

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).

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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 ($5^\circ \times 4^\circ$) 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.

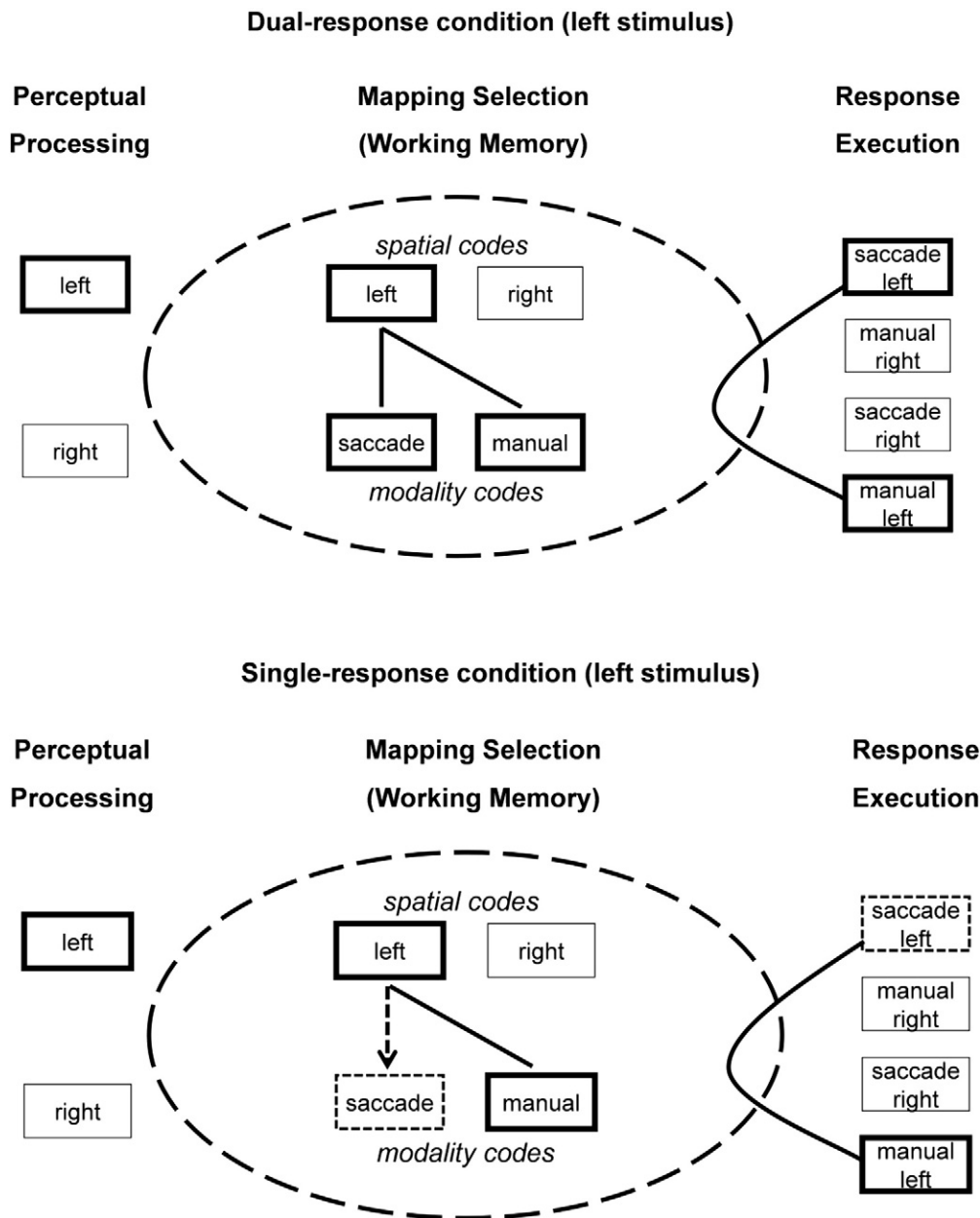


Fig. 1. Spreading activation in the cross-modal action processing model. In dual-response conditions, a left stimulus triggers a binding between the corresponding spatial code and both modalities (upper panel), whereas in the single-response condition (lower panel), the saccade modality code is erroneously co-activated (dotted lines) due to the corresponding high a priori connection strength between the corresponding spatial code and saccade modality code for visual orienting responses. The activation of the spatial “left” code thus “spills over” to the saccade code, triggering an overt saccade, which would be erroneous in the single-manual condition.

In overlap trials, the colored cue remained present for 700 ms. Then, the imperative visual stimulus appeared for 2500 ms while the cue remained present throughout the interval of imperative visual stimulus presentation. Participants were instructed to respond with a spatially compatible saccade towards the peripheral stimulus (without a manual response) in single-response saccade conditions, with a spatially compatible key press (without a saccade response) in single-response manual conditions, or with both in dual-response conditions. Finally, a black screen was presented for 1000 ms. In gap trials, the colored cue remained present for only 500 ms. Then, the screen turned black for 200 ms (gap period) before the imperative visual stimulus appeared (see Fig. 2). Participants were instructed to respond fast and accurately.

Each participant completed six blocks of 60 randomly ordered trials each (40 min in total). Prior to each block, participants underwent calibration. The first three blocks consisted of one

fixation condition (e.g., gap), whereas the remainder consisted of the other fixation condition (e.g., overlap condition). Fixation condition order was fully counterbalanced across participants, while the mapping of colors (red, green, blue) to response conditions (single-response saccade, single-response manual, dual response) was counterbalanced across participants using a Latin square design.

2.4. Design

For the analysis of response errors, the independent (within-subjects) variables were response condition (single-manual response, single-saccade response, dual response), response modality (saccade vs. manual, i.e., whether a saccade error or a manual error occurred), and fixation cross condition (gap vs. overlap). Note that errors included

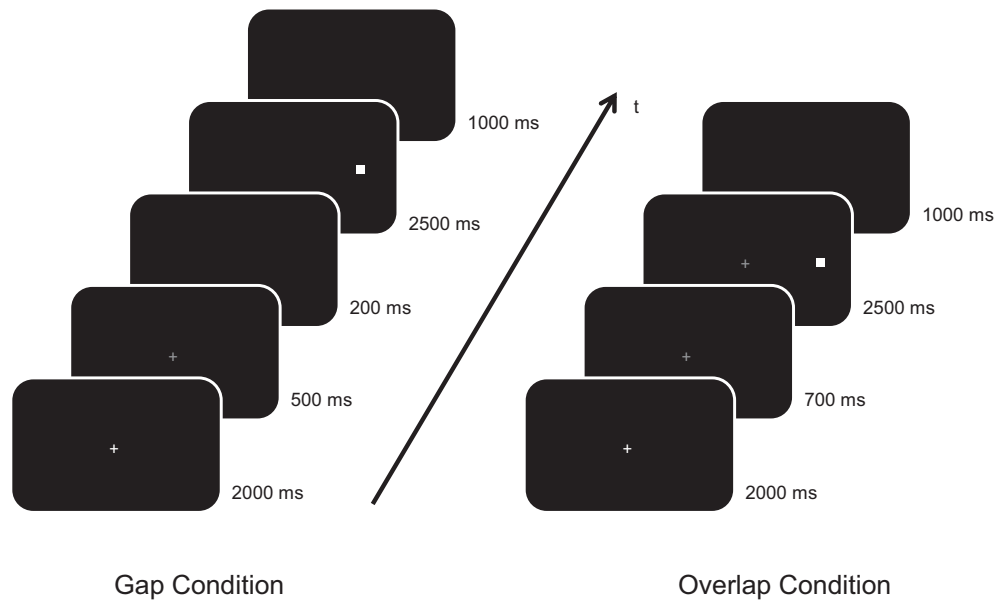


Fig. 2. Temporal trial structure of gap and overlap conditions. A change of fixation cross color from white to gray symbolizes color change indicating response condition.

directional errors (wrong key press, eye movement in wrong direction), lack of responding (e.g., omission of a saccade response in trials requiring a saccade response), and the execution of responses in a modality that was not required in the trial (e.g., the presence of saccades in single-manual trials). Correct saccades were defined in terms of eye movements that moved at least halfway towards the corresponding target location in trials requiring a saccade response.

For the analysis of response times (RTs), we included only trials without errors (in any of the two response modalities), implying that the independent variable response condition here only has two values (single-response vs. dual-response conditions). All other aspects of the design were the same as in the error analysis. Saccade RT was defined as the temporal interval between target onset and the initiation of the first saccade that moved at least halfway towards the target.

3. Results

3.1. Error data

Error data are displayed in Fig. 3. A three-way ANOVA with the independent variable response condition (single-manual response, single-saccade response, dual response), modality (saccade vs. manual), and fixation cross condition (gap vs. overlap) revealed a significant main effect of response condition, $F(2,34) = 49.62, p < .001, \eta_p^2 = .75$, indicating that participants produced fewer overall errors in dual-response conditions (5.5%) than in single-response conditions (7.2% in single-

saccade trials, 20.6% in single-manual-trials, i.e., a relative dual-response benefit). In line with our hypothesis, Bonferroni-adjusted post-hoc comparisons revealed that this dual-response benefit resulted from significantly increased error rates in single-manual conditions (where eye movements needed to be inhibited and erroneously executed saccades counted as errors) compared with the remaining two conditions, $ps < .001$, whereas there was no significant difference between the single-saccade condition and the dual-response condition, $p = .15$.

There was also a significant effect of modality, $F(1,17) = 80.24, p < .001, \eta_p^2 = .83$, reflecting overall more errors for saccade responses (16.8%) than for manual responses (5.4%). There was no main effect of fixation cross condition, $F < 1$. We also observed a significant interaction of response condition and modality, $F(2,34) = 40.42, p < .001, \eta_p^2 = .70$, indicating a greater dual-response benefit in saccade errors (due to the inflated saccade error rates in single-manual response conditions) than in manual errors.

Importantly, the interaction of response condition and fixation cross condition was significant, $F(2,34) = 4.04, p = .027, \eta_p^2 = .19$, indicating that dual-response benefits were greater in gap conditions than in overlap conditions. There was no significant interaction between modality and fixation cross condition, $F < 1$, but a significant three-way interaction, $F(2,34) = 3.43, p = .044, \eta_p^2 = .17$. The latter indicates that the interaction of response condition and fixation cross condition was more pronounced for saccade errors than for manual errors. In line with this interpretation, a post hoc two-way ANOVA only for saccade errors revealed a significant interaction between response

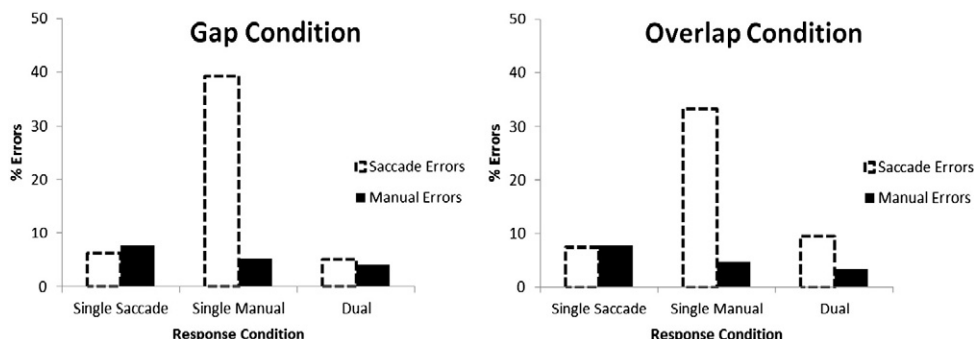


Fig. 3. Errors as a function of fixation cross condition (gap vs. overlap), modality (saccade vs. manual), and response condition (single-saccade, single-manual, dual).

condition and fixation cross condition, $F(2,34) = 3.89, p = .030, \eta_p^2 = .19$, whereas the same post-hoc ANOVA only for manual errors revealed no such interaction, $F < 1$.

Taken together, the main finding is the substantial rate of saccade errors in single-manual conditions. This clearly reflects participants' difficulties with remaining fixated (i.e., inhibiting saccade responses) in conditions where they were supposed to respond with a manual response only.

We deliberately implemented a design in which all response conditions were intermixed within blocks of trials. We reasoned that holding back saccades would be especially difficult when they were mandatory in adjacent trials. To test whether our present findings are mainly due to these rapid changes in response demands inherent in such an intermixed design, we conducted an additional analysis of sequence effects. Specifically, we analyzed (averaged across fixation conditions) whether the erroneous execution of saccades in single manual conditions was significantly more frequent when the *previous* trial also required saccade execution (either in single-saccade conditions or in dual-response conditions) vs. when the previous trial required no saccade execution (single manual response). This analysis revealed that the rate of executing an erroneous saccade differed significantly as a function of previous trial type, $F(2,34) = 3.76, p = .033, \eta_p^2 = .18$ (percentage of erroneous saccades: 35.3% when previous trial required no saccade, 32.3% when previous trial required a single saccade, 41.0% when previous trial required a dual-response). However, post hoc tests revealed that despite this overall evidence for a switch cost when switching from dual- to single-response conditions, neither of the two conditions (single, dual) requiring a saccade in the previous trial significantly differed from the condition without a saccade requirement in the previous trial, both $ps > .05$. This indicates that the difficulties associated with remaining fixated were not mainly due to trial-by-trial effects of switches from saccade-execution demands to remain-fixated demands. Thus, our observation of dual-response benefits was not mainly based on transient effects of response demand switching inherent in a mixed design (i.e., a design in which response conditions were mixed within each block of trials).

3.2. RT data

Fig. 4 summarizes the RT data. The three-way ANOVA revealed a significant main effect of modality, $F(1,17) = 74.76, p < .001, \eta_p^2 = .82$, with longer manual RTs than saccade RTs (512 ms vs. 220 ms), and a significant main effect of fixation cross condition, $F(1,17) = 27.43, p < .001, \eta_p^2 = .62$, with shorter RTs for gap vs. overlap conditions (gap effect of 54 ms). There was also a trend towards longer overall RTs in dual-response (383 ms) vs. single-response (349 ms) conditions, but this was not significant, $F(1,17) = 3.28, p = .088, \eta_p^2 = .16$.

However, this trend was qualified by a significant interaction of response condition and fixation cross condition, $F(1,17) = 11.91, p = .009, \eta_p^2 = .33$, reflecting substantial dual-response costs in overlap conditions (60 ms), but negligible costs in gap conditions

(8 ms). There was no significant interaction of response condition and modality, $F(1,17) = 2.77, p > .10$, no significant interaction of modality and fixation cross condition, $F < 1$, but a significant three-way interaction, $F(1,17) = 8.54, p = .009, \eta_p^2 = .33$.

To decompose this three-way interaction, we conducted separate two-way ANOVAs for each fixation cross condition. In gap conditions, there was no significant effect of response condition, $F < 1$, but a significant effect of modality, $F(1,17) = 70.05, p < .001, \eta_p^2 = .81$. There was no interaction between response condition and modality, $F < 1$.

In the overlap condition, however, we observed a significant effect of response condition, $F(1,17) = 6.14, p = .024, \eta_p^2 = .27$, a significant effect of modality, $F(1,17) = 67.28, p < .001, \eta_p^2 = .80$, and also a significant interaction, $F(1,17) = 5.28, p = .034, \eta_p^2 = .24$. This interaction indicates greater dual-response costs for manual responses (108 ms) than for saccades (12 ms).

Taken together, the RT data show that in gap conditions, the interpretation of dual-response benefits in errors is not compromised by a reversed RT pattern. In the overlap condition alone, however, we cannot clearly interpret the overall effect of response condition on performance, since dual-response benefits in errors went hand in hand with dual-response costs in RTs. Note that this does in no way compromise our overall interpretation, since the crucial comparison between gap and overlap conditions revealed a quite systematic pattern in line with our hypothesis that greater automaticity enhances the potential of observing dual-response benefits (or, reduced dual-response costs). Specifically, the RT data (revealing greater dual-response costs in overlap vs. gap conditions) nicely converged with a corresponding trend in the error data (revealing smaller dual-response benefits in overlap vs. gap conditions).

4. Discussion

The present study asked whether single-response performance can actually be worse than dual-response performance in situations where response inhibition strongly draws on inhibitory resources. Critically, one of the two responses (visual orienting towards salient peripheral visual stimuli) was highly automatic (i.e., comparatively difficult to inhibit), whereas the other was a manual key press response. The results indicated that participants experienced great difficulty in inhibiting saccades while performing a manual response, so that overall performance was more accurate in dual-response conditions (where eye movements were executed along with manual responses) than in single-response conditions (where in single-manual conditions participants were asked to remain fixated).

Furthermore, we directly tested our assumption that the degree of saccade automaticity affects the amount of dual-response benefits. Indeed, gap conditions (representing greater automaticity) yielded stronger dual-response benefits in the error data and smaller dual-response costs in RTs than the (less automatic) overlap conditions. Overall, this suggests that more automaticity in one of the two responses is associated with greater dual-response performance benefits.

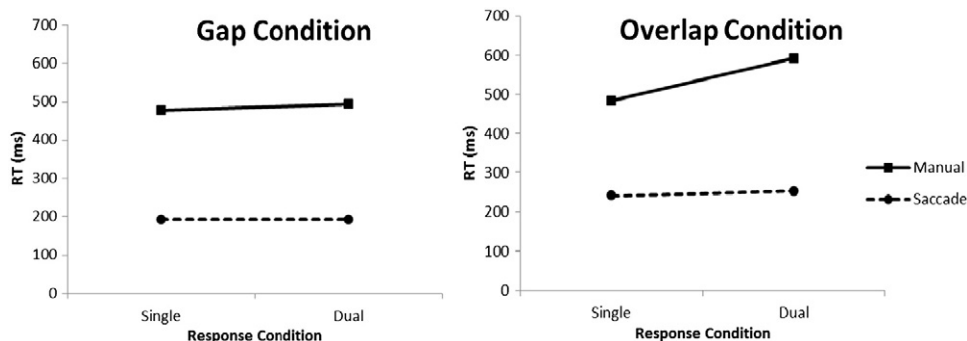


Fig. 4. RTs as a function of fixation cross condition (gap vs. overlap), modality (saccade vs. manual), and response condition (single vs. dual).

Note that color cue duration was necessarily longer in overlap than in gap conditions, potentially leaving participants more time for cue processing to achieve better performance. However, the actual results indicated *worse* overall performance in overlap (vs. gap) trials (i.e., slower RTs without significant accuracy differences), so that cue processing duration can be ruled out as an alternative explanation of the fixation condition effect.

4.1. Relation to other studies

The occurrence of dual-response benefits appears especially interesting considering that participants knew already at the beginning of each trial whether a saccade was required or not. In contrast, another approach to study mechanisms of saccade inhibition utilized a stop-signal task, where (oculo-)motor responses are initiated in each experimental trial but are sometimes canceled via a competing stop-process triggered by a stop signal (Boucher, Palmeri, Logan, & Schall, 2007). In these studies, the signal to withhold a (saccade) response comes late in a trial when it is difficult to cancel an already generated motor command, and erroneous response execution typically occurs when the stop signal onset was too late.

Another related line of research suggested that (anti-)saccade performance can be enhanced in the presence of additional perceptual task demands (vs. no additional perceptual task demands, see Evans & Ludwig, 2010; Kristjánsson, Chen, & Nakayama, 2001). However, this evidence of a dual-task benefit is not directly comparable to our present results, since the secondary task demands in these previous studies consisted of a perceptual (not a response execution/inhibition) task.

Some previous studies also explicitly addressed the issue of how two overt responses are associated with single stimuli (e.g., Nino & Rickard, 2003; Strobach, Schubert, Pashler, & Rickard, 2014). In these experiments, participants learned to associate two semantically unrelated (i.e., non-automatic) responses with a fairly large set of stimuli. The results suggested that even for a set of rather complex S–R rules, at least some participants rely on grouping strategies to produce the two responses, which is in line with our assumption of conjoint response selection processes based on single stimuli (especially for the highly S–R compatible conditions employed in our present study, see Fagot & Pashler, 1992). Overall, however, in these previous studies substantial performance costs were associated with retrieving two (vs. one) overt responses. This observation of strong dual-response costs is likely due to the comparatively complex set of learned S–R rules in these studies, especially since these rules did not rely on automatic S–R mapping routes (e.g., due to high S–R compatibility).

The data pattern change from (highly automatic) gap to (less automatic) overlap conditions in our study exhibited a tendency towards more effortful dual-response execution. This tendency finds a continuation in previously observed data patterns based on auditory (thus, even less automatic) stimuli for saccades, where we observed dual-response costs in RTs without sizable effects in errors (Huestegge & Koch, 2010a, 2013). This observation provides additional evidence that the specific stimulus modalities (here: visual vs. auditory input) involved in multiple-response control substantially affect overall processing efficiency (Huestegge & Hazeltine, 2011).

4.2. Theoretical implications

All major theoretical frameworks explaining dual-response costs were initially developed within research on dual-task performance. Typically, corresponding theoretical concepts (e.g., bottlenecks, resources, crosstalk) were designed to explain performance costs associated with multiple action demands (Meyer & Kieras, 1997; Pashler, 1994; Wickens, 2008). In the following, we will discuss the extent to which the underlying assumptions of research on dual-task performance may also shed some light on the processes involved in our present (dual-response) study, which substantially differs from previous dual-

task studies. Most dual-task models (and corresponding paradigms) typically assume that a dual-task situation is essentially characterized by the presence of a set of two overtly executed responses. For example, ECTVA (a computational model of dual-task control, Logan & Gordon, 2001) assumes that each response is associated with a response counter, which accumulates activity until a threshold is reached. Within this framework, our present paradigm would at first sight qualify as a dual-task situation (due to the two distinct responses that need to be initiated within a trial), and it consequently appears difficult to explain the occurrence of dual-response benefits when we assume that two response counters (instead of one) need to be specified.

However, when we define dual-task demands from a more cognitive standpoint (i.e., not simply through the presence of two overt responses), many dual-task models can easily be reconciled with our data by assuming that “remaining fixated” represents an (albeit covert) cognitive task on its own that can be even more resource-consuming than overt saccade execution. In this view, our single-manual response condition may actually be interpreted in terms of a dual-task situation consisting of a manual key-press demand and a (comparatively difficult) remain-fixated demand. In contrast, overt saccade execution in dual-response conditions may be relatively easy since saccade selection in dual-response conditions can be based on the same unitary response compound selection process that also specifies the manual response (Fagot & Pashler, 1992; Strobach et al., 2014). Especially flexible resource scheduling models (e.g., Meyer & Kieras, 1997; Navon & Miller, 2002; Tombu & Jolicoeur, 2003) appear to be adaptable to this finding, since inhibition might be considered as an executive control demand (e.g., Miyake et al., 2000) that may interfere with other ongoing processing demands. This interpretation suggests that inhibitory control draws on the same resources (related to action control) as overt response processing.

Interestingly, previous research in the context of the stop-signal paradigm suggested that inhibitory control does not suffer from dual-task interference. Specifically, additional response demands did not affect manual stopping performance in a dual-task paradigm with variable stimulus onset asynchrony (Yamaguchi, Logan, & Bissett, 2012). At first sight, this study appears to contradict our present findings since it suggests different resource pools for inhibitory control and overt response control. However, it is important to note two major differences between this previous study and our current study. First, our study addressed the influence of inhibitory demands on overt response control, whereas Yamaguchi et al. (2012) focused on the reversed relation (i.e., the influence of overt response selection on inhibitory control). Second, it may well be that inhibitory demands in a manual stop-signal task are generally weaker than those involved in the suppression of visual orientation responses, effectively preventing any observation of interference effects.

In line with the outlined (cognitive) interpretation of our findings, it seems important to note that we did not observe dual-response benefits in the sense that the very same response is performed more efficiently (i.e., faster) in dual- vs. single-response conditions. Rather, overall task performance exhibited fewer errors in dual- (vs. single-) response conditions. In fact, the absence of dual-response benefits in correct RTs (see Fig. 4) suggests that even under advantageous conditions dual-response RTs are at best on a similar level as in single-response conditions. From this perspective, our data are well in line with traditional dual-task accounts, which typically never predict faster RTs in dual-response conditions than in single-response conditions.

While the explanation of our findings in terms of resource conflicts (see above) operates on a quite general level by referring to the relatively loosely defined notion of resources, it is also possible to provide more specific cognitive mechanisms within a recently developed conceptual framework of multiple response control (Huestegge & Koch, 2010a). In line with traditional processing models, it incorporates distinct stages: perceptual processing, mapping selection (as opposed to response selection in the individual tasks in bottleneck models, see

Pashler, 1994), and response execution. Unlike bottleneck models, it focuses on the activation of content-based codes (representing task-relevant features like response modalities and spatial response characteristics) in accordance with pre-defined task rules (see Fig. 1).

Crucially, the framework may allow for the occurrence of dual-response benefits. By adding the assumption that activation of a specific code may spread towards closely associated codes (Huestegge, 2011), the activation of a specific response-related code (e.g., “left”) may erroneously activate a strongly associated code (e.g., referring to “saccade” modality), eventually producing an unwanted additional saccade response in single-manual conditions (see Fig. 1). This spreading of activation appears likely since visual orienting responses should involve particularly strong S–R connections, resulting in a substantial a priori connection strength between the spatial response code defined by the stimulus and the respective modality code for the saccade.

4.3. Conclusion

The major novel finding of the present study is the evidence for a (relative) dual-response benefit. This finding supports the suggestion 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 control (execution vs. inhibition). This is especially relevant in situations that require strong inhibitory control such as remain fixated demands in the presence of salient peripheral visual stimulation, as we have studied it here. The present demonstration of a relative dual-response benefit thus shows that concurrent inhibitory and execution-related control demands strongly interact.

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