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When two actions are easier than one: How inhibitory control demands affect response processing☆

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ABSTRACT

Numerous studies showed that the simultaneous execution of multiple actions is associated with performance costs. Here, we demonstrate that when highly automatic responses are involved, performance in single-response conditions can actually be worse than in dual-response conditions. Participants responded to peripheral visual stimuli with an eye movement (saccade), a manual key press, or both. To manipulate saccade automaticity, a central fixation cross either remained present throughout the trial (overlap condition, lower automaticity) or disappeared 200 ms before visual target onset (gap condition, greater automaticity). Crucially, single-response conditions yielded more performance errors than dual-response conditions (i.e., dual-response benefit), especially in gap trials. This was due to difficulties associated with inhibiting saccades when only manual responses were required, suggesting that response inhibition (remaining fixated) can be even more resource-demanding than overt response execution (saccade to peripheral target).

1. Introduction

Performance in task conditions requiring two responses is usually worse (in terms of increased response times or errors) than in task conditions requiring only one response (i.e., dual-response costs). Typically, such dual-response costs are ascribed to additional mental processing demands associated with the selection and co-ordination of two (vs. one) responses. However, we reasoned that when one of the two responses is highly automatic, executing the other response in isolation (i.e., without executing the automatic response) may be difficult because of corresponding inhibitory control demands. We thus asked to what extent overt execution of a (relatively automatic) secondary response can actually be easier than inhibition of that response by studying manual response performance under additional visual orientation (saccade execution) demands vs. remain-fixated (inhibitory) demands.

1.1. Sources of dual-response costs

In previous research, dual-response costs have mainly been studied within the field of dual-task performance. Therefore, we will briefly review corresponding studies and explanatory concepts. In typical dual-task studies, two distinct (simultaneous or systematically delayed) stimuli each define a corresponding response (e.g., Pashler, 1994). Several theoretical concepts were proposed to account for dual-response costs in dual-task studies.

For example, *central bottleneck theory* holds that the decision of which response to execute can never be made for two tasks in parallel, leading to typical processing postponements for the second response (serial central response selection, see Pashler, 1994). In contrast, *resource theory* assumes that two responses can principally be selected in parallel, but that drawing on the same limited resource(s) causes performance costs (e.g., Wickens, 2008). In line with this view, several versions of resource theory (e.g., Logan & Gordon, 2001; Meyer & Kieras, 1997; Navon & Miller, 2002; Tombu & Jolicoeur, 2003) assume that serial processing as envisioned in the bottleneck framework may only be a strategic product of flexible resource scheduling, not a generic feature of our cognitive architecture. Third, performance costs were also explained in terms of between-task *information crosstalk*. For example, performance decreases when two tasks require spatially incompatible

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(e.g., left vs. right) responses (Navon & Miller, 1987). In addition to these major theoretical frameworks of dual-task performance, other potential sources of dual-response costs were discussed, for example processes associated with task/response scheduling (De Jong, 1995; Luria & Meiran, 2003; Sigman & Dehaene, 2006; Szameitat, Lepsien, von Cramon, Sterr, & Schubert, 2006), reconfiguration of task/response requirements (Band & van Nes, 2006; Lien, Schweickert, & Proctor, 2003), and non-optimized task/response coordination skills (e.g., Kramer, Larish, & Strayer, 1995; Strobach, Frensch, Soutschek, & Schubert, 2012).

Note that all these explanatory accounts of dual-response costs in dual-task studies usually refer to additional cognitive processes associated with secondary task demands rather than to the mere presence of a secondary response per se. Thus, it appears principally possible that additional cognitive processes associated with *inhibiting* a secondary response may – under certain conditions – also yield performance costs in single-response conditions, or, conversely, performance benefits in dual-response conditions, a hypothesis that has not been explicitly tested yet.

Although dual-response *benefits* have not yet been a focus of research on action control, some studies at least reported evidence for (nearly) extinguished costs under specific circumstances, for example, after long training with specific input/output modalities (e.g., Hazeltine, Ruthruff, & Remington, 2006; Israel & Cohen, 2011; Kramer et al., 1995; Schumacher et al., 2001; Strobach et al., 2012), or in the context of specific response types (e.g., saccades triggered by salient peripheral stimuli, see Pashler, Carrier, & Hoffman, 1993). In these cases, it has been assumed that the duration of the central bottleneck was substantially shortened ("latent" bottleneck, see Ruthruff, Johnston, Van Selst, Whitsell, & Remington, 2003) or bypassed (Pashler et al., 1993), that different resource pools were involved (Wickens, 2008), or that the potential for crosstalk was minimal in the first place.

Importantly, however, all these previous frameworks never considered the case of potential *benefits* associated with executing more than one action at a time. In the present study, we explicitly questioned the claim that executing two responses (vs. one response) always comes at a cost by focusing on dual-response situations involving highly automatic actions that are difficult to inhibit. An observation of dual-response benefits under these conditions would support the assumption that it is not the presence of a secondary response per se that hampers performance, but rather the cognitive burden associated with action control, irrespective of the exact type of action control (execution vs. inhibition).

1.2. The present study

To specifically focus on late, action-related processes, we resorted to a paradigm in which (contrary to the typical dual-task studies referred to above) only one stimulus triggers both responses ("single-onset paradigm"). We reasoned that processing two stimuli (and independently selecting two appropriate responses) in traditional dual-task paradigms may result in relatively high overall processing demands on top of the need to co-ordinate the two required responses, making it virtually impossible to find better performance in dual- (vs. single-) response conditions. Previous research suggested that participants in the single-onset paradigm indeed employ a single, "compound" response selection (Fagot & Pashler, 1992), so that the remaining dual-response costs were attributable to the need to execute two (instead of one) responses, which represents the theoretical focus of our present study.

As outlined above, one of the two responses should be highly automatic, so that inhibitory control involved in its suppression in single-response conditions might be even more cognitively challenging than overt response execution in dual-response conditions. A prototype for such highly automatic (albeit cognitively controlled) responses are visual orientation responses (saccades) to salient peripheral stimuli (Findlay & Walker, 1999). This saccade demand was combined with a typical response studied in the field of action control, namely manual key press responses. Participants responded to salient peripheral (left vs. right) visual stimuli with only a saccade, only a manual response, or both. When saccades indeed are comparatively automatic in the sense that they are difficult to inhibit, it should be easier for participants to execute them along with the manual response (in dual-response conditions) than to withhold saccade execution when only a manual response is required (in single-manual response conditions), resulting in a dual-response benefit effect.

Note that this prediction was derived from a specific framework of multiple action processing that ascribes inhibitory control problems to spreading activation in a network of response-relevant cognitive codes (Huestegge & Koch, 2010a; see Fig. 1 and Section 4.2 for details). Specifically, we assumed that activating response-related codes (e.g., a "left" code) can erroneously activate strongly associated response codes (e.g., a "saccade" code), even when the activation of the latter may result in errors (e.g., saccade execution in single-manual response conditions).

To directly test our hypothesis that response automaticity may be a driving force behind the occurrence of potential dual-response benefits, we introduced two experimental conditions that differed in terms of the way a fixation cross is presented. In *overlap* trials a central fixation cross remained present throughout the trial, whereas in *gap* trials a central fixation cross was removed prior to the onset of the peripheral saccade target. Gap conditions involve greater saccade automaticity than overlap conditions due to a) a faster release of fixation cell activity in the superior colliculus (Munoz & Wurtz, 1993), b) the potential of the gap period to act as a warning signal (e.g., Ross & Ross, 1980), and c) due to the inherent lack of competition between potential fixation targets (Findlay & Walker, 1999; Huestegge & Koch, 2010b). Thus, if response automaticity is a major factor determining the amount of inhibitory control demands, dual-response benefits should be greater (or, alternatively, dual-response costs should be smaller) in gap conditions than in overlap conditions.

2. Method

2.1. Participants

Eighteen students (mean age = 24 years) with normal or corrected-to normal vision took part in this study.

2.2. Apparatus

Participants were seated at a distance of 67 cm in front of a 21″ CRT screen (temporal resolution: 100 Hz; spatial resolution: 1024 × 768 pixels) with a keyboard in front of them. A chinrest was used to minimize head movements. An EyeLink II eye tracker (SR Research, Osgoode, Ontario, Canada) with a temporal resolution of 500 Hz was used to measure movements of the right eye. The experiment was programmed using Experiment Builder (SR Research). On the keyboard, two keys (left/right Ctrl) served as response keys and were operated by the left and right index fingers, respectively.

2.3. Procedure

At the beginning of each trial, a white central fixation cross (5° × 4°) on black background appeared for 2000 ms and then changed its color to either red, green, or blue, serving as a cue that indicated the response condition (e.g., red: single-response saccade, green: single-response manual, blue: dual response). After cue onset, the imperative visual stimulus (white square of 6° diameter) appeared at an eccentricity of 12° either to the left or right.