



Happy and less inhibited? Effects of positive mood on inhibitory control during an antisaccade task revealed using topographic evoked potential mapping

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ARTICLE INFO

Article history:

Received 27 December 2014
Received in revised form 6 July 2015
Accepted 9 July 2015
Available online 18 July 2015

Keywords:

Inhibition
Positive mood
ERP
CNV
N2
Cognitive control

ABSTRACT

Affective states might influence inhibitory control, a cognitive process fundamental for goal adaptive behavior. Here, we recorded high-density EEG while participants performed an antisaccade task, after the induction of a happy ($n = 20$) or neutral ($n = 20$) mood, to compare the same inhibition-related processes across these two affective contexts. Topographical evoked potential mapping methods were used to characterize changes in the electric field depending on mood and saccade type (pro vs. anti) concurrently. Results showed that prior to target onset, the CNV component was enhanced for anti- compared to prosaccades, selectively in the neutral mood group. Following target onset, the topography of the N2 was more strongly expressed in the happy mood group, and was also altered by saccade type. The subsequent P3 components were not modulated by mood. We discuss these new findings in light of recent neurobiological and neuropsychological models that posit that positive affect dynamically changes cognitive control.

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1. Introduction

By virtue of cognitive control abilities, humans can flexibly adapt their behavior to comply with changes in context or task demands. Cognitive control is best exemplified in situations in which reflexive actions have to be voluntarily suppressed and overwritten by other, less automatic, behaviors. Inhibition is usually defined as a central regulatory mechanism for preventing the processing of task-irrelevant information or execution of prepotent responses (Friedman & Miyake, 2004). Interestingly, our capacity to exert cognitive control in general (e.g., inhibition, conflict monitoring, and selective attention) fluctuates with changes in our internal state, such as variations in motivation (e.g., triggered by reward context; Padmala & Pessoa, 2010) and positive mood (Dreisbach & Goschke, 2004; Martin & Kerns, 2011).

Although reward and positive mood share overlapping neurobiological grounds (Funahashi, 2011; Kringelbach, 2010), they seem to have opposite effects on various measures of cognitive control, with performance-contingent reward enhancing, and positive mood diminishing control (see Chiew & Braver, 2011; Fröber &

Dreisbach, 2014 for reviews). For example, positive affect has been found to reduce proactive control, as shown by a reduced ability to maintain task goals (Dreisbach, 2006) and a decreased use of predictive cues (Fröber & Dreisbach, 2012). At the electrophysiological level, Yuan et al. (2011) interpreted enhanced brain expressions of cognitive control during positive mood as a compensatory mechanism, in order to maintain behavioral performance at a similar level as when participants were in a negative or neutral mood. This paradoxical observation, with benefits from reward but reduced cognitive control during positive affect, can likely be attributed to fundamental differences between the two systems. For example, while reward is thought to be phasic, positive mood might have more tonic effects on cognitive functions. Along the same lines, reward is usually bound to specific responses or stimuli, while positive mood is often manipulated independently from the task (i.e., contextual effect), hence not directly biasing motivation toward one specific stimulus type or condition.

Given these structural differences between reward and positive mood, a similar pattern of opposing influences of these two factors can be hypothesized for inhibitory control specifically. However, while several studies show that reward can enhance inhibitory control (e.g., Boehler, Hopf, Stoppel, & Krebs, 2012; Mueller et al., 2010), it remains an open question how positive mood influences this process. Indirect evidence for an impairment of inhibitory control by positive mood comes from studies on the effects of mood on atten-

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tional processes (e.g., [Moriya & Nittono, 2011](#); [Vanlessen, Rossi, De Raedt, & Pourtois, 2013](#)). In these studies, the authors pointed to *diminished* inhibitory control as a possible underlying mechanism explaining their findings in the attention domain (as suggested by [Rowe, Hirsh, & Anderson, 2007](#)). In addition, enhanced susceptibility for distraction was found in positive mood ([Biss & Hasher, 2011](#); [Biss, Hasher, & Thomas, 2010](#); [Dreisbach & Goschke, 2004](#); [Dreisbach, 2006](#); [Rowe et al., 2007](#)), which was taken as an indication of disturbed prefrontal inhibitory control ([Chao & Knight, 1997](#)). However, these earlier studies on positive mood measured resistance to distraction, conflict monitoring or other facets of cognitive control, rather than inhibition of a prepotent response tendency per se.

A landmark paradigm to investigate inhibitory control is provided by the antisaccade task ([Hallett, 1978](#)). This task requires participants to execute a saccade toward (prosaccade) or away from (antisaccade) a unilateral visual target, appearing at a peripheral location along the horizontal axis relative to fixation, following a cue that indicates if a pro- or an antisaccade is required in that trial. Antisaccade trials typically elicit more errors and slower latencies compared to prosaccades. This presumably reflects enhanced top-down control necessary to inhibit the execution of reflexive saccades toward the target and to generate an eye movement in the opposite direction (for a review, see [Munoz & Everling, 2004](#)), although prosaccades also require some form of cognitive control ([Hutton, 2008](#)). Studies specifically focusing on the influence of positive mood on inhibition are scarce. A previous study investigated the effect of positive mood on inhibition in an antisaccade task, and reported that participants made less errors in the positive compared to the neutral mood condition ([Van der Stigchel, Imants, & Ridderinkhof, 2011](#)). Surprisingly, this improvement was confined to “express saccades” that are fundamentally different from normal latency saccades. Express saccades are defined as reflexive saccades with very short latencies that occur in conditions in which the activity of fixation neurons in the superior colliculus (SC) decrease ([Klein & Fischer, 2005](#); [Klein, Rauh, & Biscaldi, 2010](#)). This is further supported by different underlying neural networks, which attribute a strong role of the SC in express saccades, but more cortical involvement during regular saccades (see [McDowell, Dyckman, Austin, & Clementz, 2008](#)). As a result, performance of regular latency saccades are likely to be more informative about higher order cognitive functions, such as executive functions ([Klein et al., 2010](#)). Another study investigated the effects of imagining neutral, happy or pride-related events on performance in a inhibition task, in which participants had to indicate the direction of an arrow while distracting images were shown at the opposite side of the screen ([Katzir, Eyal, Meiran, & Kessler, 2010](#)). The authors found that imagining fun moments decreased inhibitory control. In a third study, Event-Related Potentials (ERPs) were used to investigate the inhibition of prepotent responses in participants who performed a Go/Nogo task while emotional stimuli were shown in the background ([Albert, López-Martín, & Carretié, 2010](#)). Larger inhibition-related activation, at the level of the P300 component, was elicited when participants had to suppress a response while positive (as compared to negative) images were shown in the background, suggesting that a greater effort was necessary to withhold a prepotent response in this condition (i.e., enhanced distraction by positive content). However, none of these earlier studies actually manipulated the felt emotional experience of the participants, but rather aimed at activating short-term (fun) or long-term goals (pride; [Katzir et al., 2010](#)), or installing a specific emotional context ([Albert et al., 2010](#)). Mood on the other hand can be conceptualized as a general, long-lasting, mild affective state, that is not elicited by specific external emotional stimuli ([Beedie, Terry, & Lane, 2005](#); [Larsen, 2000](#)). Hence, whether or not positive mood can influence inhibition remains an open question.

At the ERP level, antisaccades usually elicit an increased frontocentral negativity (N2), and a decreased later parietal positivity (P300), as compared to prosaccade trials. This “N2/P3 complex” has been proposed as a valid neurophysiological marker of inhibition in the antisaccade task ([Mueller, Swainson, & Jackson, 2009](#)). In addition, differential preparatory activity in this task is often captured by a negative wave ramping up prior to target onset ([Klein, Heinks, Andresen, Berg, & Moritz, 2000](#); [Reuter, Herzog, Endrass, & Kathmann, 2006](#); [Klein et al., 2010](#); [Richards, 2013](#)), consistent with the Contingent Negative Variation (CNV; [Walter, Cooper, Aldridge, McCallum, & Winter, 1964](#)). This preparatory activity, typically triggered by a cue preceding the target of the saccade, is generally more negative in anti- compared to prosaccades ([Ansari & Derakshan, 2011](#); [Klein et al., 2000](#); [Richards, 2003](#)), in line with the assumption of a higher preparatory control in the former compared to the latter trials.

2. Current study

The main goal of this study was to assess whether positive mood could influence inhibitory processes, and if confirmed, to better characterize at which level during stimulus processing (either before or after target onset, or maybe both). To this aim, we recorded high-density EEG while healthy adults carried out a standard antisaccade task, after receiving either a positive or a neutral mood induction (between-subjects variable), previously validated in our laboratory (see also [Bakic, Jepma, De Raedt, & Pourtois, 2014](#); [Vanlessen et al., 2013](#); [Vanlessen, Rossi, De Raedt, & Pourtois, 2014](#)). In light of the evidence reviewed above, we predicted that positive mood would be associated with a less efficient inhibition, compared to a control condition where neutral mood was used.

At the behavioral level, we expected that the classic decrease in performance (slower latencies and increased error rate) in anti- compared to prosaccades would be exacerbated in the positive relative to the neutral mood group. At the electrophysiological level, we expected that the topographical and ERP correlates of inhibition (i.e., at the level of the CNV and N2/P3 complex) would be less strongly expressed in the positive (relative to neutral) mood group. We used advanced topographical evoked potential mapping methods to characterize electrophysiological differences between the two groups during the generation of pro- and antisaccades. Such topographical analysis allows to differentiate between different brain topographies or “maps” (sometimes referred to as “microstates”) over time, that reflect activations of different neural networks and thus different cognitive or affective processes, taking the whole electrical field into account (see [Murray, Brunet, & Michel, 2008](#); [Pourtois, Delplanque, Michel, & Vuilleumier, 2008](#)). Preceding target onset, we focused on the CNV. We hypothesized that antisaccades would elicit a larger CNV than prosaccades, and that preparation in the positive mood group would be less efficient, specifically for antisaccades (in line with [Ansari & Derakshan, 2011](#); [Klein et al., 2000](#)). Following target onset, we assessed whether positive mood would influence the N2, P3a and P3b, in such a way that these components would be expressed less strongly in the positive mood group, in addition to a modulation by saccade type.

3. Methods

3.1. Participants

Forty-one undergraduate students at Ghent University participated in the study (age: $M=22$; $SD=2$; 7 male participants). All participants reported to be right-handed, to have normal or corrected-to-normal vision and no history of psychiatric or neurological disorders. Participants gave written informed consent prior

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