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# Biasing free choices: The role of the rostral cingulate zone in intentional control[☆]

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ABSTRACT

Humans have the ability to choose freely between different alternatives. It is common knowledge, however, that our free choices are influenced by the environment and by past experiences. In the present study we investigated if the involvement of the medial frontal cortex, which is known to be important for intentional control, depends on whether free choices are biased by past experiences. By using fMRI, we observed that the rostral cingulate zone (RCZ) is less activated during biased than during unbiased choices. On the basis of this finding we argue that the RCZ plays a specific role in intentional control of action by evaluating which alternative is most appropriate in a given context. In addition, we observed that free choices were biased more during mind wandering episodes than during on-task episodes. This finding suggests that during periods of mind wandering, attention is shifted away from the primary task and external factors can influence the choice process more easily.


## Introduction

An important characteristic of human behavior is the ability to choose between different alternatives. 'Free' choices, however, are not only determined by our intentions and goals but also by biases imposed by our environment and past experiences (Bargh et al., 2001). When deciding between brands of chocolate bars, for example, our choice might be determined by explicit deliberation at the moment of choice or by previous exposure to the brands. The main goal of the present study was to test the hypothesis that biased choices involve less intentional control than unbiased choices, resulting in a reduction of activation in intentional control related brain areas.

Intentional control can be interpreted as a sub-component of cognitive control. While cognitive control generally refers to the ability to guide our thoughts and actions in order to accomplish internal goals (Miller and Cohen, 2001), intentional control specifically relates to internally-guided behavior. Intentional control can be decomposed in different components (Brass and Haggard, 2008). Here we investigated the mechanisms that allow us to decide what option to choose amongst several alternatives.

But which brain regions are important for intentional control? Converging evidence suggests that the medial frontal cortex is crucial (Brass and Haggard, 2008; Forstmann et al., 2006; Lau et al., 2004; Mueller et al., 2007; Walton et al., 2004). In particular, the rostral cingulate zone (RCZ), which is part of the medial frontal cortex, is strongly involved when comparing free choices with explicitly cued choices. This finding was interpreted as evidence that the RCZ plays a crucial role for the 'what' component of intentional control, representing the choice between different alternatives (Brass and Haggard, 2008; Cunnington et al., 2006; De Baene et al., 2012; Lau et al., 2004; Mueller et al., 2007; van Eimeren et al., 2006; Venkatraman et al., 2009; Walton et al., 2004). In representing the 'what' component, this area can be distinguished from other regions in the medial frontal cortex that are involved in intentional control, such as the pre-supplementary motor areas (pre-SMA) and the SMA-proper that represent the decision when to act (Cunnington et al., 2002, 2003; Libet et al., 1983) and a more anterior and dorsal part of the medial frontal cortex that represents the decision if an ongoing action should be stopped or not (Brass and Haggard, 2007).

In the present study we focused on the 'what' component of intentional control. We used the voluntary task switching procedure in which subjects can freely choose between two tasks (Arrington and Logan, 2004, 2005; Liefooghe et al., 2009, 2010; Mayr and Bell, 2006; Orr et al., 2012; Yeung, 2010). Interestingly, recent voluntary task switching studies indicated that free task choices are not always internally guided but can also be influenced by past experiences with target stimuli (Arrington et al., 2010; Demanet et al., 2010). The likelihood of choosing a specific task depends for example on whether the target stimulus has been associated with the same or a different task context in a preceding learning phase. Subjects tend to choose the task that is compatible with the learned stimulus–task association, leading to more compatible choices (CC) than incompatible choices (IC). In addition, it was demonstrated that external biases were stronger when choices were made in the context of concurrent working memory load (Demanet et al., 2010). This result suggests that in cognitively demanding situations, cognitive control and, more

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specific, intentional control is less efficient, leading to stronger external biases (see also Arrington, 2008; Orr and Weissman, 2011). In the present study we elaborated further on that finding and tested the hypothesis that choices biased by a stimulus through past experiences put less demands on brain areas that are specifically important for intentional control. In order to investigate this hypothesis directly, we introduced a stimulus bias while subjects were making free choices (Demanet et al., 2010). By using fMRI, we compared brain activation while subjects either freely chose between biased alternatives, unbiased alternatives or when their choice was explicitly cued and choice was not free.

A second goal of the present study was to investigate the relation between intentional control and mind wandering (MW). It has been argued that, during episodes of MW, attention is shifted away from the primary task towards inner thoughts, fantasies and feeling, leading to reduced cognitive involvement in the primary task (Smallwood and Schooler, 2006). In the present study we tested the hypothesis that intentional control is less efficient during MW episodes, leading to more biased choices during MW episodes compared to on-task episodes.

## Materials and methods

### *Subjects*

Twenty-five healthy subjects (five males; age: mean = 21.4, ranging from 19 to 25) were recruited from Ghent University. The study was conducted according to the Declaration of Helsinki, with approval of the local ethical committee of the Medical Department of Ghent University. All subjects had normal or corrected-to-normal vision. No subject had a history of neurological, major medical or psychiatric disorder. All subjects were right-handed as assessed by the Edinburgh handedness questionnaire (Oldfield, 1971) (mean score = 85).

### *Stimuli*

Stimulus presentation was managed with T scope (Stevens et al., 2006). In this experiment subjects chose to perform an 'animacy' task ('non-living' or 'living'), or a 'size' task ('smaller' or 'larger than a basketball') on visually presented nouns. By using the WordGen tool (Duyck et al., 2004), 128 nouns were selected on the basis of word frequency, which represents the frequency (per million words) this word is used in the Dutch language, and word length (average frequency: 11.0; average length: 5.6). As can be seen in Table 1, the average frequency (which was relatively high) and word length did not differ between the four stimulus conditions (i.e. large living, small living, large nonliving and small nonliving objects) canceling-out any word-processing differences between conditions. For every participant, four different stimulus sets of 32 nouns were selected. All sets consisted of 8 stimuli of the four stimulus conditions.

### *Experimental procedures*

Before the scanning session, subjects performed a training session outside the scanner for 20 single-task blocks (~30 min). In this training session, the first stimulus set ('animacy' set) was only used during blocks in which the animacy task was trained; the second stimulus set ('size' set) was only used during blocks in which the size task was trained. Subjects practiced one task in the odd-numbered blocks and the other task in the even-numbered blocks. Task-to-block mapping was counterbalanced across subjects. Each training block consisted of 32 trials, and each item of the relevant set was presented once per block (see Fig. 1 for some examples of stimuli used during the training phase). All trials in the training session started with the presentation of a noun in the center of the screen. This stimulus remained on the screen for 1000 ms, regardless of the response time. The maximal-response time was 4000 ms and the response–stimulus interval was 750 ms. Subjects responded orally by saying '[bu:]' for living, '[bi:]' for non-living, '[ba:]' for small, and '[bo:]' for large. Approximately, 15 min separated the training from the scanning session.

**Table 1**
Mean word frequency (per million in Dutch lexicon; see Duyck et al., 2004) and word length (#letters) for the nouns used for the 4 noun-conditions.

| | | Small | Large |
|---|---|---|---|
| Non-living | Frequency | 5.7 | 5.8 |
| | Length | 11.3 | 10.7 |
| Living | Frequency | 5.5 | 5.4 |
| | Length | 11.0 | 11.1 |

In the scanning session the 'animacy' task (non-living: left button; living: right button) and the 'size' task (smaller than basketball: left button; larger: right button) were mapped onto different hands with the task-to-hand assignment counterbalanced across subjects (see Fig. 1 for a graphical illustration). Half of the subjects responded with the left hand when the 'animacy' task was selected and responded with the right hand when the 'size' task was selected. We could thus categorize the different task choices based on the used response hand. This task-to-hand assignment was reversed for the other half of the subjects. We used manual responses in the scanning session and vocal responses in the training session in order to avoid transfer of stimulus–response associations from the training to the scanning session (for a similar procedure see Demanet et al., 2010).

Each trial started with the presentation of a stimulus appearing within a rectangle. When a white rectangle was presented subjects had a free choice which task to perform on that stimulus. It was stressed in the instructions that on these free choices, subjects should try to perform each task an approximate equal number of times and try to select tasks in such a way that the pattern of task choices was not predictable (Arrington and Logan, 2004, 2005). When the square was presented in blue or green, subjects were forced to perform the animacy task (blue square) or the size task (green square) on that stimulus. When a response was executed or the maximum response time of 5000 ms had elapsed, a jittered response–stimulus interval started (RSI; 200–6050 ms, in steps of 350 ms; distribution with pseudo-logarithmic density). This timing manipulation allowed us to disentangle activations related to two consecutive trials (Woldorff, 1993). When subjects made an error or performed the wrong task on cued trials, the square turned red for 200 ms.

Prior to scanning, all subjects were instructed about the procedure, entered the scanner and worked through two practice blocks of 32 trials in which the tasks were performed on novel untrained nouns that did not belong to one of the four predefined stimulus sets. The practice trials were followed by the scanning session in which three blocks of 128 trials were presented. In each block, 32 stimuli of the 'animacy' set, 32 stimuli of the 'size' set, and 32 stimuli of the third and fourth neutral untrained stimulus sets were presented in a random order. The stimuli from the first three stimulus sets were only used for free task choices and were always presented within a white rectangle. Choices on which participants choose the task that was previously related to the same task in the training session are referred to as compatible choices (CC). If, for example in the training session the stimulus 'car' was always related to the size task and participants in the scanning session decided to carry out the size task on this stimulus we defined it as a compatible choice. Trials on which participants choose the task that was previously related to the different tasks are referred to as incompatible choices (IC). If, for example the stimulus 'car' was related to the size task in the training session and participants choose to carry out the animacy task on this trial we defined it as an incompatible choice (see Fig. 1 for an illustration). Choices on stimuli that did not occur in the training session are referred to as neutral choices (NC). Stimuli from the fourth stimulus set were only used for the cued trials and were presented within a blue or green rectangle that indicated the relevant task. The order of blue or green rectangles on cued trials was randomized.