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Switch hands! Mapping temporal dynamics of proactive manual control with anticues☆

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ABSTRACT

This study uses a novel behavioral paradigm—the anticue task—to investigate the temporal dynamics of proactive control aimed at the resolution of response conflict in the manual motor system. The anticue task is a 4-choice reaction time (RT) task, with left and right anticues indicating mirror-symmetrical response hands. In particular, anticues require participants to prepare fingers on the hand opposite to the side of the cue (counter-corresponding mapping), which contrasts with the more standard procues that prompt participants to prepare fingers on the hand spatially in line with the cue (corresponding mapping). In Experiment 1, we examined the effects of anticues and procues as a function of cue–target interval (range: 100–850 ms). Results showed that procues produced RT benefits (relative to neutral cues), which increased with longer cue–target intervals. Anticues, however, produced RT costs with short cue–target intervals and RT benefits with longer cue–target intervals. These findings support the view that anticues are mediated by a time-consuming, proactive control process that, using inhibition and activation, redirects the initial but wrong activation of the ipsilateral hand to the correct contralateral hand. In Experiment 2, we used a simple detection response to test, and reject, an alternative (attentional) account of these findings. Theoretical and practical implications are discussed in the context of dual-route models of response selection, the activation-suppression model, and related experimental protocols such as antisaccade, Simon, Stroop, Eriksen flanker, and task switching paradigms.

1. Introduction

Behavioral flexibility, defined as the ability to suppress or constrain an action and switch to another response, is important in a dynamic environment. This is, for instance, the case when driving a car and a pedestrian suddenly steps on the road, which requires a fast, unanticipated braking action. Sometimes, however, environmental changes can be anticipated, for example, when approaching a traffic light or a pedestrian zone with zebra crossing. Here, it is possible to adjust driving behavior in advance of possible future events. As these two examples illustrate, behavioral flexibility can be implemented in two ways: reactively, that is, in immediate reaction to the onset of an (unexpected) event, or proactively, that is, in anticipation of an upcoming event. The distinction between reactive and proactive cognitive control has been emphasized by several authors, each with its own flavor (e.g., Braver, 2012; Hikosaka and Isoda, 2010). The proactive type of control has been studied less extensively, even though it may have a wider ecological and clinical validity, especially in the field of "impulse control" (Aron, 2011). In this study, we examined the efficiency and time course of proactive control operations with a novel paradigm—the anticue task—which focuses on the resolution of response conflict in the manual motor system.

The anticue task (Fig. 1) is an extension of the finger-precuing task (Miller, 1982), and requires participants to respond to spatial-location targets with discrete keypress responses from the index and middle fingers of both hands. Critically, in the anticue task, an informative left or right spatial cue precedes the onset of the target (by a certain cue–target interval) and consistently indicates the preparation of the response hand *opposite* to the location (side) of the cue. Hence, with anticues, the mapping between cue location (left, right) and response hand (right, left) is mirror-symmetrical and thus incongruent, calling for a top-down, intention-driven process that selectively inhibits fingers on the ipsilateral hand and primes fingers on the contralateral hand. In the neutral cue (control) condition, the spatial cue occupies all four target locations, thereby negating the possibility to implement a selective motor set. This neutral condition provides a baseline against which the effects of the anticue can be evaluated.

If participants are successful in preparing the response set opposite to the anticue, a RT benefit should be observed for the anticue relative to the neutral cue. This is because successful preparation transforms

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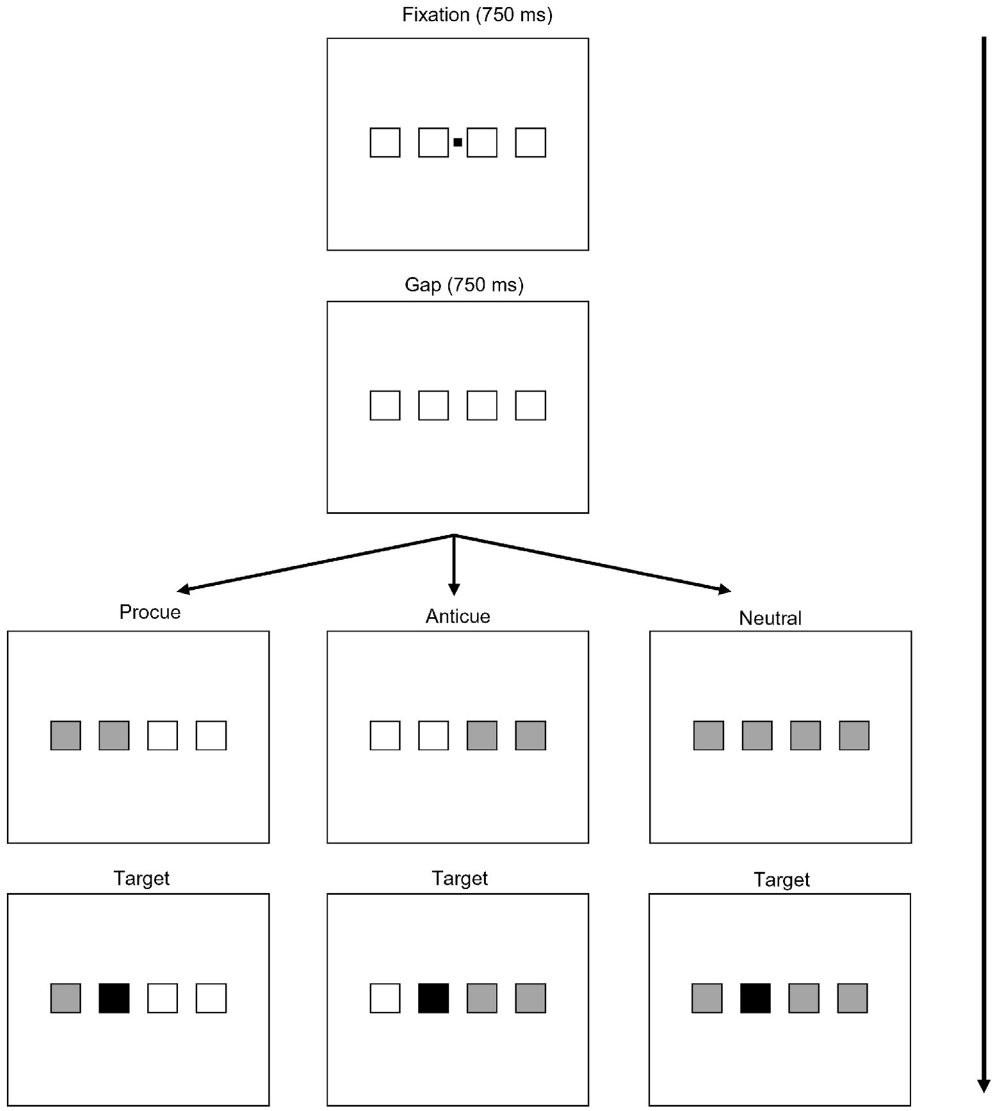

Fig. 1. Schematic representation of procue, anticue, and neutral cue conditions, showing the time line and spatial features of the paradigm. All displays spatially overlapped. Cue and target displays were temporally separated by one of five different cue–target intervals (100, 150, 250, 450, and 850 ms), presented in random order. Cued locations are represented in gray (actual color: red) and the target location in black (actual color: green). Procues indicated the selective preparation of two fingers on the ipsilateral hand, whereas anticues indicated the selective preparation of two fingers on the contralateral hand. The single target indicated the final response that was always compatible with the location of the target. Note that procues and anticues were presented in separate blocks of trials, each randomly intermixed with neutral cues. Not drawn to scale.

the 4-choice task into a 2-choice task, the latter yielding shorter RTs than the former (e.g., Miller, 1982). However, if participants are not able to successfully link the anticue with the opposite hand, then a RT *cost* should emerge. This is because left and right cues automatically activate their corresponding left and right hand finger responses, respectively (e.g., Adam, Hommel, and Umiltà, 2003, 2005; Eimer, 1995; Kornblum, Hasbroucq, and Osman, 1990), which in the case of anticues are the wrong responses. Hence, anticues create response conflict in the motor system, calling for an abort (Kornblum et al., 1990) or inhibition mechanism (Ridderinkhof, 2002) to suppress the automatic but erroneous activation of the wrong responses on the ipsilateral hand. In addition, selective activation of the correct responses on the contralateral hand is needed to produce a facilitatory effect that manifests itself as a RT benefit relative to the uncued, control condition. Hence, short cue–target intervals are expected to generate RT costs, whereas longer cue–target intervals are expected to generate RT benefits. This cost–benefit pattern for anticues with increasing cue–target interval has been demonstrated in a clinical study with Parkinson's disease patients and healthy controls (Adam, van Houdt, Scholtissen, Visser-Vandewalle, Winogrodzka, & Duits, 2011), but not in a study with children and young adults, which showed the expected RT benefits but no costs (Adam, Ament, & Hurks, 2011). The latter study, however, used longer cue–target intervals than did the former (200 to 2000 ms versus 100 to 1000 ms, respectively), suggesting that inhibitory control processes may operate quickly and that cue–target intervals shorter than 200 ms are needed to induce anticue RT costs.

In the present study, we followed up on these previous investigations by implementing three novel aspects. First, in addition to anticues, we also studied—within the same participants— the effects of the more typical procues, which relate in a spatially congruent, not crossed, manner to the response hands. The reason for including procues was to demonstrate that left/right cues in the anticue task quickly and automatically activate the response alternatives on the ipsilateral hand. Hence, procues should produce RT benefits relative to neutral cues at all cue–target intervals, including the shortest ones. Second, we optimized the range and specific levels of the cue–target intervals to more accurately trace the time course of the expected cost–benefit pattern triggered by anticues, including two very short cue–target intervals of 100 and 150 ms (expected to produce anticue costs), one intermediate interval of 250 ms, and two longer cue–target intervals of 450 and