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ORIGINAL ARTICLE

Response preparation, response selection difficulty, and response-outcome learning

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Abstract

Voluntary action control is accomplished through anticipating that action's perceptual outcomes. Some evidence suggests that this is only true when responses are intention-based rather than stimulus-based and that this difference is evidence of different response modes. More recently, however, it has been shown that response-outcome retrieval effects can occur with stimulus-based responses, and that the retrieval depended on response selection efficiency as decreasing the response selection efficiency increased response-outcome retrieval (Gozli et al., J Exp Psychol: Hum Percept Perform, 2016). We look to extend this finding by manipulating response selection difficulty within (Experiment 1) or between blocks (Experiment 2) and response preparation time (Experiment 1) within an experiment. Individuals completed a task in which they responded to onsets using the spatially corresponding finger. The onset was preceded by precues narrowing down the response possibilities from four to two. The response possibilities were either on the same hand or different hands, such that response selection was easy or hard. We also varied the amount of time between the cues and the targets to manipulate response preparation time. The results indicated that trial-by-trial manipulations of response selection difficulty did not influence response-outcome retrieval, but that the between groups manipulation of response preparation time did. With less time response preparation time, larger response-outcome compatibility effects were found. This study presents further evidence that response selection efficiency can influence response-outcome retrieval and that this difference can be accounted for in terms of how prepared the responses are at the time of target presentation.

Introduction

According to the ideomotor principle, action planning occurs through anticipating the desired, distal perceptual effects of the action. That is to say, the "idea" of what an action is intended to accomplish leads to the activation of the motor plan to bring about that idea. While the thinking underlying the ideomotor principle dates to the 1850s (Stock & Stock, 2004; see: Pfister & Janczyk, 2012 for an historical overview), empirical investigations of it began much more recently (e.g., Greenwald, 1972; Hommel, 2013; Shin, Proctor, & Capaldi, 2010). Investigations have provided support for the ideomotor principle using a wide range of paradigms, but, recently, there has been debate about a possible boundary of when ideomotor action planning occurs. That is, there is evidence, indicating that ideomotor action planning occurs only for intentional actions and is not used for stimulus-based actions (Herwig, Prinz, & Waszak, 2007). Supporting this hypothesis, additional studies indicate reduced anticipatory action control in stimulus-based contexts (Herwig & Waszak, 2009; Pfister, Kiesel, & Hoffmann, 2011) and the broader idea that the intention-based and stimulus-based action control systems are separate from each other (Obhi & Haggard, 2004). Others, however, have argued that the two control systems reflect varying parts of the same process (Krieghoff, Waszak, Prinz, & Brass, 2011) and, more recently, that both outcome learning and utilization can occur in stimulus-based tasks if the response selection process is made less efficient (Gozli, Huffman, & Pratt, 2016). Building off these later studies, the present study investigates how two factors that affect response selection efficiency,

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response preparation, and selection difficulty can contribute to whether anticipatory action selection occurs in stimulus-based contexts.

Most of the recent research investigating the ideomotor principle has used one of two paradigms. In the induction paradigm, participants go through an acquisition phase in which they learn some novel response-outcome (R-O) association and then go through a test phase designed to measure whether presentation of the outcomes would activate the associated response, even if it was task-irrelevant. For example, Elsner and Hommel (2001) had participants complete a block of trials in which they voluntarily performed left or right keypresses, and each key produced a low or high-pitched tone (response outcomes). Participants then completed a test phase that required identifying the same low- or high-pitched tones. Critically, half of the participants responded to each tone with the same hand that caused that tone during the acquisition phase (compatible group), while the other half responded using a crossed mapping (incompatible group). They predicted that if responses are represented by their perceptual outcomes, the tones should activate the responses that caused them during the acquisition phase, such that, in the test phase, the compatible group will respond faster than the incompatible group. Their data, and a wealth of other studies using similar designs (Cardoso-Leite, Mamassian, Schütz-Bosbach, & Waszak, 2010; Elsner & Hommel, 2004; Gozli, Goodhew, Moskowitz, & Pratt, 2013; Kühn & Brass, 2010; Kunde, 2004; Pfister, Heinemann, Kiesel, Thomaschke, & Janczyk, 2012), confirm this prediction, providing strong support for bidirectional link between responses and their outcomes, such that activating one will activate the other.

Another method has been to manipulate whether response outcomes are compatible or incompatible with other response features. Using a perceptual outcome paradigm, Kunde (2001) had participants complete two blocks of trials. In both blocks, they responded to a color onset with one of four keys (4–4 color-response mapping) and their response caused the appearance of a luminance onset as a response outcome. Critically, in one block, the response outcome appeared at a spatially compatible location relative to the response finger, but in the other block, the response outcome appeared at a spatially incompatible location. If responses are represented as their perceptual outcomes, responses should have been faster when they caused spatially compatible outcomes than when they caused spatially incompatible outcomes. Once again, the data were consistent with his predictions, a finding that has been replicated in multiple versions of the paradigm (Ansorge, 2002; Koch & Kunde, 2002; Pfister, Janczyk, Gressmann, Fournier, & Kunde, 2014). Complementing the induction paradigm, the perceptual outcome paradigm makes a clear case for response-outcome anticipation playing a role in action control.

There is evidence, however, of a boundary condition for finding response-outcome anticipation effects. This boundary is that R-O learning occurs only when responses are chosen by the participant (intention-based) rather than being determined by the imperative stimulus (stimulus-based). In a variation of the induction paradigm, a study had two groups complete different versions of the learning phase (Herwig et al., 2007). In the intention-based action version, participants chose whether to make a left- or right-handed response on every trial. In the stimulus-based version, participants made a left or right-handed response based on the location or color of a target stimulus. In both the stimulus-based and intention-based versions, each response caused a specific, low or high-pitched tone. Then, they had participants complete a test phase that was identical to the Elsner and Hommel (2001) test phase. Across the study, the main finding was that response-outcome anticipation effects were only found for the intention-based learning groups. This led the authors to conclude that R-O learning only occurs when actions are selected intentionally, because intention-based and stimulus-based responses are controlled by separate systems (see also: Herwig & Waszak, 2009).

Since Herwig et al.'s (2007) study, multiple studies have reported data from experiments designed to evaluate the boundaries of their intention-based hypothesis. For example, Pfister et al. (2011) had one group of participants complete a stimulus-based acquisition phase and a second group complete an intention-based acquisition phase in which their responses caused specific tones. Differing from Herwig et al., however, in the test phase participants heard one of the two tones and then made a free-choice response. That study found that participants in both groups were more likely to make the response that had generated the tone in the acquisition phase when they were presented with the tone in the test phase. This suggests that R-O learning can happen for both stimulus-based and intention-based action selection, and that the stimulus-based action group from Herwig et al.'s study did not apply their learning because of the forced-choice test phase.

In another study, Pfister, Kiesel, and Melcher (2010) manipulated whether responses generated spatially compatible or incompatible response outcomes within trial blocks while varying whether the intention-based and stimulus-based manipulation occurred within or between blocks. Participants first saw two lateralized placeholders that with the placeholders' location relative to the horizontal midline (above or below) determining whether responses would cause spatially compatible or incompatible luminance onsets. In their first experiment, one group of participants made an intention-based response and the second group made a stimulus-based response. Consistent with the previous findings, only the intention-based group showed R-O compatibility effects. In their second experiment, however, participants completed stimulus-based and intention-based trials mixed within one block. In this case, participants showed R-O compatibility effects in both the intention-driven and stimulus-driven conditions. The authors concluded that people have adaptive control over which action mode to use, with intention-based being the default mode. If the task can be accomplished using only stimulus-based action selection, however, stimulus-based action selection will be used and no R-O compatibility effects will be found. If the task requires some intention-based action selection (such as in their mixed block), the intention-based mode prevails throughout the task and R-O compatibility effects will be found. This idea of adaptive control over intention and stimulus-based action modes is consistent with other findings, showing that R-O learning is found in stimulus-based tasks insofar as the response outcome is what distinguishes one stimulus–response (S-R) context from another (Wolfensteller & Ruge, 2011).

These studies (Pfister et al., 2011; Pfister, Kiesel, & Melcher, 2010; Wolfensteller & Ruge, 2011) suggest that R-O associations are learned in stimulus-based action selection, but are not retrieved in stimulus-based contexts. This is consistent with feature integration research, indicating that stimulus and response code binding is a fairly automatic process that is relatively unaffected by how much attention is devoted to the stimulus (Hommel, 2005), whether the stimulus is task relevant (Frings, 2011), or whether the stimulus is consciously processed (Keizer, Hommel, & Lamme, 2015). Rather than stimulus-based action selection situations hindering the R-O binding process then, it may be the case that those bindings are not being retrieved during the test phase. This may be because in the stimulus-based contexts, stimulus features are being weighted more heavily than the response-outcome features (Memelink & Hommel, 2013) for action selection in a way that the R-O bindings are not retrieved leading to the lack of R-O compatibility effects. In any case, it is clear that the lack of R-O compatibility effects in a test phase does not necessarily mean that no R-O associations were formed during a learning phase and the difference between the stimulus-based and intention-based studies above may be better characterized as finding differences in R-O retrieval rather than R-O learning.[1]

While the intention-based mode tends to dominate over the stimulus-based mode leading to R-O compatibility effects when stimulus and intention-based response selection is mixed within a block, a recent study hypothesized that R-O retrieval effects might be found in a completely stimulus-based task, provided that the task was sufficiently difficult (Gozli et al., 2016). In their first experiment, each trial began with three placeholders spread horizontally across the screen. The target stimulus was the brightening of one of the two lateralized placeholders, to which participants responded using a left/right keypress. Importantly, task difficulty was manipulated by asking one group of participants to respond to left/right target stimulus with the spatially corresponding keypress, while the other group was asked to use the spatially non-corresponding keypress. Each response caused a response hand contingent color change of the central placeholder. In the test phase, the target stimuli also had a color that was compatible or incompatible with the outcome of the correct response. In this task, R-O retrieval was measured in terms of the benefit for responding to the outcome-compatible stimulus color, relative to responding to the outcome-incompatible stimulus color. Consistent with the previous research, participants in the spatially corresponding response-mapping group did not show any R-O compatibility effect. In contrast to the previous work and consistent with the role of task difficulty, participants in the spatially non-corresponding stimulus-response-mapping group did show a significant R-O compatibility effect. Converging results came from a second experiment, in which participants judged a target line as short or long. Task difficulty was manipulated between subjects, using target lengths that were easy or hard to discriminate. Results showed relatively larger R-O compatibility effects with hard to discriminate target stimuli. Furthermore, corroborating the findings of Pfister et al. (2011), stimulus discriminability during the test phase, and not during the acquisition phase, was predictive of R-O compatibility effect. These findings suggest that the difference between the intention-based and stimulus-based modes may be less dichotomous than previously suggested and R-O learning and retrieval may occur in both cases, but that response-outcome-based action selection only occurs when the test phase is sufficiently difficult (i.e., less reflex like).

In the present study, we further investigate the factors that determine the degree to which R-O compatibility effects are found in stimulus-based tasks. In particular, we look at how differences in response selection difficulty and response preparation can affect how much R-O compatibility affects performance. Although Gozli et al. (2016) demonstrated that response selection efficiency modulated R-O compatibility effects, they did not determine whether the differences were due to response preparation or response selection difficulty. That is, the role of task difficulty may have been due to differences in response preparation, with the easier S-R mappings leading to better response preparation and a reduced sensitivity to response outcomes, or response selection difficulty, with participants using response-outcome information more

[1] Similarly, Herwig and Waszak (2012) found trial-by-trial R-O binding effects for both intention- and stimulus-based responses, but found long-term learning effects (R-O compatibility effects in a test phase that followed a learning phase) only when intention-based response selection was used.

when there was greater uncertainty between the response alternatives. To measure R-O retrieval, we used a modified version of the Kunde (2001) paradigm in which participants complete two trial blocks where their responses could cause spatially corresponding or non-corresponding response outcomes. If participants are using anticipatory action selection, their responses will be faster when their responses cause spatially corresponding outcomes. We manipulated response selection difficulty using a finger precueing procedure (Miller, 1982; Reeve & Proctor, 1984) and manipulated response preparation by changing the interval between the finger precue and the target stimulus as a between-subjects factor.

Experiment 1

To manipulate response selection difficulty, we used a finger precueing procedure. Finger precueing experiments typically require participants to make one of four keypress responses with their index and middle fingers on each hand. At the start of each trial, they then receive two visual cues that spatially correspond with two of the possible responses, and are instructed to prepare those two responses (the target would always require one of those two responses). After a brief interval, they are presented with another visual onset indicating which response to make. The classic finding is that participants respond faster when they prepare two fingers of the same hand compared to fingers from different hands. This cost appears to be, at least partially, attributed to the difficulty of selecting between responses that cannot be easily grouped together (Adam, Hommel, & Umiltà, 2003; 2005). Therefore, if response selection difficulty modulates R-O retrieval, we predict that we will find an interaction between R-O compatibility and finger precue condition.

To manipulate response preparation level, we manipulated the interval between the finger precue and the target stimulus was 500 ms for one group and 750 ms for the other group. Given the spontaneous decay of response codes (Hommel, 1994), we assumed that a longer cue-target interval would result the responses being more prepared at target presentation. If the findings in Gozli et al. (2016) were due how well responses were prepared based on the similarity of the stimulus to the response outcome, then we expect to find an interaction between cue-target interval and the R-O compatibility effect. To summarize, if R-O retrieval is affected by response selection difficulty, we predict interactions between finger precueing difficulty and R-O compatibility within both cue-target intervals. If the amount of response preparation affects whether R-O retrieval takes place, then we predict to find an interaction between R-O compatibility and cue-target interval.

Methods

Participants

Forty undergraduates from the University of Toronto participated and were compensated with course credit for an introductory psychology course. They were randomly assigned to one of the cue-target interval conditions with 20 in each group. All participants provided informed consent, were naïve to the study's purpose, and reported normal or corrected-to-normal vision.

Stimuli

Stimuli consistent of four response-outcome placeholder squares subtending 2° visual angle, and '+' characters drawn in size 30 font. Stimuli were presented in white on a black background. The R-O placeholders could either be 3 pixel wide outlines filled with black or white. Participants responded with the '*z*', '*x*', '.', and '/' keys on a QWERTY keyboard.

Procedure

The trial began with the four response-outcome placeholders aligned horizontally 7° below the horizontal midline (Fig. 1). The far left and right response-outcome placeholders appeared 7° to the left and right of the midline and remaining response-outcome placeholders appeared 4.2° to the left and right of the midline. After 750 ms, four '+' characters appeared 7° above the response-outcome placeholders. These served as the warning signal that the trial was starting. We then presented two more '+' characters 5° above two of the response-outcome placeholders 500 ms after the warning display. We instructed participants that they should prepare to make the two responses that spatially corresponded with the '+' characters. For example, if the '+' characters appeared above the far left and third from the left placeholders, they should prepare the left-middle and right-index finger responses. Following 500 or 750 ms, manipulated between subjects, a single '+' character appeared 3° above a response-outcome placeholder. We instructed the participants that they should make the response that spatially corresponded to this '+' character as quickly and accurately as they could. The response was always one of the two responses that had cued by the second set of '+' characters. Following the correct response, a response-outcome placeholder filled with white for 500 ms. Depending on the trial block, response outcomes would appear in one of two places. In the R-O compatible block, the response effect appeared

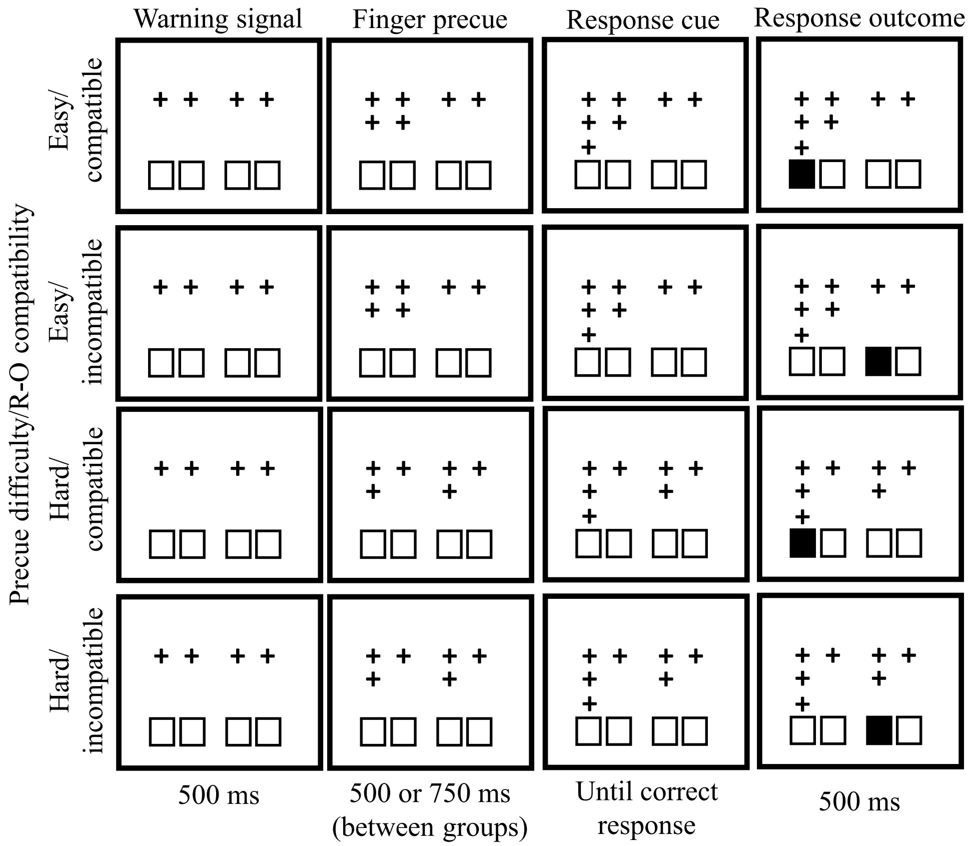

Fig. 1 Experimental procedure by precue and R-O compatibility condition. Finger precue set and R-O compatibility were manipulated within-subjects and the cue-target interval was manipulated between subjects

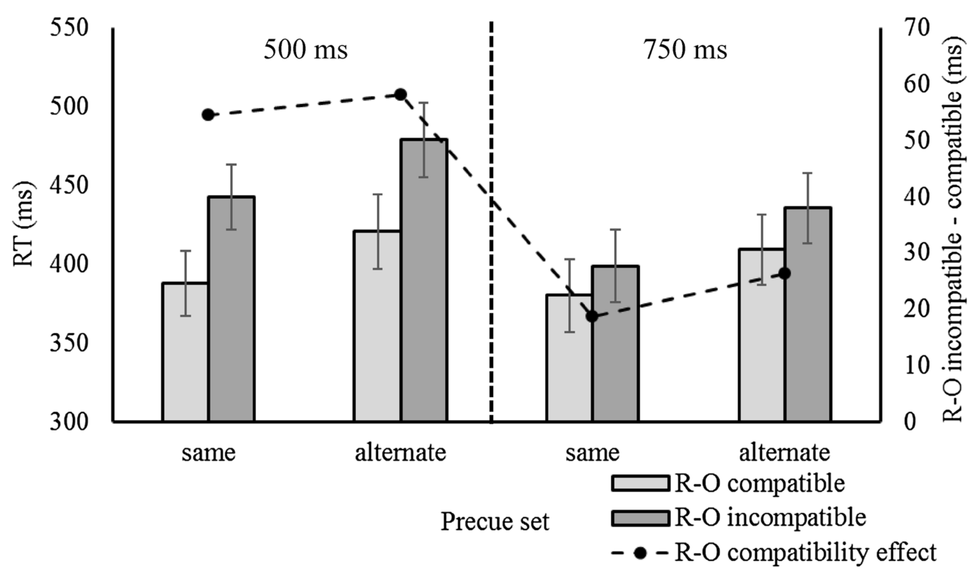

Fig. 2 The left axis shows mean RT as a function of precue set, R-O compatibility, and cue-target interval. The right axis shows the R-O compatibility effects as a function of precue and cue-target interval. The error bars represent the 95% confidence interval of the R-O compatibility effect (Pfister & Janczyk, 2013)

in the placeholder directly above the response. In the R-O incompatible condition, the response effect appeared in the placeholder on the opposite side of the display. If an incorrect response was given the trial continued until the correct response was given, or 1500 ms passed after which the trial terminated and was counted as an error. This method was used to insure that each R-O sequence was experienced equally often. As a consequence, our method does not include recording and analysis of incorrect keypress responses. The response outcome remained for 500 ms and then the next trial began (Figs. 2, 3).

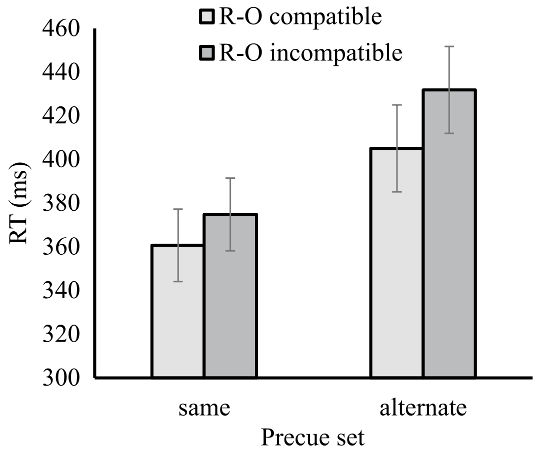

Fig. 3 Mean RTs as a function of precue set and R-O compatibility. The error bars represent the 95% confidence interval of the R-O compatibility effect (Pfister & Janczyk, 2013)

Design

Participants completed two trial blocks, an R-O compatible block and an R-O incompatible block (counterbalanced between participants). Half the participants had the 500 ms cue-target interval and the other half had the 750 ms cue-target interval. Within each block, trial type was selected randomly without replacement from a list generated by repeating each finger precue set (the same-hand or different-hand) and response cue (the left or right precued finger) 80 times each for a total of 320 trials per block.

Results

We discarded trials with RTs shorter than 200 ms or longer than 1500 ms as anticipatory response and attentional lapse trials, respectively. The mean RTs from the remaining trials were analyzed with a 2×2×2 mixed, repeating-measures ANOVA with precue set and R-O compatibility as within-subjects factors, and cue-target interval as a between-subjects factor. We found a significant main effect of precue set, $F(1,38)=69.398$, $p<0.001$, $\eta_p^2=0.646$, with faster responses in the same-hand condition compared to the different-hand condition. There was also a main effect of R-O compatibility, $F(1,38)=30.159$, $p<0.001$, $\eta_p^2=0.442$, with faster responses in the R-O compatible condition compared the R-O incompatible condition, but no evidence of a cue-target interval main effect, $F(1,38)=1.256$, $p=0.239$, $\eta_p^2=0.032$, or an interaction between precue and R-O compatibility, $F(1,38)=1.430$, $p=.239$, $\eta_p^2=0.036$. This indicated that the R-O compatibility was similar in the same-hand precue set condition (37 ms) as the different-hand precue set condition (42 ms). Precue set did not interact with cue-target interval, $F(1,38)<1$. Critically, however, R-O compatibility and cue-target interval did interact, $F(1,38)=5.541$, $p=0.024$, $\eta_p^2=0.127$. This indicated larger R-O compatibility effects in the 500 cue-target interval (56 ms) than in the 750 ms cue-target interval condition (23 ms). Finally, the three-way interaction was not significant, $F(1,38)<1$.

Discussion

In Experiment 1, we manipulated the level of response preparation and response selection difficulty and whether either or both affected the magnitude of an R-O compatibility effect. To manipulate the level of response preparation, we varied the amount of time between the response precue presentation and target presentation. To manipulate response selection difficulty, we varied whether we precued two fingers on the same-hand or different fingers on different hands. We found that the R-O compatibility effect was not affected by response selection difficulty, but was affected by response preparation level, such that we found evidence of more response-outcome-based action selection when less time was given to prepare.

A shortcoming of Experiment 1 is that response selection difficulty is manipulated within a block. This is potentially important as other studies examining R-O-based action selection have found that blocking versus mixing factors can lead to substantially different results. For example, even though stimulus-based and free-choice responses can result in different patterns of stimulus-outcome compatibility effects (Herwig, Prinz, & Waszak, 2007), when stimulus-based and free-choice responses are mixed within a block, the results resemble the conditions in which all responses are free-choice (Pfister, Kiesel, & Melcher, 2010). This suggests that when the two trial types are randomized within a block, participants adopt a single response selection mode that corresponds to the more difficult condition (e.g., the intention-based mode in the study of Pfister et al., 2010). Similarly, in the present experiment, we randomized response selection difficulty and, therefore, it is possible that individual's response selection mode (and, consequently, the extent to which they processed response outcomes) for Experiment 1 was dictated by the relatively more difficult response selection condition. Thus, before we can fully eliminate the possibility that response selection difficulty modulates R-O compatibility effects, we needed to manipulated response selection between blocks. That was the purpose of Experiment 2.

Experiment 2

Experiment 2 was a replication of the 500 ms cue-target interval condition from Experiment 1 with the exception that response selection difficulty was modulated between, rather than within, blocks. This was done to test whether the response selection difficulty did not affect the R-O compatibility effect in Experiment 1, because participants were defaulting to the state necessary for them to complete the hard response selection difficulty condition (Pfister, Kiesel, & Melcher, 2010). Like Experiment 1, if response selection difficulty affects response-outcome-based action selection, we predict that there will be a larger compatibility when response selection is more difficult.

Methods

Participants

Twenty-four undergraduates from the University of Macau participated and were compensated with coupons worth two cups of coffee at a local cafe. All participants provided informed consent, were naïve to the study's purpose, and reported normal or corrected-to-normal vision.

Stimuli, procedure, and design

The stimuli and procedure of Experiment 2 were identical to Experiment 1. The difference was in the design, such that rather than manipulating precue set within a given experimental block, we now manipulated between blocks and only the 500 ms cue-target interval was used. Therefore, participants completed each combination of the two factors (precue set and R-O compatibility) in four separate blocks. The order in which participants completed the blocks was counterbalanced across participants.

Results

We discarded trials with RTs shorter than 200 ms or longer than 1500 ms as anticipatory response and attentional lapse trials, respectively. The mean RTs from the remaining trials were analyzed with a 2 × 2, repeating-measures ANOVA with precue set and R-O compatibility as within-subjects factors. The main effect of precue set was significant indicating faster response times in the same-hand compared to the different-hand precue set conditions, $F(1,23) = 34.220$, $p < .001$, $\eta_p^2 = 0.598$. The main effect of R-O compatibility was also significant indicating faster response times in the compatible compared to the incompatible condition, $F(1,23) = 11.111$, $p = 0.003$, $\eta_p^2 = 0.326$. Finally, consistent with Experiment 1, the interaction between precue set and R-O compatibility did not reach conventional levels of statistical significance, $F(1,23) < 1$, $p = 0.334$, $\eta_p^2 = 0.041$.

Discussion

Consistent with Experiment 1, the results of Experiment 2 suggest that the effects of response selection difficulty and R-O compatibility can be independent. That is, the magnitude of the R-O compatibility effect was not statistically affected by response selection difficulty, even when it was manipulated between blocks, such that participants could have used a relatively easier response selection mode throughout an entire block. This, along with the data from Experiment 1, suggests that differences in the response preparation process rather than the difficulty of the selection process contributes to extent to which R-O compatibility effects are found.

In addition, the R-O compatibility effect seems weaker in Experiment 2 when compared to the corresponding condition Experiment 1 (cue-target interval = 500 ms). Although observed effect sizes are expected to vary across experiments (e.g., Francis, 2012), the relatively weaker effect in Experiment 2 might be due blocking of the precue type. Given that the consistency of the precue type might contribute to preparing the appropriate response subsets, and that response preparation can reduce reliance on outcome anticipation (Kunde, Koch, & Hoffman, 2004), it would be expected that consistency of precue types would reduce R-O compatibility.

General discussion

We investigated whether the difficulty of response selection can influence the extent to which observers use anticipatory action control. To do so, before presenting each target stimulus, we presented participants with response precues that rendered subsequent response selection easy or difficult (Miller, 1982; Reeve & Proctor, 1984). Participants performed both in a response-outcome (R-O) compatible condition, where their responses caused spatially compatible response outcomes, and in R-O incompatible condition, in which their responses caused spatially incompatible response outcomes. Consistent with anticipatory action selection, we found slower responses when the sensory outcomes were spatially incompatible. Critically, whether the response precue indicated difficult- or easy-response selections did not influence how much participants used anticipatory action control when it was manipulated within (Experiment 1) or between trial blocks (Experiment 2), but the cue-target interval duration did. Specifically, we found larger R-O compatibility effects in the shorter cue-target interval condition. These findings expand upon previous research on whether response selection difficulty can modulate anticipatory action selection. Our findings suggest that differences in response preparation, rather than difficulty in response selection, modulate anticipatory action selection use.

How does the cue-target interval length affect R-O compatibility effect? One possibility within the response precueing literature is that increasing the cue-target interval allows for better grouping of the stimulus and response sets (Adam, Hommel, & Umiltà, 2003). Assuming that longer cue-target interval results in better grouping among the precued S-R elements, one may propose that improved S-R grouping enabled participants to better adopt a stimulus-based response mode. It should be noted, however, that if successful grouping affected the R-O compatibility in the current study, we would expect to have found an interaction between all three factors (because the different-hand precue benefit more from the extra time). This interaction was absent.

A second possibility is related to the level of response preparation at target presentation. As such, a notable difference between the current experiments and previous ideomotor studies is that participants were asked to prepare one of two response sets ahead of time (e.g., Hommel, 2000; Kunde et al., 2004; Shin & Proctor, 2012; Wirth, Pfister, Brandes, & Kunde, 2016). According to the previous research, preparing multiple responses activates the corresponding set of possible response outcomes (Kühn, Keizer, Rombouts, & Hommel, 2010). Similarly, Gozli and Ansorge (2016) demonstrated that preparing a response that had been associated with a color outcome facilitated responding to targets appearing in placeholders matching the response associated color. Importantly, the bias in favor of the prepared response outcome took approximately 200 ms to reach its peak before it began to decay. They argued that with enough response preparation time, response uncertainty is reduced, such that participants become less sensitive to information not directly relevant to eliciting the response. This finding is consistent with the current study, if we assume that simultaneously preparing two responses takes more time than preparing a single response. That is, at the short cue-target interval, we suggest that observers are at an earlier phase of response preparation process, which may involve a more inclusive anticipation of response outcomes (Ziessler & Nattkemper, 2011). At the longer cue-target interval group, they are likely to be further in the response preparation process, which may involve a more selective anticipation of features, such that observers would weight the target information more heavily than the less relevant sensory outcomes. Thus, the short cue-target interval group shows larger R-O compatibility effects than the long cue-target interval group. This explanation can account for the current findings, and it may provide a basis for explaining why R-O compatibility effects are more difficult to find in the stimulus-driven response selection tasks.

Reduced sensitivity to response outcomes, as a result of preparation, has been reported in studies that aimed to disentangle the role of anticipation in (relatively early) selection and (relatively late) control aspects of action (Kunde et al., 2004). If an experiment signals the correct response and the time of execution, respectively, with a response cue and a go signal, a delay between the response cue and the go signal tends to reduce the effect of R-O compatibility (e.g., Kunde et al., 2004; Shin & Proctor, 2012; Wirth et al., 2016). These findings are consistent with the role of response preparation in sensitivity to task-specific response outcomes.

Given that the degree of precue generated response preparation at target presentation seems to have played a role in determining the magnitude of the action–outcome compatibility effect, but within block finger precue manipulations did not, it is informative to look at the mechanism underlying response precueing. One prominent model is that finger precueing effects reflect the relative difficulty of selecting and preparing two responses that can easily be grouped together compared to two responses that cannot be easily grouped together (Adam et al., 2003). That is, when experiments use two pairs of lateralized stimuli and responses, it is easier to select within a lateralized pair compared to selecting between pairs. In other words, different precueing conditions seem to alter response selection difficulty. This contrasts to our between groups manipulation, which seems to be more reflective of response outcomes being activated by preparing a response set. That our response activation manipulations influenced R-O retrieval is consistent with the previous research, indicating that multiple response outcomes can be activated simultaneously, leading to R-O compatibility effects (Gozli et al., 2016; Kühn, Keizer, Rombouts, & Hommel, 2010; Paelecke & Kunde, 2006).

The precueing factor used in the present study might result in a potential confound, providing basis for alternative reasons why R-O compatibility effect might be reduced in the same-hand precueing condition.[2] First, to reiterate, our hypothesis was that the same-hand precueing may reduce the R-O compatibility effect due to an increased efficiency in stimulus-based response selection. However, in addition to this possibility, the incompatible outcome in the same-hand condition always appeared at the side opposite to the responding hand. This is in contrast to the incompatible outcome in the alternative-hand condition, which always appeared at one of the cued response locations. Therefore, the fact that outcomes appeared at the non-responding side in the same-hand condition might have been an additional reason for a reduced reliance on outcome anticipation in the same-hand condition. Had we found an interaction between

[2] Thank you to an anonymous reviewer for suggesting this possibility.

R-O compatibility and precueing, we would have had to discriminate between the two possibilities. However, the absence of this interaction in both experiments means that the potential confound does not pose a problem for our main conclusions.

There is a second potential confound, which might pose a problem for our interpretation. This has to do with the possibility of inhibiting invalid precue (i.e., one of the two precued response that differs from the correct response) in the difficult-and-incompatible condition. Specifically, after its initial activation, the incorrect-precued response may have been inhibited, resembling what is commonly described as inhibition of return (e.g., Kingstone & Pratt, 1999; Klein, 2000). If such an inhibition occurs, it might result in inhibiting the corresponding sensory outcome, which happens to share the location of the inhibited precue. This possibility is important to consider, because it might cause an underestimation of the actual magnitude of the R-O compatibility effect in the difficult condition. In other words, the absent interaction between R-O compatibility and response selection difficulty might be a by-product of this underestimation. Strictly speaking, the inhibition of the invalid precue is a possibility and precludes a conclusive interpretation of our findings (i.e., independence of selection difficulty and outcome anticipation). We should, however, also add that the inhibition is not particularly plausible, because the precue consisted of not only an invalid precue but also a simultaneously valid precue. This prevents the incorrect-precued response to be more strongly activated than correct-precued response, which is prerequisite for obtaining inhibition of return. Nevertheless, the possibility of inhibited precued responses deserves further empirical investigation.

Multiple researchers have suggested that the difference between stimulus-based and intentional-based action selection may be one of degree more than a strict spilt (Gozli et al., 2016; Herwig & Waszak, 2009; Le Bars, Hsu, & Waszak, 2016). If that is the case, and finger precueing manipulates response selection trial-by-trial, why did we not observer larger R-O compatibility effects as a function of precue difficulty? One possibility is that the harder response selection condition did increased R-O retrieval, but by mixing response selection difficulty within a block participant continued to rely more on R-O response selection on the easier trials, as well. This suggestion is supported by evidence that if free- and forced-choice trials are mixed (rather than degrees of forced choice, as in the current study) within the same block and could produce R-O compatible or incompatible response outcomes, R-O compatible effects are found on the forced-choice trials (Pfister et al., 2010). Those researchers similarly suggested that the intentional action state "endured" through the stimulus-based trials, such that R-O effects continued to be found. In Experiment 1, because we mixed the different precue types within blocks, participants may have adopted one response selection mode throughout the task, dictated by the relatively more difficult precue conditions. This, in effect, might have stabilized the extent to which they anticipated the sensory outcomes (i.e., the R-O compatibility effect). In Experiment 2, however, this possibility was ruled out, because the two precue conditions were blocked. Thus, the results of Experiment 2 provide a more solid ground for concluding that response selection difficulty does not modulate outcome anticipation.

In the current study, we manipulated how much amount of response preparation time between groups and response selection difficulty within groups. Within groups, we precued either two responses on the same hand or the index and middle fingers between hands. This led to longer RTs in the between-hand condition than the same-hand condition, consistent with the previous research, but we did not find any interaction between the finger precue effect and R-O compatibility effect when response selection difficulty was manipulated between- or within-trial blocks. Between groups, we manipulated the level of response activation by lengthening how long participants had to prepare the two precued responses. By comparing the two groups, we found larger R-O compatibility effects when there was more response activation. We suggest that this difference was due to how fully prepared participants had prepared their responses. As they had more preparation time, the participants weighted the target stimulus more strongly than the irrelevant response outcomes that they used to select their responses. With greater target stimulus weighting there is a reduction in the R-O compatibility effect. This is consistent with the previous research, suggesting that response uncertainty can increase response-outcome anticipation. These findings go beyond the previous research by manipulating both response activation and selection within the same study, finding that response activation, but not selection difficulty, leads to changes in R-O retrieval.

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Compliance with ethical standards

Conflict of interest The author declares that he has no conflict of interest.

Ethical approval All procedures performed were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent All participants provided informed consent before participating in the study.

References

Adam, J. J., Hommel, B., & Umiltà, C. (2003). Preparing for perception and action (I): The role of grouping in the response-cuing paradigm. *Cognitive Psychology, 46*, 302–358. https://doi.org/10.1016/S0010-0285(02)00516-9.

Adam, J. J., Hommel, B., & Umiltà, C. (2005). Preparing for perception and action (II): Automatic and effortful processes in response cueing. Visual Cognition, 12(8), 1444–1473. https://doi.org/10.1080/13506280444000779.

Ansorge, U. (2002). Spatial intention-response compatibility. *Acta Psychologica, 109*(3), 285–99. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11881904.

Cardoso-Leite, P., Mamassian, P., Schütz-Bosbach, S., & Waszak, F. (2010). A new look at sensory attenuation. Action-effect anticipation affects sensitivity, not response bias. *Psychological Science, 21*(12), 1740–1745. https://doi.org/10.1177/0956797610389187.

Elsner, B., & Hommel, B. (2001). Effect Anticipation and Action Control. *Journal of Experimental Psychology: Human Perception and Performance, 27*(1), 229–240.

Elsner, B., & Hommel, B. (2004). Contiguity and contingency in action-effect learning. *Psychological Research Psychologische Forschung, 68*(2–3), 138–154. https://doi.org/10.1007/s00426-003-0151-8.

Francis, G. (2012). Publication bias and the failure of replication in experimental psychology. *Psychonomic Bulletin & Review, 19*, 975–991.

Frings, C. (2011). On the decay of distractor-response episodes. *Experimental Psychology, 58*(2), 125–131. https://doi.org/10.1027/1618-3169/a000077.

Gozli, D. G., & Ansorge, U. (2016). Action selection as a guide for visual attention. *Visual Cognition, 24*(1), 38–50. https://doi.org/10.1080/13506285.2016.1176095.

Gozli, D. G., Goodhew, S. C., Moskowitz, J. B., & Pratt, J. (2013). Ideomotor perception modulates visuospatial cueing. *Psychological Research Psychologische Forschung, 77*, 528–539. https://doi.org/10.1007/s00426-012-0461-9.

Gozli, D. G., Huffman, G., & Pratt, J. (2016). Acting and Anticipating: Impact of Outcome-Compatible Distractor Depends on Response Selection Efficiency. Journal of Experimental Psychology: Human Perception and Performance.

Greenwald, A. G. (1972). On doing two things at once: Time sharing as a function of ideomotor compatibility. *Journal of Experimental Psychology: General, 94*(1), 52–57.

Herwig, A., Prinz, W., & Waszak, F. (2007). Two modes of sensorimotor integration in intention-based and stimulus-based actions. *Quarterly Journal of Experimental Psychology (2006), 60*(11), 1540–1554. https://doi.org/10.1080/17470210601119134.

Herwig, A., & Waszak, F. (2009). Intention and attention in ideomotor learning. *Quarterly Journal of Experimental Psychology (2006), 62*(2), 219–227. https://doi.org/10.1080/17470210802373290.

Hommel, B. (1994). Spontaneous decay of response-code activation. *Psychological Research Psychologische Forschung, 56*(4), 261–268. https://doi.org/10.1007/BF00419656.

Hommel, B. (2000). The prepared reflex: Automaticity and control in stimulus-response translation. In S. Monsell & J. Driver (Eds.), *Control of cognitive processes: Attention and performance XVIII* (pp. 247–273). Cambridge, MA: MIT Press.

Hommel, B. (2005). How much attention does an event file need? *Journal of Experimental Psychology. Human Perception and Performance, 31*(5), 1067–1082. https://doi.org/10.1037/0096-1523.31.5.1067.

Hommel, B. (2013). Ideomotor action control: On the perceptual grounding of voluntary actions and agents. In W. Prinz, M. Beisert & A. Herwig (Eds.), *Action science: Foundations of an emerging disipline* (pp. 113–136). Cambridge, MA: MIT Press.

Keizer, A. W., Hommel, B., & Lamme, V. A. F. (2015). Consciousness is not necessary for visual feature binding. *Psychonomic Bulletin & Review, 22*(2), 453–460. https://doi.org/10.3758/s13423-014-0706-2.

Kingstone, A., & Pratt, J. (1999). Inhibition of return is composed of attentional and oculomotor processes. *Perception & Psychophysics, 61*(6), 1046–1054.

Klein, R. M. (2000). Inhibition of return. *Trends in cognitive sciences, 4*(4), 138–147.

Koch, I., & Kunde, W. (2002). Verbal response-effect compatibility. *Memory & Cognition, 30*(8), 1297–1303.

Krieghoff, V., Waszak, F., Prinz, W., & Brass, M. (2011). Neural and behavioral correlates of intentional actions. *Neuropsychologia, 49*(5), 767–776. https://doi.org/10.1016/j.neuropsychologia.2011.01.025.

Kühn, S., & Brass, M. (2010). The cognitive representation of intending not to act: Evidence for specific non-action-effect binding. *Cognition, 117*, 9–16. https://doi.org/10.1016/j.cognition.2010.06.006.

Kühn, S., Keizer, A. W., Rombouts, S. A., & Hommel, B. (2011). The functional and neural mechanism of action preparation: roles of EBA and FFA in voluntary action control. *Journal of Cognitive Neuroscience, 23*(1), 214–220.

Kunde, W. (2001). Response-effect compatibility in manual choice reaction tasks. *Journal of Experimental Psychology: Human Perception and Performance, 27*(2), 387.

Kunde, W. (2004). Response priming by supraliminal and subliminal action effects. *Psychological Research Psychologische Forschung, 68*(2–3), 91–96. https://doi.org/10.1007/s00426-003-0147-4.

Kunde, W., Koch, I., & Hoffmann, J. (2004). Anticipated action effects affect the selection, initiation, and execution of actions. *Quarterly Journal of Experimental Psychology, 57A*, 87–106.

Le Bars, S., Hsu, Y.-F., & Waszak, F. (2016). The impact of subliminal effect images in voluntary vs. stimulus-driven actions. *Cognition, 156*, 6–15. https://doi.org/10.1016/j.cognition.2016.07.005.

Memelink, J., & Hommel, B. (2013). Intentional weighting: a basic principle in cognitive control. *Psychological Research Psychologische Forschung, 77*(3), 249–259. https://doi.org/10.1007/s00426-012-0435-y.

Miller, J. (1982). Discrete versus continuous stage models of human information processing: in search of partial output, 8(2), pp. 273–296.

Obhi, S. S., & Haggard, P. (2004). Internally generated and externally triggered actions are physically distinct and independently controlled., 518–523. https://doi.org/10.1007/s00221-004-1911-4.

Paelecke, M., & Kunde, W. (2006). Action-Effect Codes in and Before the Central Bottleneck: Evidence From the Psychological Refractory Period Paradigm. *Journal of Experimental Psychology. Human Perception and Performance, 33*, 627–644.

Pfister, R., Heinemann, A., Kiesel, A., Thomaschke, R., & Janczyk, M. (2012). Do endogenous and exogenous action control compete for perception? *Journal of Experimental Psychology: Human Perception and Performance, 38*(2), 279–284. https://doi.org/10.1037/a0026658.

Pfister, R., & Janczyk, M. (2012). Harleß' Apparatus of Will: 150 years later. *Psychological Research Psychologische Forschung, 76*(5), 561–565. https://doi.org/10.1007/s00426-011-0362-3.

Pfister, R., & Janczyk, M. (2013). Confidence intervals for two sample means: Calculation, interpretation, and a few simple rules. *Advances in Cognitive Psychology, 9*(2), 74–80. https://doi.org/10.2478/v10053-008-0133-x.

Pfister, R., Janczyk, M., Gressmann, M., Fournier, L. R., & Kunde, W. (2014). Good vibrations? Vibrotactile self-stimulation reveals anticipation of body-related action effects in motor control. *Experimental Brain Research, 232*(3), 847–854. https://doi.org/10.1007/s00221-013-3796-6.

Pfister, R., Kiesel, A., & Hoffmann, J. (2011). Learning at any rate: Action-effect learning for stimulus-based actions. *Psychological Research Psychologische Forschung, 75*, 61–65. https://doi.org/10.1007/s00426-010-0288-1.

Pfister, R., Kiesel, A., & Melcher, T. (2010). Adaptive control of ideomotor effect anticipations. *Acta Psychologica, 135*(3), 316–322. https://doi.org/10.1016/j.actpsy.2010.08.006.

Reeve, T. G., & Proctor, R. W. (1984). On the advance preparation of discrete finger responses. *Journal of Experimental Psychology. Human Perception and Performance, 10*(4), 541–553. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/6235318.

Shin, Y. K., & Proctor, R. W. (2012). Testing the boundary conditions of the ideomotor hypothesis using a delayed response task. *Acta Psychologica, 141*, 360–372.

Shin, Y. K., Proctor, R. W., & Capaldi, E. J. (2010). A review of contemporary ideomotor theory. *Psychological Bulletin, 136*(6), 943–974. https://doi.org/10.1037/a0020541.

Stock, A., & Stock, C. (2004). A short history of ideo-motor action. *Psychological research, 68*(2–3), 176–188.

Wirth, R., Pfister, R., Brandes, J., & Kunde, W. (2016). Stroking me softly: Body-related effects in effect-based action control. *Attention, Perception, & Psychophysics, 78*, 1755–1770.

Wolfensteller, U., & Ruge, H. (2011). On the timescale of stimulus-based action-effect learning. *Quarterly Journal of Experimental Psychology (2006), 64(February 2015)*, 1273–1289. https://doi.org/10.1080/17470218.2010.546417.

Ziessler, M., & Nattkemper, D. (2011). The temporal dynamics of effect anticipation in course of action planning. *The Quarterly Journal of Experimental Psychology, 64*, 1305–1326.