Soutschek et al., 2014).

More specific, effects of gain have been shown to be implemented via two different strategies (Braver, 2012; Engelmann et al., 2009; Jimura et al., 2010). On the one hand, motivation can lead to transient effects, which modulate attention on a trial-by-trial basis only when control is needed. On the other hand, a sustained mechanism can increase attentional control throughout a whole task block, thus being activated independent of the control requirements for specific trials. While the first is a reactive strategy in response to a single stimulus, the latter sets up a state of proactive control (Braver, 2012). Transient control can be assumed to require less cognitive resources but also to be more vulnerable to distracting stimuli than sustained control. Contrary, sustained control is less sensitive for unexpected but potentially relevant stimuli. Whether a transient or sustained processing mode is implemented might depend on several factors, such as the degree of reward sensitivity of individuals (Jimura et al., 2010) or the task-specific demands interference expectancy: D'Esposito et al., 1999; working memory load expectancy: Speer et al., 2003).

In the present study we investigated the question, whether different types of motivation, i.e. motivation by monetary gain compared to monetary loss, affect the degree to which transient and sustained control mechanisms are recruited in an attentional control task.

Surprisingly little is known about differential effects of loss as compared to gain in an attentional control context. A general discrepancy of these incentive conditions is represented by the *loss aversion* theory by Kahneman and Tversky (1979), which assumes that people in general have the tendency to give more weight to losses than to symmetric gains. However, in contrast to this idea, loss motivation does not lead to the same degree of performance improvement (accuracy and reaction time) like gain motivation (Camerer and Hogarth, 1999; Richter et al., 2013), despite being associated with increased effort as measured by fMRI and EEG (Dambacher et al., 2011; Potts, 2011). A plausible assumption for increased effort associated with potential loss is the induction of worries to lose money based on one's bad performance (cf. Kahneman and Tversky, 1979). These worries might compete for cognitive resources (Ashcraft and Kirk, 2001; Beilock, 2008) and result in an overall increased activity in the attentional network, which lasts across the whole block of trials. The finding that increased effort is not accompanied by better performance indicates reduced *processing efficiency* for loss compared to gain motivation. This means that more effort in terms of additional processing resources is spent to achieve a specific level of performance (Eysenck and Calvo, 1992; Eysenck et al., 2007).

An interesting question is whether this loss motivation effect is associated with a more state-like, sustained effect in task- and stimulus-related brain regions compared to gain motivation, which can be assumed to involve fewer performance-related worries. In the current study, a task design which combines different motivational valences as well as a neutral condition in the same attentional control task was used, thus allowing for a direct comparison of transient and sustained effects for gain and loss in attentional control.

A few studies have already compared the neural effects of gain and loss in attentional control, using variants of the Flanker task (Ivanov et al., 2012; Potts, 2011; Richter et al., 2013). While these studies widely support the idea of reduced processing efficiency for loss avoidance compared to gain, they also contained limitations: First, the usage of pure event-related or pure block designs did not allow for the direct comparison of transient vs. sustained motivational effects. Second, the absence of behavioral effects (Ivanov et al., 2012; Richter et al., 2013) as well as the missing inclusion of a neutral non-incentive condition (Ivanov et al., 2012) further limit the conclusions of these studies.

Here, we used a semantic interference task in a mixed block and event related design to test (i) whether loss motivation is less effective than gain motivation in a semantic attentional control task and (ii) whether loss motivation involves sustained control mechanisms in task- and stimulus-related regions to a higher degree than gain.

We addressed these questions in a semantic version of the Flanker task (Eriksen and Eriksen, 1974), which is an established paradigm to study attentional processes such as interference inhibition. In this modified version (Ochsner et al., 2009), conflicts were induced by differences in the semantic categories of target and flanker words. Using functional magnetic resonance imaging (fMRI), Ochsner et al. (2009) showed that this version of the task induces anticipated behavioral and neural effects: incongruent trials were associated with increased activity in areas suggested to play a role in interference inhibition (lateral PFC) and performance monitoring (medial PFC) and regions associated with response selection under interference.

Using word stimuli has the advantage that the key brain regions associated with the processing of such word stimuli is well known: visual identification of letter strings has been shown to be particularly related to responses in a specific area of the left fusiform gyrus (VWFA) (e.g., Cohen et al., 2000, 2002; McCandliss et al., 2003; Polk and Farah, 2002). Thus, using a semantic Flanker task allows assessing different motivational effects on task – (i.e., incongruent vs. congruent) related as well as stimulus – (i.e., word) related areas and to compare them directly by conducting a priori region-of-interest (ROI) analyses.

Note that an incentive scheme was chosen which involves uncertain incentives, provided at the end of the experiment instead of immediate gains and losses after each trial. This was done to achieve more similarity with motivated attentional control situations in real life, where incentives usually do occur after a delay and also involve uncertainty. Additionally this approach has the advantage not to confound effects related to the anticipation and actual receipt of incentives with the fMRI effects.

We expected that both potential gain and potential loss would enhance motivation and lead to performance improvement compared to a non-incentive condition. For the fMRI data, we expected transient and sustained motivational effects in task-related (lateral PFC, medial PFC and inferior parietal cortex) and stimulus-related (VWFA) regions. We hypothesized that both gain and loss lead to the implementation of additional attentional control, but by different strategies. As stated