Does feature-based attention play a role in the episodic retrieval of event files?

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In press (accepted September, 2019) at the *Journal of Experimental Psychology: Human*

Perception & Performance

RUNNING HEAD: Episodic retrieval and feature-based attention

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Abstract

In stimulus identification tasks, stimulus and response, and location and response information, is thought to become integrated into a common event representation following a response. Evidence for this feature integration comes from paradigms requiring keypress responses to pairs of sequentially presented stimuli. In such paradigms, there is a robust cost when a target event only partially matches the preceding event representation. This is known as the partial repetition cost. Notably, however, these experiments rely on discrimination responses. Recent evidence has suggested that changing the responses to localization or detection responses eliminates partial repetition costs. If changing the response type can eliminate partial repetition costs it becomes necessary to question whether partial repetition costs reflect feature integration or some other mechanism. In the current study, we look to answer this question by using a design that as closely as possible matched typical partial repetition cost experiments in overall stimulus processing and response requirements. Unlike typical experiments where participants make a cued response to a first stimulus before making a discrimination response to a second stimulus, here we reversed that sequence such that participants made a discrimination response to the first stimulus before making a cued response to the second. In Experiment 1, this small change eliminated or substantially reduced the typically large partial repetition costs. In Experiment 2 we returned to the typical sequence and restored the large partial repetition costs. Experiment 3 confirmed these findings, which have implications for interpreting partial repetition costs and for feature integration theories in general.

Public Significance Statement

Efficiently acting upon objects requires the creation and retrieval of links between perceptual and action information. The current study shows that these links are retrieved more selectively than previously thought. Rather than being retrieved for all actions upon objects, they are only retrieved when identifying the object is necessary for action planning. These findings reveal an intelligent boundary condition on when previously formed action-perception links are retrieved when processing new information.

Perceptual and motor processing occur largely independently of each other in the brain. Yet, successful actions need to be informed by perceptual information, thus creating a binding problem across perception and action. Given this distributed and independent processing of perceptual and motor codes, how does perception inform action? The Theory of Event Coding (TEC; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Hommel, 2004; 2019) offers an answer to this fundamental question. It suggests that when acting upon an object the features of that object and the features of the action directed to the object are integrated into a temporary representation called an event file. By integrating perceptual and action codes into a common representation perception can readily inform actions and vice versa. One major source of evidence for these event files comes from the partial repetition cost (PRC) paradigm (Hommel, 1998) in which participants respond to sequences of simple visual stimuli. In the current study, we investigate the role of feature-based attention in perception and action planning by manipulating when it is necessary to identify a visual stimulus in the PRC paradigm.

The PRC paradigm (see Figure 1, right panel; Hommel, 1998; Hommel & Colzato, 2004; Hommel, Memelink, Zmigrod, & Colzato, 2014) builds on Kahneman, Treisman, and Gibbs's (1992) object preview paradigm. In the PRC paradigm, participants first see a central arrow (a "Response Cue") pointing to the left or right. Based on the Response Cue's direction, the participants prepare a left or right-handed keypress response. The prepared response is made to the next stimulus (the "Cued Response Stimulus") regardless of its location or identity. The Cued Response Stimulus is typically a simple stimulus varying in color, form, or both color and form (but see: Colzato, Raffone, & Hommel, 2006; Singh, Frings, & Moeller, 2017, for examples using more complex stimuli) appearing in one of two marked ("placeholder") locations. This stimulus disappears after the response is made to it and shortly thereafter another stimulus (the

"Discrimination Response Stimulus") that varies along the same features (e.g. color, form) appears randomly in one of the two possible locations. The participants must discriminate this stimulus based on one of its non-spatial (i.e., form or color) features with either a left- or right-handed keypress (i.e., the same response options as for the cued response).

The typical findings from the PRC paradigm are, broadly, as follows. When the Discrimination Response Stimulus repeats either all features or none of the features (e.g., color, form, location, response, etc.) of the Cued Response Stimulus and response, responses are relatively fast and error rates are relatively low. When the Discrimination Response Stimulus repeats some, but not all, features of the Cued Response Stimulus, responses are relatively slow and error rates are relatively high. This slowing is the PRC. When looked at in more detail, however, this pattern of results typically is driven by interactions between feature pairs. In particular, there are commonly interactions between location and response repetition as well as response repetition and the task-relevant feature. When the stimulus location repeats, response repetitions are faster relative to response switches, but when stimulus location switches response switches are faster relative to response repeats. Likewise, when the task-relevant feature repeats response repetitions are fast, but when the task-relevant feature switches response switches are fast. Furthermore, it is uncommon to find higher order interactions in these tasks.

The explanation of this data pattern according to TEC is that features of the Cued Response Stimulus and response are integrated into common, binary (e.g., location and response, and response and task-relevant feature bindings) representations, referred to as "event files" (Hommel, 2004). If any feature of the Discrimination Response Stimulus matches any feature of the event file, the event file is retrieved. When there is a partial match between the Discrimination Response Stimulus and the event file, the retrieved event file interferes with the

current event processing. Resolving this interference leads to a response time cost. When the Discrimination Response Stimulus and response completely match an event file, the event file is retrieved but no such interference occurs. When the Discrimination Response Stimulus and response completely mismatch an event file, no event file is retrieved and thus no such interference occurs.

Recent research has qualified TEC. In one study (Huffman, Hilchey, & Pratt, 2018), we reviewed a subset of attentional orienting studies in which individuals needed to respond to each serially presented stimulus (Fox & de Fockert, 2001; Kwak & Egeth, 1992; Pratt & Castel, 2001; Tanaka & Shimojo, 1996, 2000; Taylor & Donnelly, 2002). In those studies, the stimuli randomly repeated or switched locations across trials. Likewise, the stimuli randomly repeated or changed their identities (i.e., color and/or form) across trials. Critically, identity information was unnecessary for responding – instead, the participants simply indicated each stimulus's presence or location, regardless of its identity. The review's purpose was to determine whether event file retrieval occurs in studies requiring no identity information processing; it does not. Their absence suggests that attending to stimulus' identities is a precondition for event file retrieval. Thus, contrary to strong, early forms of the TEC, the results suggest that links between different sources of information and actions depend on feature-based attentional control settings (e.g. Folk, Remington & Johnston, 1992), with event files containing attended features being more likely to be retrieved (e.g., Hommel, 1998; Colzato, Raffone & Hommel, 2006; Memelink & Hommel, 2013; Memelink et al., 2014; Schumacher & Hazeltine, 2016).

In another study (Hilchey, Rajsic, Huffman, Klein, & Pratt, 2018), we used a paradigm in which participants responded to two serially presented targets within each trial. In Experiment 1, the targets could be a white '×' or a '+' symbol appearing to the left or right fixation. A critical

difference between this study and the typical PRC paradigm (e.g., Hommel, 1998) is that

participants responded in two steps. First, they made an eye movement to the target stimulus – an

abrupt onset – precluding the need to process target identity information before making the eye

movement. Then, after completing the eye movement, they discriminated the stimulus with a

left- or right-handed manual keypress response. In this study, a strong form of TEC would

predict PRCs in both the saccadic and manual response times. The manual response data

replicated previous PRCs. In the saccadic response times, however, there were no PRCs. Rather,

eye movements were biased against returning to a previously fixated location with little to no

effect of form repetition or color repetition (Experiment 2). The findings indicate that a general

attentional control setting for processing target identity is insufficient for event file retrieval.

Rather, the data strongly suggest that event file retrieval only occurs when stimulus identification

is necessary before action planning can occur (see also, e.g., Hilchey, Leber & Pratt, 2018).

That said, there are arguably alternative explanations for the lack of event file retrieval in

the saccadic reaction times in Hilchey, Rajsic et al. (2018) and in the detection and localization

responses in Huffman et al. (2018). In Huffman et al., encoding any target identity information

was, by design, completely unnecessary. In Hilchey, Rajsic et al., encoding target identity

information was, also by design, completely unnecessary for the eye movements. Thus, the

stimulus identity information may have been completely ignored or filtered out for the required

response (e.g., Folk et al., 1992). If so, stimulus identity may not have been processed to the

extent necessary to create an event file or provoke event file retrieval (but see, Hommel (2005)

and Moeller and Frings (2014), for evidence that event file creation requires minimal attention).

Accordingly, there would be no potential for event file retrieval. This leaves us wondering: if

stimulus identity is relevant for a particular response (such that stimulus identity cannot be

ignored or filtered), would repeating any of that stimulus's features lead to event file retrieval, even when that stimulus's identity is later irrelevant for responding?

The question is fundamentally important. If event file retrieval occurs even when it is unnecessary to process identity information prior to forming a response, then that would suggest that feature-based attention is unnecessary for event file retrieval. If event file retrieval occurs only when a stimulus must be identified, then that would suggest that feature-based attention is necessary for event file retrieval. Here, we answer this question by partly reversing the order of events in the PRC paradigm in Experiment 1. Whereas the typical serial order of events in the PRC paradigm is an arrow cue followed by the Cued Response Stimulus and then the Discrimination Response Stimulus, in our first experiment the order is the Discrimination Response Stimulus followed by the arrow cue and then the Cued Response Stimulus (see Figure 1). To anticipate the results, we found little to no evidence of event file retrieval in Experiment 1. To clarify whether the lack of event file retrieval was due to our partial reversal of the PRC paradigm and not some other peculiarity of our implementation, Experiment 2 was essentially identical to Experiment 1 except we changed the order of events to match the typical PRC paradigm. Finally, in Experiment 3 we replicated Experiments 1 and 2 in a single within-subjects experiment to verify our findings.

EXPERIMENT 1

In Experiment 1, we reversed the typical PRC paradigm to test whether event file retrieval also occurs when the first stimulus in the sequence needs to be identified while the final one does not, and instead requires the execution of the preplanned response. Critically, our design matched the stimulus processing demands of the typical PRC paradigm. Thus, if PRCs are absent we can confidently conclude that event file retrieval is dependent upon stimulus

discrimination. To reiterate, if PRCs are found in this experiment they are most likely to be found as interactions between response and location repetition as well as between response and the task-relevant feature repetition (in this case, color), whereas no interaction is expected between target location and color repetition (Hommel, 1998; Hilchey, Rajsic, Huffman & Pratt, 2017a).

Methods

Participants. Twenty-Four University of Toronto undergraduate students (mean age = 18.8, *SD* = 2.1, 14 females) participated in the experiment in exchange for course credit. In order to estimate an appropriate sample size, we conducted a power analysis on data from a previous study using GLIMMPSE's open source software (Kreider et al., 2013) using previously collected data from a different study. This data was from a PRC study in which context was manipulated, but did not affect the PRCs. For our current purposes, we estimated the samples size required to achieve 95% power with a α level of .05 for finding the color repetition × response repetition interaction. To estimate the sample size required to achieve a desired power level, GLIMMPSE requires expected mean response times for each combination of color and response repetition, the correlation between each level of response repetition across conditions of color repetition, the correlation between each level of color repetition across conditions of color repetition,[1] and the response time *SD*. In our previously collected data, there was a ~50ms advantage for response alternations compared to repetitions when color switched while the response times were approximately equal for response repetitions and switches when color repeated. The correlation

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[1] Note that these correlations are almost never reported in published research, which is why we relied upon previously collected, but unpublished study that was as close to the current study as we had available to us.

between each level of response repetition was ~.9 as was the correlation between each level of

color repetition. The highest *SD* within any cell of the design was 180 ms. Using those estimates

as the parameters for GLIMMPSE and also assuming an effect size 80% of the observed effect

and 20% more variability than observed it was estimated that we needed 20 participants to

achieve 95% power. We ran 24 participants in order to remain on the conservative side while

also protecting against the possibility of needing to remove participants due to poor performance.

All participants reported normal or correct-to-normal visual acuity and normal color vison.

   Stimuli and apparatus. Participants completed the experiment using a PC connected a

LCD monitor (screen resolution: 2560×1440; refresh rate: 144 Hz). We used Matlab by

Mathworks with the Psychophysics toolbox (Kleiner, Brainard, Pelli, Ingling, Murray, &

Broussard, 2007) for stimulus presentation. The stimuli were presented within three, vertically

arranged, $1.2 ˚ \times 1.2˚$ white boxes. The stimuli consisted of '<<<' or '>>>' cues and $1˚ \times 1˚$ blue

(RGB: 012 000 164) and green (RGB: 026 096 034) squares. Participants responded using the 'z'

and '?/' keys on a QWERTY keyboard.

   Procedure. See Figure 1, left panel, for the stimulus presentation sequence. Each trial

began with the three-box array. After 2,000 ms, we presented a green or blue square in the upper

or lower box (the Discrimination Response Stimulus). We asked participants to discriminate this

square's color as quickly as possible without sacrificing accuracy. If this response was incorrect,

we presented an error screen ('MISTAKE' in red text for 2,000 ms) and the next trial began. If

the response was correct, the square disappeared, and then 1,000 ms later, we presented a left or

right arrow cue (the Response Cue). We instructed participants to prepare to make the response

indicated by the Response Cue. The Response Cue remained onscreen for 1,000 ms. After a

variable 500 – 2000 ms interval (separated into 100 ms increments for a total of 16 intervals)[2],

chosen randomly on each trial, a second blue or green square appeared in the upper or lower box

(the Cued Response Stimulus). We asked participants to execute the prepared response upon this

stimulus's onset, regardless of its location or color (cued response). Following a correct

response, the next trial began. If a mistake was made, an error screen appeared for 2,000 ms.

Design. All combinations of Discrimination Response Stimulus color (green and blue),

Discrimination Response Stimulus location (top or bottom), Response Cue ('<<<' and '>>>'),

Cued Response Stimulus color, and Cued Response Stimulus location were repeated seven times

in a random order for a total of 224 trials. The color-response mappings were counterbalanced

across participants. For analysis, the trials were coded in terms of whether color, location, and

response repeated between the Discrimination Response Stimulus and the Cued Response

Stimulus.

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[2] The jittered interval was implemented in order to limit the participant's ability to anticipate the exact onset time of the cued response stimulus.
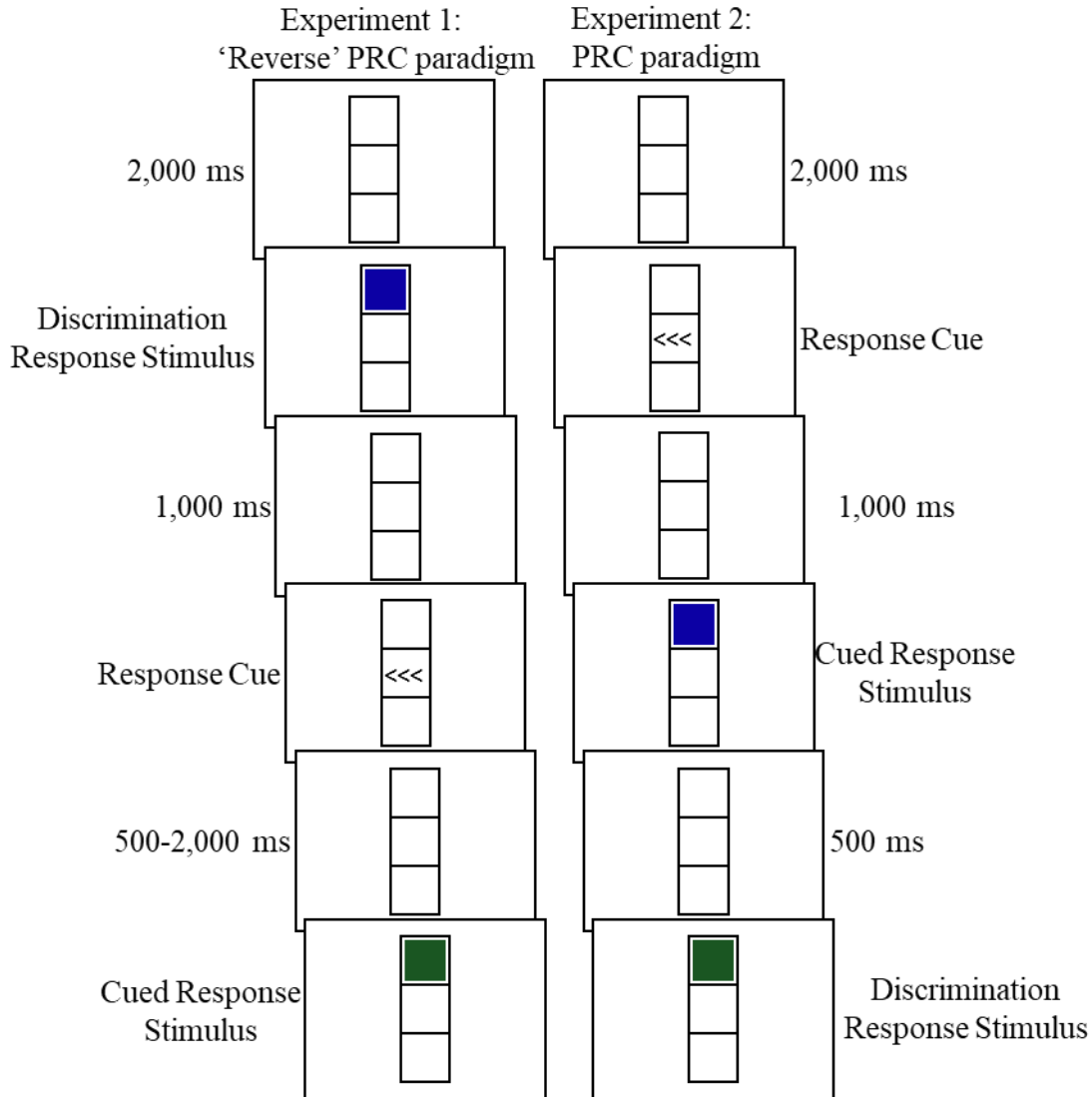
Experiment 1:
'Reverse' PRC paradigm

Experiment 2:
PRC paradigm

2,000 ms

2,000 ms

Discrimination
Response Stimulus

Response Cue

<<<

1,000 ms

1,000 ms

Response Cue

<<<

Cued Response
Stimulus

500-2,000 ms

500 ms

Cued Response
Stimulus

Discrimination
Response Stimulus

Figure 1. The stimulus presentation sequence for Experiments 1 and 2. Note that in the "reverse" Experiment 1 participant made a discrimination response to the first target and then made a cued response to the second target. In Experiment 2, participants made a cued response to the first target and then made a discrimination response to a second target, as in the typical PRC paradigm.

Results

To prepare the data for analysis we first removed trials in which participants made errors on the first response (4.8%). We then removed trials in which participants responded in less than 100 ms (0.3%), assuming that these were anticipations, and trials in which they took longer than 2000 ms (2.1%) to response, assuming that these reflect lapses in attention. Finally, we removed trials in which participants made errors with their second response (2.3%). With these error rates

being too close to ceiling to meaningfully analyze, we did not do so. In total, we removed 9.4%

of trials for analysis.

The response time data were analyzed using a 2 (color repetition: repeat or switch) $\times$ 2

(location repetition: repeat or switch) $\times$ 2 (response repetition: repeat or switch) repeated

measures ANOVA. See Figure 2 for a visualization of the results. The analysis revealed a main

effect of location repetition, $F(1,23) = 22.21$, $p < .01$, $\eta_p^2 = .49$, indicating faster response times

when location switched ($M\pm SE$: 410±16 ms) than repeated (445±17 ms). The main effects of

color repetition, $F(1,23) = 1.67$, $p = .21$, $\eta_p^2 = .07$, and response repetition, $F(1,23) < 1$, $p = .90$, η_p^2

$< .01$, were not significant. Likewise, the location repetition $\times$ response repetition interaction was

not significant, $F(1,23) = 2.35$, $p = .14$, $\eta_p^2 = .09$. There was a small but significant response

repetition $\times$ color repetition interaction, $F(1,23) = 5.20$, $p = .03$, $\eta_p^2 = .18$. When the color

switched, response times were numerically faster when the response switched (424±16 ms)

versus repeated (438±18 ms), $t(23) = 1.92$, $p = .07$, *Cohen's d_z* = .40. When the color repeated,

response times were numerically slower when the response switched (432±17 ms) versus

repeated (419±17 ms), $t(23) = 1.57$, $p = .13$, *Cohen's d_z* = .32. The color repetition $\times$ location

repetition interaction was not significant, $F(1,23) = 2.76$, $p = .11$, $\eta_p^2 = .11$. Finally, the color

repetition $\times$ response repetition $\times$ location repetition interaction was not significant, $F(1,23) < 1$,
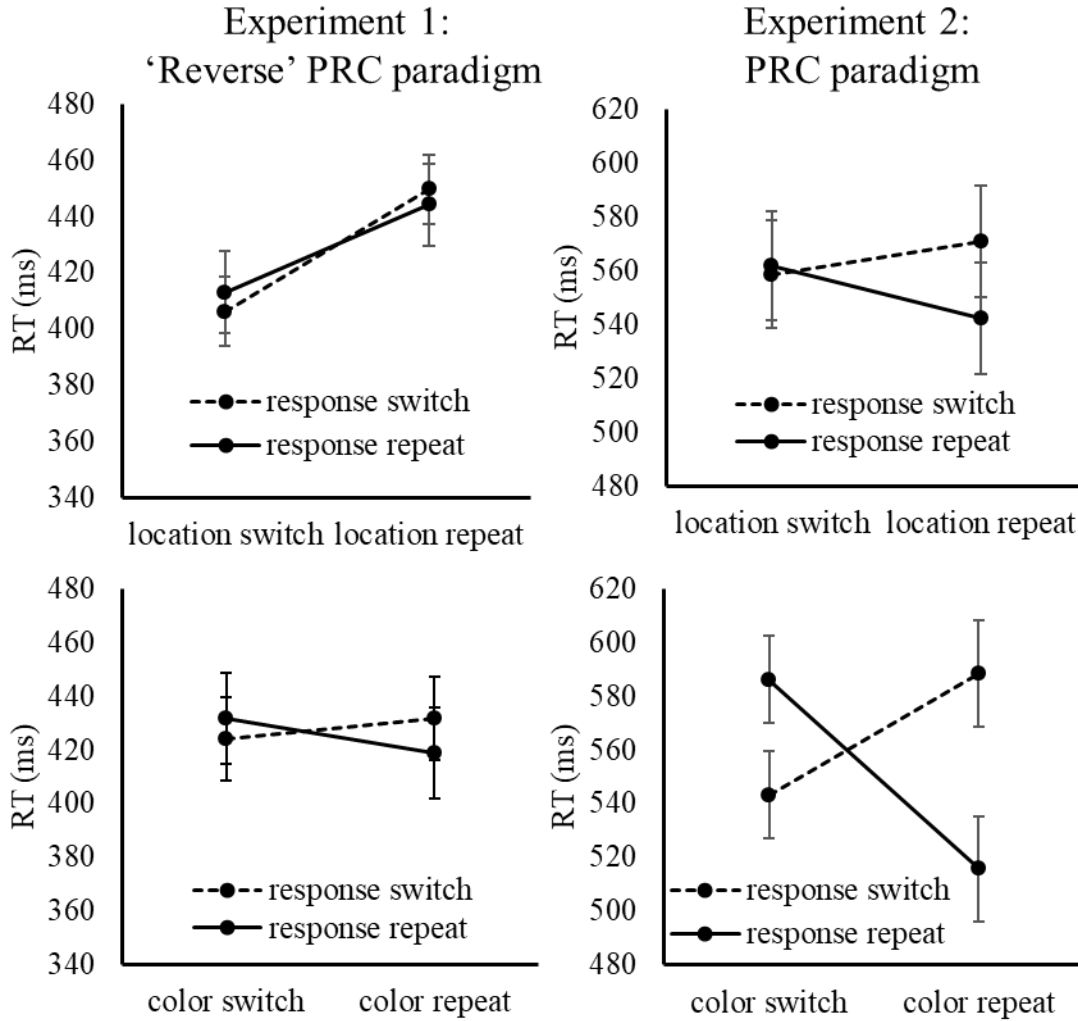
$p = .59$, $\eta_p^2 = .01$.

Figure 2. The results from Experiment 1 (left panel) and Experiment 2 (right panel). In typical PRC experiments both the location by response and color by response interactions are expected to be significant. Error bars represent the 95% confidence intervals of the mean color switch – color repeat effect within each response repetition condition (Pfister & Janczyk, 2013).

Discussion

In this experiment, we required participants to process stimulus identity to make the correct response to an initial stimulus in order to examine whether event file retrieval would also occur if the subsequent target stimulus did not necessitate stimulus identification (because a preplanned response was made to it, regardless of its identity). We observed two significant effects. First, we found a location repetition cost. As we have noted before (Hilchey, Rajsic et al., 2018; Huffman et al., 2018), this location repetition effect likely reflects some form of inhibition

of return, whereby there is either a selection or orienting bias against previously attended locations (Klein, 2000; Lupianez, 2010). When event file retrieval effects are in play, this inhibition of return effect is masked (Hilchey, Rajsic, Huffman, Klein & Pratt, 2018; Hilchey, Antinucci, Lamy & Pratt, 2019; Hilchey, Pratt & Lamy, in press). Second, we found a small color by response interaction, consistent with PRCs, in apparent contradiction with the idea that episodic retrieval depends on feature-based attention. That said, the effect size of this interaction was relatively weak, and considering also the absence of a response by location interaction, it becomes clear that a lack of feature-based attention at least makes event file retrieval substantially less likely. That a lack of feature-based attention at least substantially reduced the partial repetition costs is further supported by the lack of a response by location repetition interaction.[3] We see two possibilities: the relationship between color and response repetition is either spurious or on some small proportion of trials, participants identified the Cued Response Stimulus instead of, or in addition to, making the prepared response. In summary, in Experiment 1, we found no compelling evidence for PRCs in the location dimension and, at best, an unusually weak PRC in the color dimension when the final stimulus in the sequence did not require feature-based attention.

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[3] To have event file retrieval without a location by response interaction would be highly unusual. The tendency for response switches when the stimulus location changes is highly replicable and robust. Indeed, Hilchey, Weidler, Rajsic, and Pratt (in press) recently replicated this effect 16 times with the smallest η_p^2 being .45. Second, while the effect was significant, its size is much smaller (η_p^2=.18) than typically seen in these types of experiments. In Hilchey, Rajsic et al. (2018), for example, the value for that interaction was .71 in Experiment 1 and in Experiment 2 it was .69. In Hommel (1998) that interaction had η_p^2 values of .76, .89, .80, and .48 across experiments

EXPERIMENT 2

In Experiment 1, we found little evidence of event file retrieval when the final stimulus in the sequence did not require identification, suggesting that event file retrieval may depend on feature-based attention. Before hashing out the implications of this, it is prudent to replicate the PRCs by "un-reversing" our paradigm. In our first experiment, the first target vanished at the time of the response whereas in Hommel (1998) the first target was on for 500 ms, regardless of when participants responded. Furthermore, we used simple square stimuli rather than letters. While the PRC effects are thought to be robust to small timing differences (e.g., Hommel & Colzato, 2004), and we have found retrieval effects using colored squares previously (Hilchey, Rajsic, Huffman, & Pratt, 2017a, 2017b), Experiment 2 was conducted to ensure that the typical PRC effects can be obtained with our timing and stimuli in the standard PRC paradigm. As a reminder, PRC effects are anticipated as interactions between location and response repetition and between color and response repetition.

Methods

Participants. Twenty-Four University of Toronto undergraduate students (mean age = 18.9, *SD* = 1.9, 16 females) participated in the experiment in exchange for course credit. All participants reported normal or correct-to-normal visual acuity and normal color vison.

Stimuli and apparatus. The stimuli and apparatus matched those used in Experiment 1.

Procedure. See Figure 1, right panel, for the stimulus presentation sequence. The procedure closely matched that of Hommel (1998). Participants first saw the Response Cue, indicating which response to prepare. This cue remained for 500 ms and was followed by a display containing only the white boxes for 500 ms. Upon the Cued Response Stimulus's onset, participants executed the prepared response. Upon their response, the Cued Response Stimulus

disappeared, with the display consisting of only the white boxes for 500 ms.[4] Next, the

Discrimination Response Stimulus appeared in the top or bottom square and participants were

asked to discriminate its color. The intertrial interval was 2,000 ms.

Design. The design matched Experiment 1.

Results

To prepare the data for analysis we first removed trials in which participants made errors

on the first response (1.6%). We then removed trials in which participants responded in less than

100 ms (0.4%), assuming that these were anticipations, and trials in which they took longer than

2000 ms (0.7%) to responses, assuming that these reflected lapses in attention. Finally, we

removed trial in which participants made errors with their second response (4.3%). In total, we

removed 6.9% of trials for analysis.

The analysis revealed no main effect of location repetition, $F(1,23) < 1$, $p = .61$, $\eta_p^2 = .012$,

or response repetition, $F(1,23) = 2.26$, $p = .15$, $\eta_p^2 = .09$, while there was a main effect color

repetition, $F(1,23) = 5.15$, $p = .03$, $\eta_p^2 = .18$. Response times were faster when colors repeated

(551±29 ms) than when they switched (566±29 ms). Critically, however, there was a significant

location repetition × response repetition interaction, $F(1,23) = 9.30$, $p = .01$, $\eta_p^2 = .29$, as well as

a profound response repetition × color repetition interaction, $F(1,23) = 100.00$, $p < .01$, $\eta_p^2 = .81$.

For the location repetition × response repetition interaction, when location switched, response

switches were numerically faster (559±30) than response repetitions (562±27 ms), $t(23) < 1$, $p =$

.75, *Cohen's d_z* = .07, and when location repeated, response repetitions were significantly faster

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[4] We no longer jittered the interval between stimuli in this experiment because the critical response was a discrimination response which could not be anticipated.

(542 ± 21 ms) than response switches (571 ± 30 ms), $t(23) = 2.83$, $p = .01$, *Cohen's d_z* = .58. For

the color repetition × response repetition interaction, when color switched, response switches

(543 ± 27 ms) were faster than response repeats (586 ± 32 ms), $t(23) = 5.45$, $p < .01$, *Cohen's d_z* =

1.11, and when color repeated response repetitions (516 ± 26 ms) were faster than response

switches (588 ± 27 ms), $t(23) = 7.65$, $p < .01$, *Cohen's d_z* = 1.56. The color repetition × location

repetition interaction was not significant, $F(1,23) < 1$, $p = .46$, $\eta_p^2 = .02$. Finally, the location

repetition × color repetition × response repetition interaction was not significant, $F(1,23) < 1$, $p =$

.94, $\eta_p^2 < .01$.

Response time quartile analysis of Experiment 1. Due to task differences between

Experiments 1 and 2, the response times in Experiment 1 were significantly faster than those in

Experiment 2. This raises the possibility that this general slowing, rather than the degree to

which feature-based attention was required, can account for the differences between Experiments

1 and 2. To test this possibility, we re-analyzed Experiment 1's data looking only at the two

slowest quartiles of each participant's data within each condition. Here we report the relevant

interactions with quartile. There was no quartile × location repetition interaction, $F(1,23) < 1$, $p =$

.586, $\eta_p^2 = .01$, or quartile × response repetition interaction, $F(1,23) < 1$, $p = .48$, $\eta_p^2 = .02$.

Interestingly, however, there was a quartile × response repetition × color repetition, $F(1,23) =$

10.01, $p < .01$, $\eta_p^2 = .30$. In both the 3rd and 4th quartile data there were significant response

repetition × color repetition interactions with that interaction being more pronounced in the 4th

quartile than in the 3rd quartile data. There was also a significant quartile × location repetition ×

color repetition interaction, $F(1,23) = 5.56$, $p = .03$, $\eta_p^2 < .19$, which reflected a location

repetition × color repetition interaction in the 4th quartile data, but not in the 3rd quartile data. In

contrast, the location repetition x response repetition interaction did not interact with quartile, nor did it emerge in either quartile. Response time quartile did not interact with any other factors.

Discussion

In this experiment we had participants make a precued response to a stimulus that was followed by a stimulus discrimination response, as is typically done in PRC studies. The results from Experiment 2 are consistent with the PRCs predicted by TEC. That is, feature repetition caused the previous event file to be retrieved. When the retrieved event file conflicted with the current event we found relatively slow response times. Experiment 2 confirms that PRCs can be found using stimuli such as those used in Experiment 1.

Additionally, we conducted a follow-up analysis on the Experiment 1 data looking only at the slowest half of the response times to test whether the lack of retrieval effects in that experiment were due to the faster response times rather than reduced feature-based attention. The results with respect to the interaction between location and response repetition were clear whereas the results with respect to the interaction between color and response repetition were more ambiguous. On the one hand, we found a response repetition by color repetition interaction, which is consistent with event file retrieval. We also found that interaction was larger in the 4th compared to the third 3rd response time quartile, consistent with the hypothesis that the lack of response times in Experiment 1 were due to the fast response times rather than reduced feature-based attention. On the other hand, even in the 4th response time quartile the response repetition by color repetition interaction was substantially smaller than that found in Experiment 2 (Experiment 1, $\eta_p^2 = .33$, Experiment 2, $\eta_p^2 = .81$). Furthermore, we found a location by color interaction in the slowest response time quartile that, in theory, would be consistent with event file retrieval, but it should be noted that this interaction is not typically found in Partial

Repetition Costs paradigms. Critically, we could find no evidence for an interaction between response repetition and location repetition, which are commonly found in Partial Repetition Costs paradigms.

Taken together, Experiment 2, along with the additional analyses of Experiment 1, are consistent with feature-based attention playing a role in whether event file retrieval occurs. When the task required feature-based attention, we found the predicted, large color by response and location by response interactions, whereas these interactions were small to non-existent when feature-based attention was not required. What is to make of these interactions between color and response repetition, and location and color repetition in the slower response time quartiles? As noted above, we believe that these reflect imperfect switching out of the color processing mode needed to make the first response. That is, because it was necessary to process color for the first response it is possible that, on some trials, participants did not switch out of that color processing mode and processed the color of the second stimulus. We would expect that trials in which participants did not switch out of the color processing mode to have slower response times and, since they processed the color, for partial repetition costs involving color to appear. Before speculating on this finding, and making conclusions about the study as a whole, however, we looked to replicate the two experiments using a single, within-subjects, design.

<div align="center">EXPERIMENT 3</div>

While the comparison of PRCs between Experiments 1 (PRC absent) and 2 (PRC present) provide the essential data to the question we are asking, a confirmation of these effects in a within-subject comparison would provide a stronger foundation on which to base our conclusions. Therefore, in this third, preregistered (https://osf.io/rx3q7) experiment, we looked to replicate the effects of the prior two experiments using a within-subjects design.

Methods

Participants. Twenty-Four University of Toronto undergraduate students (mean age = 19.8, *SD* = 2.7, 18 females) participated in the experiment in exchange for course credit. All participants reported normal or correct-to-normal visual acuity and normal color vison.

Stimuli and apparatus. The stimuli and apparatus matched those used in the previous experiments.

Procedure. In Experiment 3, participants completed two blocks of trials. The procedure for one block matched Experiment 1's procedure exactly. The procedure for the other block matched Experiment 2's procedure exactly.

Design. The order in which participants completed the two trial blocks was counterbalanced across participants. The designs of each block replicated the corresponding experiment exactly.

Results

To prepare the data for analysis we first removed trials in which participants made errors on the first response (4.1%). We then removed trials in which participants responded in less than 100 ms (0.2%), assuming these reflect anticipations, and trials in which they took longer than 2000 ms (2.0%), assuming that these response reflected lapses in attention. Finally, we removed trial in which participants made errors with their second response (3.1%). In total, we removed 9.3% of trials for analysis.

Across task effects. The mean RT data were analyzed using a 2 (task) $\times$ 2 (location repetition) $\times$ 2 (response repetition) $\times$ (color repetition) repeated measures ANOVA. There was a main effect of location repetition, $F(1,23) = 16.71$, $p < .01$, $\eta_p^2=.42$, with faster responses when location switched (507±23 ms) than when it repeated (526±23 ms). The was also a main effect of

color repetition, $F(1,23) = 5.93$, $p = .02$, $\eta_p^2 = .21$, with faster responses when color repeated

(510±22 ms) than when it switched (523±24 ms). The main effect of response repetition was not

significant, $F(1,23) = 2.34$, $p = .14$, $\eta_p^2 = .09$.

As for two-way interactions, the location repetition × response repetition interaction was

significant, $F(1,23) = 11.11$, $p < .01$, $\eta_p^2 = .32$. When location switched, response switches

(495±23) were faster than response repeats (520±24 ms), $t(23) = 3.19$, $p < .01$, *Cohen's d_z* = .65,

but when location repeated there was only a numerical difference between response switches

(531±23 ms) and repeats (523±23 ms), $t(23) = 1.22$, $p = .23$, *Cohen's d_z* = .25. The response

repetition × color repetition interaction was also significant, $F(1,23) = 48.91$, $p < .01$, $\eta_p^2 = .68$.

When color switched, responses switches (503±23) were faster than response repeats (544±23

ms), $t(23) = 5.16$, $p < .01$, *Cohen's d_z* = 1.05, but when color repeated response repeats were

faster (498±22 ms) than response switches (522±23 ms), $t(23) = 3.76$, $p < .01$, *Cohen's d_z* = .77.

The location repetition × color repetition interaction was not significant, $F(1,23) < 1$, $p = .35$, η_p^2

= .04. Finally, the three-way location repetition × response repetition × color repetition

interaction was not significant, $F(1,23) < 1$, $p = .55$, $\eta_p^2 = .02$.

The effects of task. Crucially, turning to the effect of task, there was a main effect of task

with faster responses times in the detection (441±25 ms) as compared to the discrimination task

(592±25 ms), $F(1,23) = 74.23$, $p < .01$, $\eta_p^2 = .76$. There was a location repetition × task interaction,

$F(1,23) = 11.62$, $p < .01$, $\eta_p^2 = .34$. In the discrimination task, there was no difference in RTs

depending on whether location switched (591±26 ms) or repeated (593±23 ms), $t(23) = .24$, $p =$

.81, *Cohen's d_z* = .05, but in the detection task responses were faster when location switched

(423±24 ms) than when it repeated (460±26 ms), $t(23) = 7.22$, $p < .01$, *Cohen's d_z* = 1.47. There

was also a significant color repetition × task interaction, $F(1,23) = 9.23$, $p = .01$, $\eta_p^2 = .29$. In the

discrimination task, responses were faster when color repeated (577±23 ms) than when it switched (607±27 ms), $t(23) = 3.26$, $p < .01$, *Cohen's d_z* = .67, but in the detection task responses were no different depending on whether color repeated (445±26 ms) or switched (440±24 ms), $t(23) = .61$, $p = .55$, *Cohen's d_z* = .13. Task did not interact with response repetition, $F(1,23) < 1$, $p = .96$, $\eta_p^2 < .01$.

Importantly, there was a significant location repetition × response repetition × task interaction, $F(1,23) = 5.77$, $p = .03$, $\eta_p^2 = .20$. In the discrimination task, there were significant partial repetition costs, $F(1,23) = 11.29$, $p < .01$, $\eta_p^2 = .33$, whereas in the detection task they were either weak or non-existent, $F(1,23) = 3.34$, $p = .08$, $\eta_p^2 = .13$.

The was a significant response repetition × color repetition × task interaction, $F(1, 23) = 5.73$, $p = .03$, $\eta_p^2 = .20$. Within the discrimination task condition, the response repetition × color repetition interaction was significant, $F(1, 23) = 29.51$, $p < .01$, $\eta_p^2 = .56$. Within the detection task, the color repetition × response repetition interaction was also significant, though much smaller than in the discrimination task, $F(1, 23) = 6.02$, $p = .02$, $\eta_p^2 = .21$.

Finally, the task × location repetition × color repetition interaction, $F(1, 23) = 2.57$, $p = .12$, $\eta_p^2 = .01$, and the location repetition × color repetition × response repetition × task interaction were not significant, $F(1, 23) < 1$, $p = .46$, $\eta_p^2 = .02$.

As with Experiments 1 and 2, there was a significant difference in overall response times between the discrimination and detection tasks. Due to that, we once again re-analyzed the data from the detection task looking only at each participant's two slowest response time quartiles within each condition. Focusing on the interactions that included quartile as a factor. There was no quartile × location repetition interaction, $F(1, 23) = 2.60$, $p = .12$, $\eta_p^2 = .10$, no quartile × response repetition interaction, $F(1, 23) < 1$, $p = .34$, $\eta_p^2 = .04$, and no quartile × color repetition

interaction, $F(1, 23) < 1$, $p = .59$, $\eta_p^2 = .01$. The location repetition x response repetition was not

significant, $F(1, 23) = 2.55$, $p = .12$, $\eta_p^2 = .10$, and did not interact with quartile, $F(1, 23) < 1$, $p =$

.36, $\eta_p^2 = .04$. There was a response repetition $\times$ color x quartile interaction, $F(1, 23) = 5.44$, $p =$
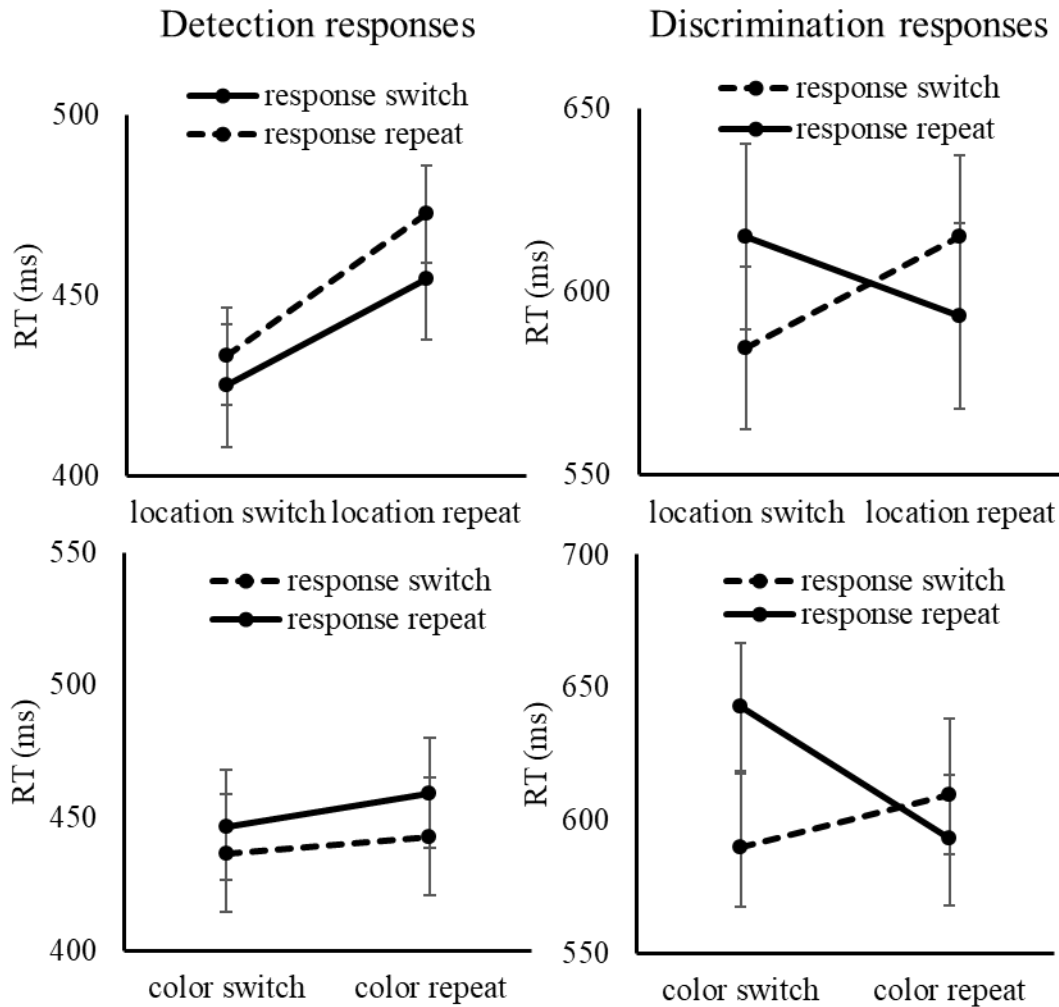
.03, $\eta_p^2 = .19$.

Figure 3. The results from Experiment 3 for the detection and discrimination. In typical PRC experiments both the location by response and color by response interactions are expected to be significant. Error bars represent the 95% confidence intervals of the mean color switch – color repeat effect within each response repetition condition (Pfister & Janczyk, 2013).

Within the 3rd quartile data, there was a response repetition × color repetition interaction, $F(1, 23) = 5.57$, $p = .03$, $\eta_p^2 = .19$. This interaction was a bit larger in the 4th quartile, $F(1, 23) = 8.06$, $p < .01$, $\eta_p^2 = .26$. None of the remaining three-way interactions or the four-way interaction neared significance, Fs < .88, ps > .35.

Discussion

In Experiment 3, we examined the role of feature-based attention in the partial repetition costs paradigm using a within subjects design that combined Experiments 1 and 2. Importantly, the overall data were mostly consistent with the prior two experiments. One exception is that, unlike the Experiment 1 quartile analysis, we did not find the color by location interaction overall or in the detection task alone (nor did the quartile analysis reveal such effects). This is notable since that interaction is unusual in the PRC paradigm and its lack of replication supports the idea it was a spurious effect in the Experiment 1 quartile analysis. In addition, two sets of findings are worth noting. First, in the discrimination task, we found no main effect of location repetition, but in the detection task responses were faster when location switched than when it repeated. This effect likely reflects inhibition of return which becomes obscured by feature integration effects in the discrimination task. In particular, in the discrimination task, location repetition interacted with response repetition such that, when location switched, response switches were faster than response repeats and, when location repeated, response switches numerically were faster than response repeats.

A second finding of note occurred in the discrimination task where there was a color repetition benefit that we did not find in the detection task. This effect was further modified by whether response repeated. In the discrimination task, there was a large color by response

interaction that is consistent with feature integration effects. That is, when color switched there was a large response switch cost and when color repeated there was a large response repetition benefit. This interaction was also present in the detection task, but was much smaller with a response switch benefit when color switched, but no response repetition benefit when color repeated. Though this interaction increased for longer response times, it is notable that the location by response interaction was still absent, which suggests that the longer response times are themselves not causing the increase in partial repetition costs. Instead, it is possible that trials in which participants made slower responses were trials in which participants failed to switch out of the color processing mode required for the first response and processed the color of the second stimulus. Taken together with how task affected the location by response interaction, we can conclude that, at the very least, feature integration is reduced in tasks that do not require feature-based attention.

General Discussion

In the current study, we investigated whether event file retrieval (e.g., Hommel, 1998) is dependent on feature-based attention; i.e., whether attention must be paid to a stimulus' identity before responding. To do this, we partly reversed the PRC paradigm such that participants first discriminated a stimulus's color and then made a prepared response to the subsequent stimulus. In this way, and unlike in the standard paradigm, the identity of the last stimulus in the sequence need not be attended. With this approach, we did not observe the typical PRCs involving location and responding and observed only weak evidence for a relationship between color and response repetition with the slower RTs. Instead, the dominant force was expressed as a location repetition cost that was unmodified by response and color repetition. This is a form of inhibition of return that is now known to be masked by PRCs when they are in effect (Hilchey, Rajsic et al., 2018;

Hilchey, Antinucci, Pratt & Lamy, 2019). When we restored the paradigm back to the typical

PRC paradigm, we observed the typical, robust PRCs at both the color and response, and

location and response levels. Finally, consistent with past results from detection, localization,

and discrimination response studies, we found no interactions between color and location in

either experiment (but see Hilchey, Pratt & Lamy, in press; Campana & Casco, 2009; Frings &

Moeller, 2010; for counterexamples from visual search).

Our findings are broadly consistent with previous research looking at the effects of

feature-based attention on event file retrieval. For example, event files involving task-relevant

features are more likely to be retrieved than those involving only task-irrelevant features. This

appears to be true when the task-relevant feature is manipulated between trial blocks (Hommel,

1998) or within trial blocks (Hommel et al., 2014). Our findings show further that even features

that are task-relevant within a trial are not obligatorily retrieved when the target stimulus does

not need to be identified. Furthermore, we demonstrated this in a paradigm that requires the same

stimulus processing and response demands as the typical PRC paradigm without switching

feature-based attentional control sets between trials. These findings, while consistent with our

previous findings (Hilchey, Rajsic et al., 2018; Huffman et al., 2018), go beyond them by

showing that stimulus identification is crucial during the retrieval phase.

It has been thought that orienting the attentional spotlight (Treisman & Gelade, 1980;

Treisman & Sato, 1990) onto or acting upon a stimulus (Hommel, 2004; Hommel, et al., 2001)

leads to event file retrieval when the current stimulus repeats any feature within an existing event

file. Recently, however, more focus has been given to the role of feature-based attention in event

file retrieval. Hommel et al. (2014), for example, demonstrated that changing the task-relevant

feature on a trial-by-trial basis changed which PRCs they observed. If color was task-relevant,

they observed larger color by response repetition interactions as compared to shape by response repetition interactions. If shape was task-relevant, they observed larger shape by response interactions as compared to color by response repetition interactions. Furthermore, this continued to be the case when the task-relevant feature was not known until after the first stimulus and response.

One way to interpret the findings from Hommel et al. (2014) is that attention or action towards the stimulus feature caused event file retrieval. Following retrieval, feature-based attention then modulated how strongly different features within the event file affected responding. A second possibility is that feature-based attention has a causal role in event file retrieval. That is, it is possible that attention needs to be oriented towards and engaged with a stimulus to cause event file retrieval. Indeed, the 'camera' metaphor of attention suggests that attention can be oriented to a stimulus without becoming engaged with it (Zivony & Lamy, 2016, 2018; see also, e.g., Posner, Walker, Friederich & Rafal, 1984). Our data support this latter possibility. In Experiment 1, it is likely that attention oriented towards the stimuli, given that it was a task-relevant onset (Folk, Remington, & Johnston, 1992), and the stimulus triggered an action. Despite that, we found no evidence of event file retrieval. This finding suggests a larger than previously understood role of feature-based attentional engagement in event file retrieval.

An important note regarding our suggestion that event file retrieval requires feature-based attention is that our study was not designed to look at stimulus-stimulus integration effects (i.e., form did not vary, see: Hommel & Colzato, 2004; 2009). It remains possible that interactions between, say, form and color, relate to early perceptual processing while integrating stimulus and response features requires feature-based attention. While the current study cannot speak to this issue, there is some evidence that this is not the case. For example, Experiment 2 of Hilchey,

Rajsic et al. (2018) added color as an irrelevant feature such that interactions between form and color were possible. Yet, saccadic reaction times were still unaffected by whether these features repeated or switched. Furthermore, there are studies in the attentional orienting literature where participants needed to localize or detect targets that could vary in color and shape and whether color and shape repeated or switched did not affect response times (Pratt & Castel, 2001; Tanaka & Shimojo, 1996; 2000; Taylor & Donnelly, 2002). If event file retrieval is related to low-level perceptual processes, then a PRC would have been expected. That said, it remains possible that event files are more effector specific than previously believed (Moeller et al., 2015), but even then, low-level perceptual integration effects would thus be confined to particular types of responses, making the effects seem decisional.

Another possibility is that event file retrieval does not reflect stimulus processing at all, but instead reflect processing related to making a decision about how to respond to the stimulus or its location. That is, PRCs may reflect decision-making heuristics that, while advantageous in real-world interactions, would lead to a cost in these lab-based experiments. Under most stimulus identification circumstances, a heuristic that facilitates repeating a response to a repeat stimulus or location would still be appropriate, assuming that repeating an old location or stimulus implies that repeating the prior response remains appropriate (Egner, 2014; Hilchey, Leber, & Pratt, 2018). Similarly, a heuristic that facilitates switching the response when the stimulus or location spontaneously vanishes and re-appears anew would likely also still be appropriate, assuming a new location or stimulus implies a different, more appropriate response. This is consistent with the recent proposal that there exists a metacontrol system that determines if and when event file retrieval occurs (Hommel, 2015; 2019; Hommel & Wiers, 2017). According to that view, whether or not event file retrieval occurs depends on whether conditions favor a

persistence/exploitation bias or a flexibility/exploration bias. In tasks that favor a persistence/exploitation bias, event file retrieval occurs. This includes the typical PRC task where participants have a goal to discriminate stimuli and decide between competing responses. In contrast, the critical response in the reverse version does require stimulus discrimination or deciding between competing responses, conditions that are unfavorable for a persistence/exploitation metacontrol state such that event file retrieval does not occur.[5]

Within the existing literature there are instances were PRCs are obtained in experiments with detection responses, but the mechanisms behind that PRCs are likely different than event-file retrieval. For instance, when participants need to simply detect a stimulus that have previously been associated with a prepared response, the prepared response interferes with stimulus detection when the stimulus is incompatible with the prepared response (Meiran, Pereg, Kessler, Cole, & Braver, 2014; Pfister, Heinemann, Kiesel, Thomaschke, & Janczyk, 2012). These effects, however, are likely due to the features needed to perceive the to-be-detected stimulus being included in a currently activated action plan, rather than event-file retrieval. In another related finding, Stoet and Hommel (1999) had participants prepare, but not execute, a response, had them complete a discrimination task, and then execute the previously prepared response. Most relevant for our current purposes is that feature overlap between the discrimination task and prepared response sped executing the prepared response, but only when there was a short time between the discrimination task and executing the prepared response. This

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[5] It is notable that, while we have been interpreting our data in terms of whether or not feature-based attention was necessary, it is also the case that the reversed PRC procedure essentially eliminated the response selection requirements to the final stimulus in the trial sequences. Therefore, we cannot rule out the possibility that whether or not response competition exists plays a role in whether event file retrieval occurs.

finding likely reflects priming of the prepared response by residual feature activation from the discrimination response, rather than event file retrieval.

When considering these results in a broader context, it is worthwhile considering the wide range of visual cognition tasks that are susceptible to PRCs. Generally, as shown here, it seems that any two-choice study requiring the identification of stimuli during the retrieval phase should be cognizant of potential contamination from PRCs. The current study, as well as other recent studies (Hilchey, Rajsic et al., 2018; Huffman et al., 2018), indicate that these problems can be alleviated by amending the designs to reduce the target identity processing requirements. Of course, in some cases, as in when the goal of the study is to understand feature-based attention, this may be impossible. In those cases, given how powerful these PRCs are, it is imperative that TEC be considered before interpreting data in terms of the question of interest.

Taking a broader perspective, we conclude by highlighting the important theoretical implications for understanding perception and action interactions that arise from this study. Prevailing theories of feature integration suggest that when a response is made to a stimulus the stimulus and response features are automatically bound into an event file. Then, if any bound stimulus and/or response feature is re-encountered then that event file will be retrieved automatically and affect how quickly a response can be made (depending on whether there is a full or partial repetition of those features). Our observations here, however, show for the first time that feature-based attention plays an important role for event file retrieval. How can this finding be accommodated by the event file concept within the TEC framework? We see two likely possibilities, essentially opposite sides of the same coin, on how this can be accomplished. On the one hand, when a task requires feature-based attention, the event file is retrieved which gives the response and/or feature selections a head-start prior to more fine-grained perceptual

analysis. This would allow for efficient processing in most everyday circumstances where objects' perceptual features mostly remain stable. On the other hand, when feature-based attention is not required and a preplanned response is being made, that preplanned response is created before the event file can be retrieved. This would be consistent with weak event file retrieval effects being observed in the slow response time quartiles of Experiment 1 and the reverse PRC condition of Experiment 3. Together, these would add an attentional prioritization role to how event files are retrieved (i.e., the presence or absence of feature-based attention modulates whether event files will be retrieved before or after a response is planned). Whatever the case may be, it is clear that the role of feature-based attention in event file retrieval warrants further investigation.

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