

Feature Overlap in Action Sequence

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Abstract

This study determined if features of an action plan held in working memory are activated to the same extent (consistent with serial memory theories) or in a gradient (consistent with theories that assume serial order is imposed prior to response selection). Two visual events (A and B) occurred in a sequence. Participants planned an action (3-finger, key sequence) to the first event (Action A) and maintained this action in working memory while executing a speeded response (1-finger key-press) to the second event (Action B). Afterwards, participants executed Action A. We manipulated whether Action B overlapped with the first, second or final feature of Action A, and examined the pattern of correct, Action B RTs at the different overlap locations by finger (index, middle, ring), as well as the error rates of both Action A and Action B. Results indicate that 3-finger sequences were not activated equally or in a gradient. Instead, feature activation reflected a serial position curve or a reverse serial position curve dependent on finger.

Keywords: feature overlap, cognitive interference, action planning, partial repetition costs

Introduction

Everyday actions such as reaching for a water glass or preparing a meal require action planning; one must decide what to do and when to do it (Keele, 1968; Lashley, 1951). In some cases action plans can be comprised of complicated sequences that must be planned, like preparing a meal (Rhodes, Bullock, Verwey, Averbeck, & Page, 2004). When carrying out these action sequences, some elements of the sequence need to be held in memory, while others are being executed (Logan, 2004; Schneider & Logan, 2006). Various theories provide different ideas as to how these action elements are represented in memory. There are theories of serial memory, which posit that all action features within an action plan are activated equally and simultaneously (Crump & Logan, 2010; Hartley & Houghton, 1996; Lashley, 1951; Rosenbaum, Inhoff, & Gordon, 1984). These theories assume that serial order may be imposed later, during response selection and execution. On the other hand, there are theories that postulate that earlier features within the action plan are more active than later ones, creating a gradient of activation in working memory (WM) that preserves serial order (Averbeck, Chafee, Crowe, & Georgopoulos, 2002; Page & Norris, 1998; Dell, Burger, & Svec, 1997; Rhodes et al., 2004). How the features of an

action plan are represented in WM was investigated in the current study.

Research consistent with theories of serial memory has shown that highly skilled, hierarchically controlled tasks, such as speaking or typing, appear to activate all action features within an action plan in parallel (Rosenbaum, Inhoff, & Gordon, 1984; Crump & Logan, 2010; Logan, Miller, & Strayer, 2011). Crump and Logan (2010) gave skilled typists words five to seven letters long as a prime, followed by either a repeated exposure to the same word that typists had to re-type or a single-letter prompt they had to type. If the single-letter prompt was given, it was the first, middle, or last letter of the original word, or it was a completely unrelated letter. Results showed that the single-letter prompt was typed faster if the letter appeared in the original word, and that priming was greater for the first letter than for the middle or last letters - with no difference in priming between the middle and last letters. This suggests that the original word primed all the letters in the word sequence. The authors assumed that activation of the first letter was greater due to priming, likely because it needed to be typed first. They stated that since the middle and last letters were activated to a similar extent, that their results support the idea of equivalent parallel activation of features. They argue that their findings are consistent with models that suggest equivalent, parallel activation with serial order determined at response selection (Crump & Logan, 2010; Hartley & Houghton, 1996; Lashley, 1951; Rosenbaum, Inhoff, & Gordon, 1984).

In contrast, some models assume that serial order is determined by a gradient of parallel feature activation (Dell et al., 1997; Page & Norris, 1998; Rhodes et al., 2004). These models assume that tasks that are less practiced may produce a primacy gradient of parallel feature activation in which each successive feature in the sequence is activated less than the preceding one (Rhodes et al., 2004; Dell et al., 1997; Page & Norris, 1998). Neurophysiological evidence for this model is provided by Averbeck, Chafee, Crowe, & Georgopoulos (2002), who trained rhesus macaque monkeys to draw geometric shapes (e.g. triangle, rhombus) using a specific line segment order. The researchers first identified patterns of neural activity in the prefrontal cortex that corresponded to the drawing of each segment, and then recorded activity from these neurons just prior to and during the time in which the monkeys drew a shape. They found that prior to executing the segments, the neurons associated

with the different segments of the shape were activated in parallel, and the strength of activation was highest for neurons corresponding to the first segment drawn, followed by a decrease in neuronal activation corresponding to each subsequent segment drawn, revealing a gradient of activation of features within the action plans.

Other evidence supporting the idea that feature activation within an action plan may follow a gradient is provided by Fournier, Gallimore, Feiszli, and Logan (2014). They used a partial repetition paradigm (Stoet & Hommel, 1999). In this paradigm, two stimuli were presented in a sequence. Participants were instructed to plan an action to the first stimulus and hold it in memory while they perceived and responded to a second stimulus. After they responded to the second stimulus, they executed the response of the action plan maintained in memory. Previous research showed that the execution of an action plan can be delayed if there are features of that plan that partially overlap with features of another action plan currently maintained in WM, relative to when there is no overlap between action plans (e.g., Stoet & Hommel, 1999; Wiediger & Fournier, 2008). This delay in responding is referred to as partial repetition costs. Partial repetition costs are assumed to occur when a feature code from the current action plan reactivates (primes) the action plan maintained in WM (Hommel 2004; Fournier et al., 2014). Reactivating the action plan retained in WM leads to temporary confusion as to which action plan is relevant for the current task: the current plan or the plan maintained in WM (Hommel 2004; 2005; Mattson & Fournier 2008, Fournier et al., 2014). Fournier et al. (2014) found partial repetition costs when the current action overlapped with the first feature of the action sequence maintained in WM, but no significant costs when the overlap was on the last feature. Partial repetition costs were used to measure activation strength of each feature in the action feature sequence within an action plan. Larger partial repetition costs (or greater reaction times [RTs]) when overlap is on a particular feature, are indicative of higher activation of that feature compared to others in the action plan; lower costs (lower RTs) are indicative of less activation of that feature. The authors concluded that the features of an action plan are not activated to the same degree in WM. Rather, the first feature of the action plan is activated to a greater extent than the last feature, consistent with a gradient of activation.

However, a limiting factor of the Fournier et al. (2014) study is that there were only two action features representing the action plan maintained in WM (e.g., move joystick “left” then “up”). As a result, it is not clear whether this pattern of activation truly follows a gradient of activation (Dell et al., 1997; Page & Norris, 1998; Rhodes et al., 2004) or if there is just something special about the first feature (Dell et al., 1997; Crump & Logan, 2010). The present study investigated whether action plans are represented by a gradient of feature activation in memory by improving upon Fournier et al.’s design. Participants in this study maintained action plans that consisted of three features, as opposed to two features. The advantage of

using a partial repetition paradigm to understand how action plans are represented in working memory is that it allows insight into the representation of an action plan prior to execution.

A modification of the partial repetition paradigm (Stoet & Hommel, 1999) was employed to determine if features of an action plan maintained in WM are represented by a gradient of activation or whether the first feature in the action sequence has a higher level of activation than other features in the sequence which do not differ in activation strength (no gradient). Participants planned an action to the first stimulus event (Event A) and maintained this action plan in WM while waiting for the presentation of a second visual event (Event B) that required an immediate speeded response. After participants executed the response to Event B, they executed the planned action for Event A. The main manipulation was whether response to Event B overlapped with the first, second, or third response in the action sequence planned for Event A. If features of an action plan maintained in WM are activated in a gradient, then response RTs to Event B (Action B) should differ based on whether Action B overlaps with the first, second, or third feature of the action plan maintained in WM (Action A). Specifically, Action B RTs should be slowest when it overlaps with the first feature, intermediate when it overlaps with the second feature, and fastest when it overlaps with last feature of Action A. If instead, there is not a gradient of activation but rather just something special about the first feature, there should be higher activation for the first feature relative to the second and third features, and equivalent activation between the second and third features.

Methods

Participants

Forty-four undergraduates from Washington State University participated for optional extra credit in psychology courses. This study was approved by the Washington State University Institutional Review Board, and informed consent was obtained. All participants were right-handed and had at least 20/40 uncorrected or corrected visual acuity assessed using a Snellen eye chart.

Apparatus

Instructions and stimuli were presented on a computer screen 61 cm from the participant. Key-press responses were collected using a standard keyboard. The keys 7, 8, and 9 on the keyboard were covered with white stickers, and were used to record responses from the index, middle, and ring finger of the right hand respectively. The space bar on the keyboard was pressed by the thumb of the right hand to initiate each trial and the pinky finger rested on the P key. The participants’ right hand placement on the keyboard and space bar were consistent throughout the task.

Event A was a sequence of three different boxes lighting up. The three boxes were arranged in a horizontal array centered one half centimeter above a white fixation cross at the center of the screen. The boxes were each two

centimeter squares, spaced a half centimeter apart from one another. The sequence in which the three boxes lit up varied, and each box lit up once in the sequence (i.e. “left box–right box–middle box”). Event A required a three key-press response using the index, middle and ring fingers of the right hand. Finger mappings for this response were always spatially compatible where the first box corresponded to the index finger, the middle box corresponded to the middle finger, and the last box corresponded to the ring finger. Participants planned and maintained an action for Event A in the reverse order in which the Event A stimuli appeared. For example, if the light stimulus appeared first in the right box, then in the middle box, followed by the left box, then the participant planned to press the key corresponding to the left box first (index finger), then the middle box (middle finger), followed by the right box (ring finger).¹

Event B was a left arrowhead (<), a circle (O), or a right arrowhead (>) centered one half centimeter below the fixation cross. Each symbol measured two centimeters in height. Event B required a speeded double key-press response with the index, middle, or ring finger of the right hand, dependent on the particular symbol presented. Participants responded with a double key-press with the index finger to the right arrowhead, a double key-press with the middle finger to the circle, and a double key-press with the ring finger to the left arrowhead. These finger mappings were consistent across all participants.

Procedure

All stimuli appeared on a black background. The sequence of events for each trial is presented in Figure 1. A white fixation cross occurred in the center of the screen and remained throughout the trials. When initiating a trial by pressing the space bar, the fixation cross appeared for 1000ms followed by a horizontal array of three boxes above the fixation cross (Frame A₀). After this, Event A (Frames A₁, A₂, and A₃) appeared for 1200ms above the fixation cross, followed by the fixation cross alone for 1500ms. During this inter-stimulus interval, participants were instructed to plan their response (Action A) to the lighted box sequence (Event A). Event B then appeared for 50ms below the fixation cross followed by a blank screen which appeared until a response to Event B (Action B) was detected, or for 1300ms in the absence of a response.

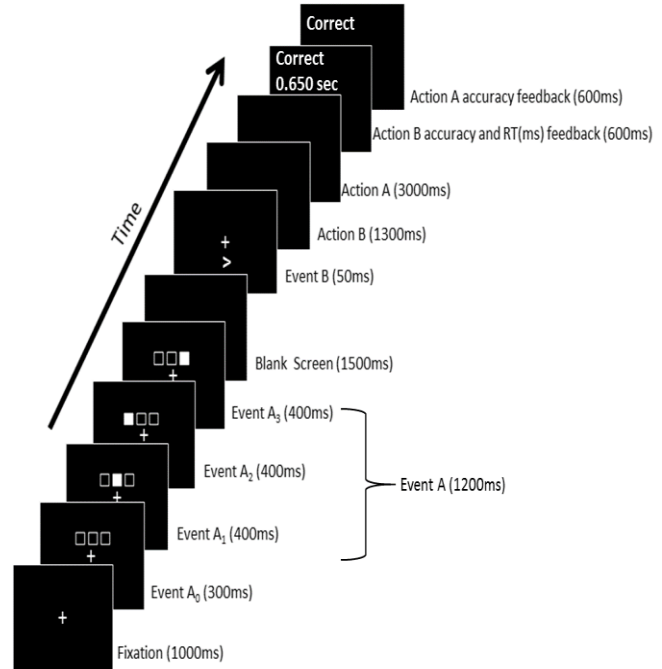


Figure 1: The sequence of events for each trial.

Following Action B, a blank screen appeared until Action A was executed, or up to 3000ms. Participants were instructed to respond to Event B (Action B) as quickly and accurately as possible. They were instructed to then execute their response to Event A (Action A) maintained in memory as accurately as possible. Following the execution of Action A, reaction time (RT) and accuracy feedback for Action B was presented (600ms), followed by accuracy feedback for Action A (600ms). The initiation screen, with the instructions “Press Space Bar to continue,” then appeared until the next trial was initiated. The next trial began when participants pressed the space bar on the keyboard with their right thumb.

Both RT and accuracy for Action B were measured. Action B RT was measured from the onset of Event B until the first key press response was detected. Only accuracy was measured for Action A. Participants were instructed to not execute Action A until after executing Action B. Participants were also instructed not to use any finger movements or other external cues to help them remember Action A, but instead to hold this action plan in memory. Those who used body movements or other external cues (identified via post-task questionnaire) were eliminated from data analyses (eight participants), as they did not follow instructions. Additionally, any participants with an overall task accuracy below 80% were excluded (two participants). Data were analyzed for the remaining thirty-four participants.

Feature overlap between Action B and Action A was manipulated within participants. Action B, executed with the index, middle, or ring finger overlapped with the first, second, or third response feature of Action A. All possible

¹ The box sequence was chosen as a stimulus after many pilot studies were run that included stimuli with response associations that proved to be too complex for participants to learn. These included, but are not limited to, colored shapes and number sequences. It would be possible to train participants to provide sufficient practice for them to learn more difficult tasks; however it was important to the study that responses not be highly automatic. Additionally, participants responded to the reverse box order in attempt to make sure participants’ working memory was being sufficiently engaged by the task, as pilot studies indicated that responding to the same order was too easy of a task to elicit significant interference effects.

stimuli for Action A and Action B were equally paired together, and feature overlap (first, second, or third feature) occurred with equal probability in a random order in each block of trials. Participants completed 24 practice trials followed by ten blocks of 24 experimental trials.

Results

A 3 X 3 repeated measures analysis of variance (ANOVA) with the within-subjects factors of feature overlap (first, second, or third) and finger (index, middle, or ring) was conducted separately on the correct RTs for Action B, percentage of errors for Action B, and the percentage of errors for Action A. Analysis of mean RTs for Action B was restricted to trials in which Action B and Action A were both executed accurately. Analysis of Action B error rate was restricted to trials in which Action A was executed accurately. All comparisons between means were conducted using Bonferroni Pairwise Comparisons ($p < .05$). Figure 2 shows the mean correct RTs and correct error rates for Action B. As is evident in the figure, RTs based on feature overlap varied, and this RT pattern differed depending on which finger was used to respond.

Action B There was a significant main effect of feature overlap [$F(2,32)=8.51$, $p < .01$, $\eta^2=.21$], and of finger [$F(2,32)=42.65$, $p < .01$, $\eta^2=.56$], and a significant interaction between these two factors [$F(4,30)=8.63$, $p < .01$, $\eta^2=.21$] for RT. For the middle finger, the pattern of responses across feature overlap conditions (see Figure 2) resembled a serial position curve, while the pattern for the index and ring finger responses resembled a reverse serial position curve. Pairwise comparisons conducted on the main effect of finger showed that RT for the index and ring fingers were overall slower compared to the middle finger ($ps < .01$), while index and ring fingers did not differ from one another ($p=.56$). Moreover, pairwise comparisons conducted on the interaction showed the following. For the middle finger, RTs were significantly slower when Action B overlapped with Action A on the third feature ($M=652$ ms) compared to the second feature ($M=624$ ms; $p < .01$), and RT for the first feature overlap condition ($M=640$ ms) was not significantly different than the second or third feature overlap conditions ($p=.09$, $p=.19$ respectively). For the index finger, RTs were significantly slower when Action B overlapped with Action A on the second feature ($M=718$ ms) compared to the first feature ($M=685$ ms; $p < .01$), and RTs for third feature overlap condition ($M=703$ ms) were not significantly different than first ($p=.17$) or second ($p=.13$) feature overlap conditions. For the ring finger, RTs were significantly slower when Action B overlapped with Action A on the second ($M=726$ ms) and third feature ($M=705$ ms) compared to the first feature ($M=686$ ms; $p < .01$; $p=.05$, respectively), and RTs were not significantly different between the second and third feature overlap conditions. These results suggest that the amount of feature activation within the planned action sequence was not equal across the first, second, and third feature overlap conditions. Also, the

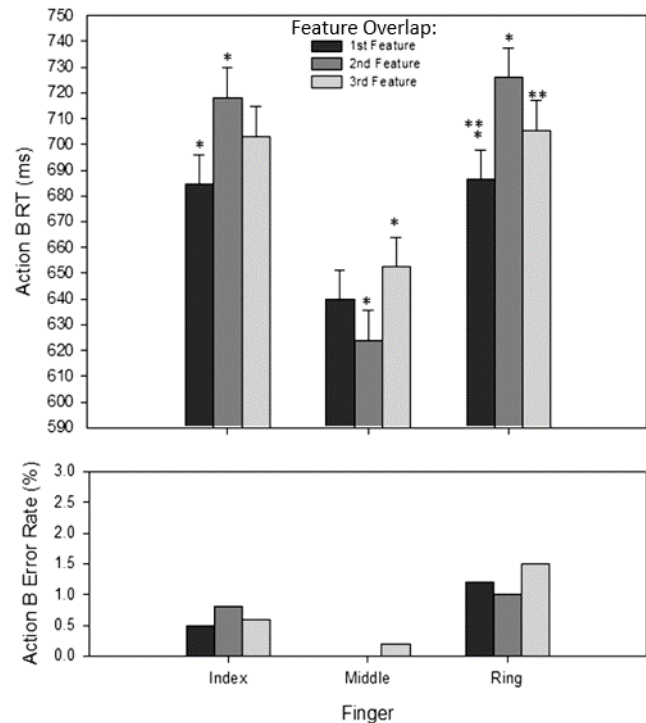


Figure 2: Feature Overlap. Action B correct reaction times (RTs) and percent error rates for each Action B finger response (index, middle, and ring) when Action B overlapped with Action A on the first, second, or third feature.

finger used to respond to Action B influenced the speed of Action B responses and the pattern of Action B responses found across feature overlap conditions.

Mean error rate was small, only 1%. There was a significant effect of finger [$F(2,32)=6.31$, $p < .05$, $\eta^2=.16$] for error rate. However, the main effect of feature overlap ($F < 1$) and the interaction between feature overlap and finger ($F < 1$) were not significant. Pairwise comparisons conducted on the main effect of finger showed that error rate for the middle finger was significantly smaller than that for the index finger ($p=.04$) and the ring finger ($p=.01$). These results suggest that the Action B RT interpretations above are not due to a speed-accuracy tradeoff.

Action A Mean error rate was 12%. There was a significant main effect of feature overlap [$F(2,32)=5.72$, $p < .01$, $\eta^2=.15$] and a significant interaction between feature overlap and finger [$F(4,30)=2.52$, $p=.05$, $\eta^2=.07$] for error rate. There was no main effect of finger [$F(2,32)=0.20$, $p=.82$, $\eta^2=.006$] on error rate. Pairwise comparisons conducted on the interaction showed the following. For the ring finger, error rates were significantly greater when Action B overlapped with Action A on the first feature ($M=13%$) and second feature ($M=17%$) compared to the third feature ($M=9%$; $p=.05$; $p < .01$, respectively). For the index finger, error rates did not significantly differ across the first ($M=12%$), second ($M=15%$), or third ($M=10%$)

feature overlap conditions ($ps > .08$). For the middle finger, error rates also did not significantly differ across the first ($M=13\%$), second ($M=11\%$), or third ($M=12\%$) feature overlap conditions, (all $ps=1.0$). The error rate in recalling Action A across the feature overlap conditions resembles a serial position curve for the middle finger and a reverse serial position curve for the index and ring fingers – although this pattern was not significant. This error rate pattern was similar to the pattern of RTs found for Action B. This suggests that both responding to Action B and recalling Action A were similarly affected by feature overlap.

Discussion

In summary, results revealed differences in Action B performance when Action B overlapped with Action A on the first, second, or third feature in the Action A sequence. Also, the differences in Action B performance across the action overlap conditions varied depending on the finger involved in executing Action B. The results suggest that features of the action sequence maintained in WM have different levels of activation. However, the predicted gradient of activation was not found. Instead the pattern of activation resembled a serial position curve for actions executed with the middle finger, and a reverse serial position curve for actions executed with either the index finger or ring finger. Importantly, variable activation across action features within an action plan is not consistent with serial memory models that assume equal activation of features within an action plan (Crump & Logan, 2010; Hartley & Houghton, 1996; Lashley, 1951; Rosenbaum, Inhoff, & Gordon, 1984), or those models that assume features are activated in a gradient (Averbeck, Chafee, Crowe, & Georgopoulos, 2002; Page & Norris, 1998; Dell, Burger, & Svec, 1997; Rhodes et al., 2004).

The current findings are consistent with Fournier et al. (2014) in that they also showed unequal activation between conditions of feature overlap on the first feature and second feature. More specifically, they found higher activation of the first feature of an action plan than the second, which is consistent with the results of the middle finger in the present study. However, the pattern for the index and ring fingers showed the opposite pattern. It is unclear, given the design of their study, if the response pattern they got would have represented a serial position curve if they had included a third feature overlap condition in their study.

There were some differences in design between the current study and Fournier et al. (2014) that may account for the different feature activation patterns. In their study, the design used a more fluid joystick response to execute the action being maintained in working memory, compared to the more distinct key-press movements of this study. For example, actions requiring a left and upward response were carried out by moving a joystick with the right hand to the left and then upward. In the current study, fingers were mapped to particular keys, and required three very distinct key-presses using different digits on the right hand. It is possible that fluid movements within an action plan are

represented differently than discrete movements within an action plan. For example, action features representing fluid movements may be more strongly associated within a single action plan (e.g., Fournier & Gallimore, 2013). Also, in the Fournier et al. study, participants were taught to associate certain stimuli with directional movements (e.g. left-up), and those directional movements were spatially congruent with the physical movement they executed with the joystick. This was also true in the current study, however, most participants (87%) subjectively reported (via questionnaire) representing the sequence of finger movements in memory as numbers (index as 1, middle as 2, ring as 3). It is possible that differences in how the action plan is represented could have contributed to differences in response patterns.

The different Action B response patterns found across feature overlap conditions dependent on response finger may be simply due to the faster Action B responses for the middle finger versus the index and ring fingers. This response speed difference may be attributed to differences in discriminability among the stimuli mapped to the middle versus the index and ring fingers. It may also be due to the differences in the speed at which one can execute a motor response with the middle finger versus the index and ring fingers. Why the different response patterns occurred across feature overlap conditions based on the overall speed of the Action B response is an interesting question for future research. In a follow-up experiment (not reported here), Action B was reduced to two responses (index and ring finger based on direction of arrowheads), and the same feature overlap patterns for the index and middle fingers were found. Other follow-up experiments investigating the different feature overlap patterns across fingers (i.e., whether due to the actual finger or the spatial representation of finger response) are in progress.

One important limitation of the current study is that we could not be certain that participants represented the Action A sequence (the reverse box order of Event A) in WM or the Event A sequence (the forward box order of Event A) in WM prior to executing Action B. This is currently being addressed in follow-up experiments via post-task survey. Also, we do not know if the activation patterns found in this study are limited to the stimulus and responses used in this study or whether they will generalize to other types of stimuli and responses.

The serial-position curve pattern of activation found across the different feature overlap conditions for middle finger responses is similar to that found in a comparable study by Mushiake, Saito, Sakamoto, Itoyama, & Tanji (2006), though the patterns found across the index and ring fingers both show the opposite pattern. Importantly, the features within the action plan maintained in WM showed variable activation, indicating that these action features maintained in WM were not equally activated.

In summary, this study shows variable patterns of activation across multiple features within an action plan maintained in working memory. This study also provides additional evidence that serial order is represented prior to

response execution in that the different patterns of activation across features were not equal. This contradicts both serial order models that predict equal activation across all features, and those that predict a gradient of activation across features. Specific patterns of feature activation might be dictated by task goals, the response requirement of the task, or how one is representing the task goals themselves.

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