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Traditional response interference effects from anticipated action outcomes: A response–effect compatibility paradigm

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ABSTRACT

An act as simple as pressing a button involves various stages of processing. Each stage of action production is susceptible to interference from competing representations/processes. For example, in the Simon Effect, interference arises from an incongruence between incidental spatial information and the spatial properties of intended action; in the flanker task, interference arises when visual targets and distracters are associated with different responses (*response interference* [RI]). Less interference arises in the flanker task when targets and distracters are different in appearance but associated with the same response (*perceptual interference* [PI]). Interference also stems from the automatic activation of representations associated with the anticipated effects of an action, *response-effect* (R–E) *compatibility* (e.g., the presence of a left-pointing arrow after one presses a button on the right will increase interference in future trials). This has been explained by *ideomotor theory*—that the mental representation of anticipated action-effects are activated automatically by voluntary action and that such representations can cause facilitation or interference by automatically priming their associated action plans. To illuminate the nature of action production and provide additional support for ideomotor theory, we examined for the first time the effects of PI and RI in a new R–E compatibility paradigm.

An act as simple as pressing a button in response to a visual cue involves various stages of processing (e.g., encoding, response selection, and response execution; Hommel & Elsner, 2009), each of which is susceptible to interference from competing representations/processes (Desimone & Duncan, 1995; Di Lollo et al., 2000; Eriksen & Schultz, 1979; van Veen et al., 2001). Interference at different stages of processing leads to distinct behavioral, neural, and subjective effects (Coles et al., 1985; Eriksen & Schultz, 1979; Morsella et al., 2009; van Veen et al., 2001). Interference can stem from the mere presence of action-related stimuli (Eriksen & Eriksen, 1974; Stroop, 1935; see review in Morsella et al., 2011), from an incongruence between incidental spatial information (e.g., a flash of light on the left) and the spatial properties of intended action (e.g., a button-press with the right hand; Simon et al., 1970), from representations held in working memory (Gazzaley et al., 2005; Hubbard et al., 2010), or from representations that are triggered by anticipatory processes in the brain, as in the case of *response-effect* (R–E) *compatibility* (Koch & Kunde, 2002; Kunde, 2001; Kunde, 2003), when interference stems from the automatic activation of representations associated with the anticipated effects of an action (e.g., the presence of an arrow pointing left after one has pressed a button on the right will increase response times in future trials).

1. Ideomotor theory

R–E compatibility has been explained by *ideomotor theory* (cf., Hommel, 2009; Hommel et al., 2001), which proposes that the mere 'image' (or mental representation) of action effects can automatically trigger the action plans that give rise to those effects. When popularizing ideomotor theory, William James (1890) proposed that the mere thoughts of actions produce impulses that, if not curbed or controlled by thoughts of incompatible actions, result in the performance of the imagined actions. Thus, activating the perceptual effects of an action leads to the corresponding action—effortlessly and without awareness of the motor programs involved (cf., Gray, 2004; Grossberg, 1999; Kunde, 2004).

2. Response-effect compatibility paradigms

An important component of ideomotor theory is that actions are initiated by evoking images of future events, events that are not yet instantiated in the environment (Kunde, 2001). In an effort to provide empirical support for this aspect of ideomotor theory, Kunde (2001)

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developed a paradigm utilizing R–E compatibility, whereby anticipation of future stimuli elicits facilitation or interference effects. In Kunde (2001; Experiment 1), participants responded to the color of a centrally-presented circle on a computer screen by pressing one of four buttons on a button box. This was followed by the illumination of one of four rectangles on the screen. Pressing the button illuminated a rectangle that corresponded to the button's position or one that was on the opposite side of the array. Response times (RTs) were faster in blocks of trials in which there was a corresponding mapping, despite the fact that the stimulus followed the response (Kunde, 2001). (It is important to note that R–E compatibility effects are found at the block level.) In Experiment 2, similar effects were found with auditory stimuli: A soft tone produced by a forceful button-press produced more interference in future trials than a loud sound produced by a forceful button-press. Similarly, Kunde (2003) established support for temporal response–effect compatibility in an experiment involving short and long key-presses, followed by short or long auditory tones. Participants exhibited longer RTs in blocks of trials where the response and tone durations were incongruent (e.g., short keypress, long tone) compared to congruent (e.g., short keypress, short tone).

In each case above, responses and effects shared a common perceptual dimension (spatial position, intensity, or duration). Koch and Kunde (2002) utilized an R–E compatibility paradigm using color words to establish whether anticipatory images are also processed at the conceptual level. Participants responded to stimuli (digits) by uttering color words (e.g., "green"). Following their response, they were presented with color words written in a congruent color (e.g., RED in red). Again, the compatibility effect persisted: RTs were faster when the utterance and the subsequent color word were compatible (e.g., "red" followed by RED) versus incompatible (e.g., "red" followed by GREEN; Koch & Kunde, 2002). In order to disentangle the effects of the word stimulus itself and of the color dimension, in other trials, participants were also presented with colored X's (Experiment 1) and color words written in white (in Experiment 2) following their responses. While the color words written in a congruent color elicited the strongest compatibility effect, the condition involving color words in white text still led to a significant effect, suggesting that anticipatory images are processed at a conceptual as well as at a perceptual level (Koch & Kunde, 2002).

Ideomotor theory predicts that R–E compatibility should occur, not only from associations established through a lifetime of experience, as in the cases reviewed above, but from recently acquired, arbitrary stimulus–response associations. Hence, a more compelling R–E manipulation would utilize stimuli that are arbitrarily related to a particular action, a relationship that was learned only in the laboratory and does not exist outside the context of the laboratory session. To address this issue, it is useful to consider the kinds of interference found in variations of the classic Eriksen flanker task (Eriksen & Eriksen, 1974). As explained below, these distinct interference effects stem from stimuli that have no *a priori* relationship with their associated actions; moreover, the interference elicited by such stimuli cannot arise simply from the processing of their superficial (e.g., perceptual) features.

3. Flanker interference

Two kinds of interference from recently acquired stimulus–response contingencies have been demonstrated in the classic Eriksen flanker task (Eriksen & Eriksen, 1974). In one version of the task, participants are trained to press one button with one finger when presented with the letter S or M and to press another button with another finger when presented with the letter P or H. Participants are then instructed to respond to the stimulus presented in the center of an array (e.g., SSPSS, SSMSS, targets underscored) and to disregard the 'flanking' distracters. Of all the flanker conditions, measures of interference such as RTs, error rates, and self-reported 'urges to make a mistake' are lowest when flankers and targets are identical (e.g., SSSSS). It is well established that interference is greater when distracters are associated with a response that is different from that of the target (*response interference* [RI]; e.g., SSPSS) than when the distracters are different in appearance but associated with the same response (*perceptual interference* [PI]; e.g., SSMSS; Eriksen & Schultz, 1979; Morsella et al., 2009; van Veen et al., 2001).

To build upon both ideomotor theory and R–E compatibility paradigms, the authors developed an R–E compatibility variation of the flanker task, whereby participants responded to single letters (S, M, P, or H) in the center of the screen. After their response, participants were presented with a second, incidental letter that they were instructed to disregard and not respond to in any way. With respect to the subject's response, this second stimulus letter was either congruent (e.g., S followed by M) or incongruent (e.g., S followed by P). In line with other R–E paradigms, compatible and incompatible trials were presented in a blocked format (Koch & Kunde, 2002; Kunde, 2001; Kunde, 2003). Based on previous research (Hubbard et al., 2010), it was expected that the self-generated anticipatory representations of the letter stimuli can elicit interference in ways that are similar to that triggered by externally-presented stimuli. We predicted that RTs would be longer on RI trials, where the to-be-performed action and the anticipated action-effect are incompatible, compared to PI and Identical trials, where targets and distracters lead to the same response.

Positive findings from this new, 'flanker-based' variant of the R–E compatibility paradigm would build on the literature in three ways: 1) extending and complementing findings by Koch and Kunde (2002) concerning the 'depth' of processing of anticipatory images in ideomotor processing; 2) illuminating whether recently learned, arbitrary stimulus–response associations can lead to flanker-like effects in an R–E compatibility scenario; and 3) shedding some light on the complex inter-representational dynamics occurring between self-generated, anticipatory representations and representations triggered by externally-presented stimuli.

4. Method

4.1. Participants

San Francisco State University students ($n = 22$) participated for course credit. Based on the procedures of van Veen et al. (2001), participants were first trained in 32 trials to press specified computer keys when presented with certain letters (48-point Helvetica) in the center of a computer screen: When presented with S or M, they pressed a key (occupying the "4" position on the number pad of the keyboard) with their right index finger; when presented with a P or H, they pressed the adjacent ("5") key with their right middle finger. Participants were instructed to respond as quickly and as accurately as possible. Occupying less than 2 cm^2, each target was presented 8 times in random order. Stimuli were presented on a white background of a 50.8 cm Apple iMac computer with a viewing distance of approximately 48 cm, and stimulus presentation was controlled by PsyScope software (Cohen et al., 1993). In accordance with previous R–E compatibility experiments, trials were blocked by compatibility condition. The total number of trials ($n = 288$) was determined based on previous experiments (e.g., Kunde, 2001, Experiment 2; Koch & Kunde, 2002; Kunde, 2003) and the number of unique combinations of the flanker stimuli.

In the experimental phase, participants were informed that they would continue to respond to the letters in the same fashion and that a second letter would flash briefly following their response. As in previous R–E compatibility experiments, participants were informed that they did not have to respond to this second letter in any way and the letter may be associated with the same or different response than the action they just performed. Each trial proceeded as follows: Following a 1000 ms intertrial interval, a fixation cross appeared for 1000 ms, followed immediately by the target letter (48-point

Helvetica), which remained onscreen until a response was made. Moments (100 ms) after the response, the 'distracter' letter appeared for 500 ms.

In accordance with Kunde (2001), stimuli were presented in blocked format. While previous R–E paradigms had only two possible conditions (compatible and incompatible), the flanker stimuli have three possible conditions: Identical (e.g., S followed by S), PI (e.g., S followed by M), and RI (e.g., S followed by P). Given the relative weakness of perceptual interference even in the traditional flanker task (Morsella et al., 2009), and the fact that both the Identical and PI trials involve a compatible response effect, the Identical and PI blocks were treated as a single block when it came to the number of trials and counter-balancing. Accordingly, the Identical and PI blocks consisted of 72 trials each (18 replications of each combination), and the RI block consisted of 144 trials (36 replications of four combinations), and the Identical and PI blocks were always run successively. Between each block, participants were given a one-minute break before continuing.

5. Results

The data from one participant were excluded from analysis because the participant failed to follow instructions. Ten participants began the experiment with compatible mapping first (either Identical then PI, or PI then Identical), while 11 began with an incompatible (RI) block. While the Identical and PI blocks were always run sequentially, their order was counter-balanced across participants. Due to a randomization error stemming from a limitation in the stimulus presentation software, repetition of individual items (e.g., S followed by P) was not completely counter-balanced for 10 participants: Within each block, one item was repeated too many times (e.g., 19 repetitions instead of 18), and a second item was repeated too few times (e.g., 17 repetitions instead of 18). The total number of trials for each block remained the same, and the counter-balancing by interference condition was never violated. This randomization error affected only two trials per block and thus affected 60 out of 6048 total trials. Following Morsella et al. (2009) and Woodworth and Schlosberg (1954), RTs below 200 ms and above 2000 ms were excluded from analysis, resulting in a loss of 15 out of 6048 (0.25%) trials. Regarding error rates, there were no significant differences between the mean error rates for Identical ($M=.034$, $SEM=.011$), PI ($M=.032$, $SEM=.009$), and RI ($M=.041$, $SEM=.011$), $F(2, 40)=1.212$, $p>.30$.

For the RT analysis, Identical and PI conditions produced almost identical mean RTs ($M_{\text{Identical}}=597.16$, $SEM_{\text{Identical}}=26.09$; $M_{\text{PI}}=597.00$, $SEM_{\text{PI}}=29.68$), and RI yielded longer RTs ($M_{\text{RI}}=619.65$, $SEM_{\text{Identical}}=25.30$) (Table 1). A 3×2 ANOVA with Condition (Identical, PI, or RI) as a within-subjects factor and Block Order as a between-subjects factor revealed a main effect of Condition, $F(2, 38)=3.337$, $p<.05$, $\eta_p^2=.15$, but no main effect of Block Order, $F(1, 19)=.058$, $p>.80$, and no significant interaction between Condition and Block Order, $F(2, 38)=.071$, $p>.90$. The same pattern of results is obtained with an ANOVA having only the three interference conditions and omitting the Block Order factor, $F(2, 40)=3.459$, $p<.05$. For this analysis, planned contrasts indicate that the difference between RI and PI was significant, $t(20)=2.11$, $p<.05$, as was the difference between RI and Identical, $t(20)=2.32$, $p<.05$. However, the difference between Identical and PI was non-significant, $t(20)=.017$, $p>.98$. Hence, Identical and PI blocks were collapsed into one 'Compatible' block, and the RI block was treated as 'Incompatible.' The mean RTs show the predicted effect (Table 1), with the Incompatible block exhibiting longer RTs compared to the Compatible block. The data were submitted to a repeated-measures ANOVA with Compatibility as the within-subjects factor and Block Order as the between-subjects factor. The effect of Compatibility was significant, $F(1, 19)=5.90$, $p<.05$, $\eta_p^2=.24$. The effect of Block Order was non-significant, $F(1, 19)=.051$, $p>.80$.

Since the Incompatible block had twice as many trials as the individual PI or Identical blocks, the authors conducted a distribution analysis to investigate whether fatigue contributed to the effect. Trials were split into 8 'miniblocks,' and mean RTs were observed separately for the block order (i.e., Compatible block first, or Incompatible block first). The resulting pattern (Fig. 1) mirrored that found in a previous R–E Compatibility experiment (Koch & Kunde, 2002): Those who began with the RI block had longer mean RTs in the beginning, which decreased as the experiment continued into the Compatible Block. Those who began with the Compatible Block (Identical and PI) exhibited the opposite pattern, beginning with lower RTs that increased as the experiment progressed into the Incompatible block. Such a pattern runs counter to the notion that participants simply got fatigued as a result of there being more trials in the RI block.

Table 1
Mean reaction time (ms) by block condition.

Block	Mean response time	SEM
Compatible	597.11	27.56
Incompatible	619.65	25.30
Identical	597.16	26.09
Perceptual interference	597.00	29.68
Response interference	619.65	25.30

6. Discussion

We report for the first time an RI effect in an R–E compatibility paradigm that was designed to assess the different kinds of interference found in the classic flanker task. Our experimental procedures were based on those of previously published studies (Koch & Kunde, 2002; Kunde, 2001; Kunde, 2003; van Veen et al., 2001). However, unlike in previous R–E compatibility paradigms, our study involved different kinds of interference manipulations (e.g., PI versus RI), and the effect observed was based on arbitrary stimulus–response associations that were acquired, not through inborn mechanisms or knowledge gained in normal everyday experience, but through a laboratory training session based on the 1979 flanker task (Eriksen & Schultz, 1979).

These basic findings are consistent with ideomotor theory, in which the representations of action-effects are activated automatically during voluntary action, and the representations can, in turn, activate action plans that can interfere or facilitate intended action (Hommel, 2009; Hommel et al., 2001). As outlined by Kunde (2001, 2003), the unintentional and anticipatory effects found in R–E compatibility provide the most compelling support for ideomotor theory.

One aim of this experiment was to explore whether internally-generated representations of arbitrary stimuli are capable of eliciting RI in an R–E compatibility paradigm. Given that R–E compatibility

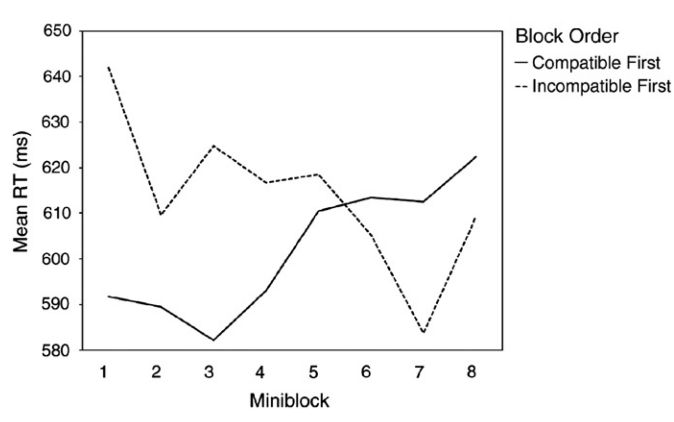

Fig. 1. Mean response time (ms) across trials, separated by block order.

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paradigms work in virtue of activating anticipatory images in ideomotor processing, such images must be internally-generated (because their associated stimuli occur in the future). Indeed, the data support the hypothesis that RI effects would persist in this variation of the paradigm, as indicated by increased RTs in trials where actions were followed by incongruent flanker-based stimuli. Importantly, this effect was present even though the stimuli (S, M, P, or H) had no perceptual overlap with the actions (left- and right-button presses). Thus, in order to produce a reliable RT effect, the identity and associated responses of these internally-generated representations had to be processed. The evidence was strengthened by the distribution analysis: The longest RTs were observed in the Incompatible blocks, regardless of whether they occurred at the beginning or end of the experiment. These findings complement a previous series of experiments, where flanker stimuli held in working memory over a delay elicited the behavioral and subjective effects of representations triggered by external stimuli (Hubbard et al., 2010). The finding is consistent with the view that mental representations retain aspects of the sensorimotor processes associated with their acquisition (cf., Barsalou, 2008; Zwaan, 2008).

Additionally, these findings are important for illuminating the dynamics involved between internally-generated representations. It appears that R–E compatibility is not due to a simple isomorphic, perceptual-like overlap between anticipatory images and a to-be-performed response. Instead, it functions much like S–R compatibility in that it is capable of eliciting interference with arbitrary stimuli. However, the lack of a PI effect reveals the ways in which representations activated through different means may differ. In this paradigm, different looking stimuli that were associated with a congruent response were processed as if they were the same stimulus, reflected in the almost equal RTs for the Identical and PI blocks.

The limitations of the present study naturally include the limitations of the classic flanker task. For example, representations giving rise to response interference must include some perceptual interference. This may render the RI condition more complicated than the PI condition and could lead to the kinds of effects reported above. Unfortunately, a flanker-like paradigm that can induce response interference without also invoking perceptual interference has never been developed. Perhaps this could be instantiated by having targets and distracters be perceptually identical but somehow cue different responses, if such a scenario is possible.

Why is it that RI tends to always produce stronger interference effects than PI? There are empirical and theoretical reasons to believe that RI is qualitatively distinct from PI. Regarding empirical developments, in a neuroimaging study of the flanker task, van Veen et al. (2001) demonstrated that, although both RI and PI are associated with differences in performance, the former is the condition that activates the anterior cingulate cortex, a brain region located in the frontal lobe that is interconnected with many motor areas and is believed to be involved in conflict detection and response selection (Cohen et al., 1990; Enger & Hirsch, 2005; MacLeod & McDonald, 2000; van Veen et al., 2001). Regarding theoretical developments, the observation that RI leads to stronger behavioral and subjective interference effects (e.g., 'urges to err' or 'perceptions of interference') than PI has been explained by theoretical developments about the primary function of consciousness (Morsella, 2005), developments that, importantly, were intended to explain a different class of phenomena, such as the subjective correlates of intersensory conflicts versus conflicts involving visceral urges.[1]

Future research may examine the subjective effects of RI in a variant of our R–E compatibility paradigm.

More generally, this study reveals how informative findings can emerge from the simple inter-mixing of two research lines (e.g., paradigms on R–E compatibility and on flanker interference). It is our hope that this rich and intriguing basic finding will inform theories about cognitive control and action production.

[1] According to Supramodular Interaction Theory (SIT; Morsella, 2005), RI leads to the strongest subjective effects because people are most likely to be conscious of conflicts involving competition for control of the skeletal muscle system, because the primary function of consciousness is to integrate such incompatible skeletomotor intentions (see quantitative review of evidence in Morsella, Berger, & Krieger, in press).

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