PROXIMAL AND DISTAL EFFECTS IN

ACTION PLAN REPRESENTATION

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Abstract

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The current study examined whether an action plan based on stimulus discrimination can be represented by action features corresponding to the perceptual effects of an action (distal features) - when both proximal features (action features corresponding to the motor movements of an action) and distal features were available. And if so, can an action plan represented by distal features reside in a similar cognitive domain as an action plan represented by proximal features. Participants planned and held a series of key presses (with their right or left hand), according to the identity of a stimulus (A), and then immediately executed a key press response (with their right or left hand) to a second stimulus (B). Past research has found that when the action plan held in memory (Action A) and the intervening action plan (Action B) share an action feature (partial feature overlap), the reaction time for Action B can be delayed (a partial repetition cost) compared to when they do not share an action feature (no feature overlap). Across experiments, spatial compatibility of proximal and distal features were manipulated [i.e., these features were spatially compatible (Experiment 2) or spatially incompatible (Experiment 3)]. Results showed partial repetition costs for partial feature overlap between proximal features when Action A could be represented by only proximal features (Experiment 1) or spatially compatible proximal and distal features (Experiment 2). However when Action A could be represented by spatially incompatible proximal and distal features (Experiment 3), no partial repetition costs were observed. When debriefed, most participants explicitly represented Action A with proximal features. Therefore, spatially incompatible distal features in Experiment 3 may have been implicitly represented in Action A because the presence of distal features eliminated partial repetition costs. Taken together, these results suggest that an action plan based on stimulus discrimination can be represented by proximal features (explicitly) and distal features (implicitly) when both features were available and these features were represented in a similar cognitive domain. These results are not consistent with the theory of action control proposed by Herwig and colleagues but are consistent with the Theory of Event Coding.

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INTRODUCTION

People routinely use action plans when doing everyday tasks such as drinking from a glass, typing on a keyboard, or using a smart phone; yet, psychology does not have a thorough understanding of how action plans are structured and represented. Action plans are assumed to be the instructions representing action operations that are structured before the action is executed to guide the entire action sequence (Jeannerod, 1997; Keele, Cohen, & Ivry, 1990; Wiediger & Fournier, 2008). Numerous theories have been proposed that discuss how action plans are formed, represented, and executed (e.g., Perception-Action model, Goodale, 2010; Stimulus-based and Intention-based action control systems, Herwig, Prinz, & Waszak, 2007; Theory of Event Coding, Hommel, Musseler, Aschersleben, & Prinz, 2001; Ideomotor theory, James, 1890; Hierarchical action control, Logan & Crump, 2009; Common Coding, Prinz, 1990; Competitive Queuing model, Rhodes, Bullock, Verwey, Averbeck, & Page, 2010; Hierarchical Editor model, Rosenbaum, Inhoff, & Gordon, 1984). Many of these theories recognize a distinction between two types of actions (e.g., sensorimotor actions based on stimulus-response associations and ideomotor actions based on action-effect associations). However, these theories differ in their assumptions as to whether or not the action plans for sensorimotor and ideomotor actions are represented in a similar cognitive domain (i.e., the action systems interact) or different cognitive domains (i.e., the action systems do not interaction).

Some action control theories suggest that actions represented by proximal features (sensorimotor learning) and actions represented by distal features (ideomotor learning) share a cognitive domain (e.g., Theory of Event Coding, Hommel et al., 2001; or Common Coding, Prinz, 1990). The Theory of Event Coding assumes that action plans can be represented by the features corresponding to the motor movements (i.e., proximal features; sensorimotor learning) and/or the perceptual effects (i.e., distal features; ideomotor learning) of an action (Hommel et al., 2001). For example, checking email on a smart phone could be represented by a sequence of arm and finger movements (proximal features) and/or the perceptual outcome of seeing the email screen (distal features). In contrast, other action control theories suggest that actions represented by proximal features (sensorimotor learning) and actions represented by distal features (ideomotor learning) do not share the same cognitive domain (e.g., Stimulus-based and intention based action control, Herwig et al., 2007; Herwig & Waszak, 2009). The theory of action control proposed by Herwig et al. (2007) assumes that action plans can be represented by stimulus-based action control (i.e., proximal features; sensorimotor learning) or intention-based action control (i.e., distal features; ideomotor learning). For example, seeing a red light and pressing the brakes could be represented in the cognitive domain for stimulus-based actions; whereas, finding a parking spot could be represented in the cognitive domain for intention-based actions. The current study focused on the representation of deliberative actions and examined whether an action plan based on stimulus discrimination can be represented by the distal features of the action when both proximal and distal features are available. If so, can this action plan be represented in a similar cognitive domain (as suggested by the Theory of Event Coding, Hommel et al., 2001; and Common Coding, Prinz, 1990) as an action plan represented by the proximal features.

The Theory of Event Coding (Hommel et al., 2001) assumes that the codes representing action features and perceptual features of an action are bound together to form an event file, or an action plan. Action features are assumed to be the most basic unit of meaningful, intentional action such as moving a limb “left”, “right”, “up”, and “down”; whereas, perceptual features are the characteristics of a stimulus such as the identity, orientation, spatial location, or movement direction of a stimulus. The Theory of Event Coding also assumes that action features can be coded in terms of proximal features that represent the motor movements of the action (e.g., moving your left arm up, grasping a lever, and pushing the lever up), consistent with Sensorimotor theory, and actions can be coded in terms of the distal features that represent the perceptual effects of the action (e.g., activating the right turn signal light on your car), consistent with Ideomotor theory. Much of the evidence in support of the Theory of Event Coding is based on actions generated from learned stimulus-response associations.

Whether an action plan is represented by proximal features or distal features may depend on the task goal. For example, Cattaneo, Caruana, Jezzini, and Rizzolatti (2009) showed that different action features were activated when participants watched an experimenter manipulating pliers with different goals. They used two types of pliers (normal and reverse) that required opposing finger movements to perform the same operation. When participants observed an experimenter manipulating the pliers to pick up a peanut, the Motor Evoked Potential (MEP) of the right thumb muscle of participants was consistent with the closing-action of the pliers to pick up the peanut (distal features), regardless of the motor movements needed to operate each type of pliers (closing or opening of one's grip; proximal features). In this case, the action plan was represented by the perceptual effects of the action (distal features), or the goal of picking up the peanut, and not the motor movement goals needed to operate the pliers (proximal features). However, when participants watched the experimenter operate the pliers alone or participants imagined operating the pliers, then the MEP recorded was consistent with the motor movements (proximal features) needed to operate the pliers. The results of Cattaneo et al. (2009) show that action plans can be represented by distal features or proximal features. Moreover, results by

Cattaneo et al. (2009) suggest that when both distal and proximal features were available, action plans were represented by the perceptual effects of an action (distal features) as opposed to the motor movements needed to execute an action (proximal features).

Other evidence indicates that action plans may be represented by either proximal features or distal features depending on task goals. Hommel (1993) presented high and low tones either to the left or right of participants, and reverse mapped lights to buttons so that a left button illuminated a right light and a right button illuminated a left light. Half of participants were instructed to respond to the tones with a left- or right- button press (button-instruction group; proximal features). The other half of participants were instructed to respond to the tones by illuminating the left or right light (light-instruction group; distal features). As expected, participants in the button-instruction group responded faster and more accurately when the button press and tone were spatially compatible compared to spatially incompatible (Simon, 1969). However, participants in the light-instruction group responded faster and more accurately when the light and tone (not the button press and tone), were spatially compatible compared to spatially incompatible (Hommel, 1993). This result shows that the perceptual effects of illuminating the lights (distal features) or the motor movements for pressing the buttons (proximal features) can be represented in the action plan, and the type of features used to represent an action plan depends on the goal of the task. Similar to Cattaneo et al. (2009), these findings indicate that action plans can be represented by the features corresponding to the perceptual effects of an action (illuminating a left or right light; distal features) or the features corresponding to the motor movements needed to execute an action (pressing a left or right button; proximal features). What participants attended to, or perceived as the goal, (e.g., proximal features based on stimulus discrimination versus distal features based on stimulus discrimination) may determine how an action plan is represented.

Herwig et al. (2007) suggests that whether an action plan is represented by proximal or distal features depends on whether the action plan is exogenous (stimulus driven; e.g., a red or green box indicating a left or right key press, respectively) or endogenous (internally generated; e.g., flipping a mental coin to indicate a left or right key press), respectively. In addition, they assume that exogenous and endogenous action plans are represented in separate cognitive domains by different action control systems: one that is stimulus-based and one that is intention-based, respectively. The action plans for stimulus-based action control are represented by the proximal features needed to execute that action because the goal is to execute a specific motor sequence when a particular stimulus is present. For example, hearing a particular tone may require a specific key-press response; seeing a red stoplight elicits a braking behavior in drivers. In the intention-based action system, action plans are selected and controlled by internally generated goals. The action plans for intention-based action control are represented by the perceptual effects or the anticipated perceptual effects (distal features) of an action because the goal of the action is to achieve a specific effect within the environment. For example, writing an email may elicit the goal of the communicating ideas to another person, or making a right turn in a car may elicit the goal of activating the right turn signal.

Evidence that stimulus-based actions and intention-based actions belong to separate cognitive domains comes from an experiment by Herwig et al. (2007). Participants were assigned to one of three groups: intention group (self generated key presses), spatial group (key presses corresponded to the spatial location of a stimulus), or arbitrary group (key presses corresponded to the color of a stimulus). Participants made left or right key presses that were followed by high or low tones. After being exposed to several hundred trials of specific key-tone pairings (e.g., a right key press elicited a high tone), participants completed a test phase where they responded to the tones with key presses. In the test phase, half of the participants in each group were instructed to press the key that corresponded to each tone (compatible group) and the other half in each group were instructed to press the key that did not correspond to each tone (incompatible group). Results showed that only the intention group (distal features) responded consistently faster to the tones when the key-tone mappings were compatible versus incompatible which suggests that only the intention group learned the key-tone pairings during training. Herwig et al. (2007) argued that when an action is driven by the identity of a stimulus (spatial and arbitrary group), sensorimotor learning occurs and proximal features are represented in the action plan as opposed to distal features. In contrast, when the identity of a stimulus does not drive an action, but the action consistently leads to a specific action effect (intention group), ideomotor learning occurs and distal features are represented in the action as opposed to proximal features. This result led Herwig et al. (2007) to suggest that ideomotor learning (i.e., linking the tones to the key presses) applies to internally generated actions (distal features) in an intention-based system, and sensorimotor learning applies to externally generated actions (proximal features) in a stimulus-based system.

However, a more parsimonious explanation of Herwig et al. (2007) is that the salience of the stimuli and responses influenced how participants represented the goal of the task. During the acquisition phase, participants in the spatial and arbitrary groups likely focused attention only on the stimuli that indicated the correct key press [i.e., the red or green squares (arbitrary group) or the square location (spatial group)] and did not attend to the tones that followed the key presses because the stimuli - and not the tones - were necessary to perform the task. Furthermore during the test phase, participants in the spatial and arbitrary groups were not shown the stimuli used during the acquisition phase. During the acquisition phase, it is possible that the action plan representations of participants incorporated all of the features of the action into one event (e.g., visual, auditory, and tactile information). When the events in the test phase only included some of the features from the events in the acquisition phase, performance could be negatively affected (i.e., incorrectly recalling which key was associated with which tone) due to a partial match between events in the acquisition and test phase.

Furthermore, recent research by Janczyk, Pfister, Crognale, and Kunde (2012) showed that actions based on stimulus discrimination can be represented by the perceptual effects of those actions (distal features) or the motor movements needed to execute those actions (proximal features). They had participants perform a mental rotation task and then execute a manual rotation task. When a left or right manual wheel rotation (proximal features) was cued by the color of the hull of an airplane, the mental rotation task facilitated spatially compatible manual wheel rotations. That is, manual wheel rotations were faster when the mental rotation and the manual wheel rotation moved in the same direction compared to different directions. However when a left or right manual wheel rotation (proximal features) was cued by one of two types of attitude indicators (i.e., horizon or plane), the mental rotation task facilitated spatially compatible attitude display rotations (distal features) but not manual wheel rotations (proximal features). That is, manual wheel rotations were faster when the mental rotation task and attitude display rotated in the same – not the opposite – direction. This result was observed despite the horizon attitude display rotating in the opposite direction of the manual wheel rotations (i.e., a right wheel rotation resulted in a left horizon display rotation). The results from Janczyk et al. (2012) suggest that action plans can be represented with proximal features (i.e., the manual wheel rotation in Experiment 1) or distal features (i.e., the attitude display rotations in Experiment 3) depending on the task goal. In contrast to the action system distinction made by Herwig et al., (2007), Janczyk et al. (2012) used stimulus-based actions (i.e., actions were based on discriminating the letter orientation, airplane hull color, and display type/position) and found that action plans were represented with action features corresponding to the anticipated perceptual effects (distal features) of the manual wheel rotation (i.e., the attitude display rotations) not the action features corresponding to the motor movements needed to manually rotate the wheel (proximal features).

Taken together, past research suggests that action plans can be represented by proximal features or distal features. However, it is not clear whether externally generated action plans (i.e., those based on stimulus discrimination) are necessarily represented by proximal features as opposed to distal features since Janczyk et al. (2012) suggests that actions based on stimulus discrimination can be represented by proximal or distal features. It is also not clear whether proximal features and distal features are necessarily represented in separate cognitive domains as suggested by Herwig et al. (2007). The assumptions of Herwig et al. (2007) contrast those of the Theory of Event Coding (Hommel et al., 2001). The purpose of the current study was to determine whether an action plan based on stimulus discrimination can be represented by distal features - when both proximal and distal features are available. And if so, can an action plan represented by distal features reside in the same cognitive domain as an action plan represented by proximal features. To accomplish this, we used the partial repetition paradigm developed by Stoet and Hommel (1999) to examine whether an action plan represented by distal features can interfere with an action plan represented by proximal features.

Design and Rationale

One way to test whether the proximal and distal features corresponding to actions can be represented in similar or separate cognitive domains is to see if an action plan represented by proximal features interferes with an action plan represented by distal features. In the partial repetition paradigm, two visual stimuli (A and B) occur in a sequence. Participants created and held in memory an action plan to the first visual stimulus (Action A), and then participants were shown the second visual stimulus which required an immediately response (Action B). After this immediate response, the action held in memory was executed. Previous research has shown that maintaining an action plan in memory to the first stimulus (Action A) can delay execution of the action to the second stimulus (Action B) if these two action plans partially overlap (e.g., Action A required a left-up button press and Action B required a left button press) compared to when they do not overlap (e.g., Action A required a left-up button press and Action B required a right button press; Fournier et al., 2010; see review in Hommel, 2004; see review in Hommel, 2005; Mattson & Fournier, 2008; Stoet & Hommel, 1999; Wiediger & Fournier, 2008). This delay in executing Action B when it partly overlaps with Action A is called a partial repetition cost. Whether or not a partial repetition cost is observed can provide information about whether or not the action features representing the two action plans (Action A and Action B) were coded similarly and represented in a similar cognitive domain (Hommel et al., 2001; Wiediger & Fournier, 2008).

It is assumed that if the features for Action A are bound together into a single action plan and a feature for Action B matches one of the features for Action A, this Action B feature will activate the matching Action A feature as well as the other action features relevant to Action A (Hommel, 2004; 2005; Mattson, Fournier, & Behmer, 2012). As a result, both of the action plans for Action B and Action A become activated and hence the irrelevant Action A feature (or action plan) will need to be inhibited to correctly select and execute Action B. The time required to inhibit the irrelevant Action A feature (or action plan) will take time, and hence cause a delay (or a partial repetition cost) in executing Action B. See Figure 1, in Experiment 1 panel. To date partial repetition costs have only been observed between actions corresponding to learned stimulus-response associations (proximal features). It is unclear whether partial repetition costs would be observed when an action plan held in working memory (Action A) is represented by distal features and an intervening action (Action B) is represented by proximal features.

To determine whether proximal features and distal features are represented in similar or different cognitive domains, three experiments were conducted using the partial repetition paradigm (Stoet & Hommel, 1999) described above. Experiment 1 was conducted to ensure that a partial repetition cost could be obtained for two action plans based on stimulus discrimination when the goals corresponding to Action A and Action B were both represented by proximal features (consistent with previous research, e.g., Fournier et al., 2010; Mattson & Fournier, 2008; Mattson et al., 2012; Stoet & Hommel, 1999). Experiment 2 examined if a partial repetition cost occurred for two action plans based on stimulus discrimination when the goals corresponding to Action A could be represented by proximal features and/or distal features that were spatially compatible, and Action B was represented by proximal features. Experiment 3 examined if a partial repetition cost occurred for two action plans based on stimulus discrimination when the goals corresponding to Action A could be represented by proximal features or distal features that were spatially incompatible, and Action B was represented by proximal features. See Figure 1, in Experiment 3 panel. In this experiment, if Action A was represented by proximal features and Action B was represented by proximal features, then a partial repetition cost was expected, consistent with past research. If instead, Action A was represented by distal features and Action B was represented by proximal features and both action plans were represented in a similar cognitive domain, then a partial repetition facilitation was expected for partially overlapping proximal features (as suggested by Hommel et al., 2001). However, if Action A was represented by only distal features and Action B was represented by proximal features and both action plans were represented in different cognitive domains, then no partial repetition cost was expected (as suggested by Herwig et al., 2007).

---insert Figure 1 about here ---

EXPERIMENT 1

The purpose of this experiment was to replicate past research by obtaining a partial repetition cost between two action plans based on stimulus discrimination when the goals corresponding to the Action A and Action B were both represented by proximal features (see Figure 1, in Experiment 1 panel). A partial repetition cost was expected for partially overlapping proximal features indicating that these action plans were represented in a similar cognitive domain.

Methods

Participants. Thirty-two undergraduates from Washington State University participated for optional extra credit in a psychology class. This study was approved by the Washington State University Institutional Review Board (IRB), and informed consent was obtained from all participants. Participants had at least 20/40 visual acuity. Eight participants were excluded for not following instructions (*n*=4 used strategies that they were explicitly told not to use) or low accuracy (*n*=4 were less than 80% accurate to Action A and Action B), and data were analyzed for the remaining 24 participants.

Apparatus. Stimuli appeared on a 17-in. computer screen approximately 61 cm from the participant. E-prime software (version 2.0) presented stimuli and collected data. Two keypads were used to input responses with one keypad placed to the left (for left-hand responses) and one to right (for right-hand responses) of the midline of the participant. The distance between keypads was 21.6 cm and the keypads were 15.9 cm in front of the computer screen. Each keypad had three keys centered on it and the keys were arranged in a vertical array. Each key was 1 cm^2 and the keys were separated from each other by 0.2 cm. Responses were recorded by the left or right keypad and executed with the left or right index finger, respectively (see Figure 2). During the practice trials, participants had a sheet of paper indicating the correct response to the letter and the arrowhead and asterisk (if needed) placed on the desktop to right of the keypads. All stimuli were white and presented on a black background.

---insert Figure 2 about here ---

Stimuli and Responses.

Action A. Action A represents responses mapped to Stimulus A. Stimulus A (2.45° of visual angle) was a white arrowhead (1.75° of visual angle) pointing to the left (<) or right (>) and an asterisk (1.05° of visual angle). The asterisk was centered 0.35° of visual angle above or below the arrowhead (1.40° of visual angle), and the arrowhead was centered 2.45° of visual angle above a central fixation cross. Stimulus A required participants to select between their left and right hand, and then execute the correct key press sequence. The hand that participants used (left or right) was indicated by the arrowhead direction; a left-pointing arrowhead indicated the left hand and a right-pointing arrowhead indicated the right hand. The sequence of keys to press (i.e., an up or down response) was indicated by the asterisk. An asterisk above the arrowhead indicated an "up" response where the participant pressed the center key, the key above the center key, and then the center key. An asterisk below the arrowhead indicated a "down" response where the participant pressed the center key, the key below the center key, and then the center key. Thus, four possible responses were mapped to Stimulus A (see Figure 2). For example, a left-pointing arrowhead with an asterisk above it indicated the left hand to move up, or a "left-up" response; a left-pointing arrowhead with an asterisk below it indicated the left hand to move down, or a "left-down" response; a right-pointing arrowhead with an asterisk above it indicated the right hand to move up, or a "right-up" response; and a right-pointing arrowhead with an asterisk below it indicated the right hand to move down, or a "right-down" response.

Action B. Action B represents the responses mapped to Stimulus B. Stimulus B was a white, uppercase H or S (2.45° of visual angle) centered 1.75° of visual angle below a central fixation cross. Stimulus B required a speeded double press of the center key with either the left or right hand based on letter identity. Half of participants made a double key press to the H with their left hand and to the S with their right hand, and the other half had the opposite stimulus-response assignment.

---insert Figure 3 about here ---

Procedure. The sequence and timings of the frames for a trial are shown in Figure 3. Each trial began with an initiation screen that contained a fixation cross (centered in the screen) with a message above it that read 'Press both center keys to start trial'. Once both center keys were pressed simultaneously (with both index fingers), a fixation cross appeared for 200 ms followed by Stimulus A (which appeared above the fixation cross) for 1,000 ms. Next a screen with the fixation cross was presented for 1,000 ms. Participants had from the onset of Stimulus A until the onset of Stimulus B (2,000 ms total) to plan their response for Stimulus A. Stimulus B was presented below the fixation cross for 100 ms followed by a blank response screen for 4,900 ms or until a response to Stimulus B was executed. Participants were instructed to respond as quickly and accurately as possible to Stimulus B. Stimulus B reaction time (RT) was measured from the onset of Stimulus B until a key was pressed. After responding to Stimulus B, participants had up to 5,000 ms per key press to recall and correctly enter their response to Stimulus A. Participants were instructed to be accurate, not fast, to Stimulus A. After all responses were entered, participants were shown a single feedback screen (duration = 600 ms) indicating their accuracy to Stimulus B, their reaction time to Stimulus B (ms), and their accuracy to Stimulus A. After a 500 ms inter-stimulus-interval (blank screen), the initiation screen appeared signaling a new trial. Participants initiated a new trial by pressing both center keys simultaneously and the sequence of events repeated.

During the practice trials, participants were observed by an experimenter and, if needed, given additional instructions to help with learning the correct responses. Participants were told not to execute their planned Stimulus A response until they had perceived and executed their response to Stimulus B. In other words, participants were instructed to maintain their response to Stimulus A in memory. Additionally, participants were instructed *not* to tense muscles in anticipation, move body parts, or use other external cues to help them recall their response to Stimulus A. During the practice trials, if participants engaged in these strategies, they were reminded to use only their memory; however, if these strategies were still used during the experimental trials, then their data was excluded for not following instructions.

Participants completed an 80-minute session consisting of 80 practice trials followed by seven blocks of 32 experimental trials. Participants took a break after the third experimental block. After the experimental trials, participant answered debriefing questions about the strategies used for the task. The four possible stimuli for Action A were equally paired with the two possible stimuli for Action B and appeared in a random order with equal probability of occurrence. Within each block of 48 trials, 24 trials required key presses (proximal features) with the same hand for Action A and B (partial feature overlap), and the other 24 trials required key presses (proximal features) with different hands for Action A and B (no feature overlap; see Figure 1, in Experiment 1 panel).

The manipulated factor was feature overlap between key presses (proximal features) for Action A and Action B. Either the key presses (proximal features) had partial feature overlap (i.e., both action plans shared a proximal feature) or no feature overlap (i.e., both action plans did not share proximal features; see Figure 1, in Experiment 1 panel). To determine whether the plan for Action A was represented by proximal features, participants were asked if they represented their action plan with key presses (proximal features) during debriefing.

Results and Discussion

A repeated measures analysis of variance (ANOVA) with the factor of feature overlap (partial feature overlap or no feature overlap) was conducted separately on Action B correct RT and Action B error rate. The correct RT and error analyses for Action B were restricted to trials where responses to Action A were accurate. Additionally, correct RT data were restricted to trials that were 3 standard deviations from the mean of each participant (approximately 0.07 % of trials from each participant were lost). Figure 4(A) shows the Action B correct RTs and error rate for the partial feature overlap and no feature overlap conditions. As evident in Figure 4(A), a partial repetition cost was found.

---insert Figure 4 about here ---

Action A. The average error rate was 9.0% indicating that participants accurately recalled Action A 91% of the time.

Action B. Mean correct RT was significantly greater for the partial feature overlap (M = 509 ms) compared to the no feature overlap (M = 498 ms) condition, $F(1,23) = 6.24$, $p < .05$, $\eta_p^2 = .21$ – indicating a partial repetition cost. Also, mean error rate was significantly greater for the partial feature overlap (M = 3.7%) compared to the no feature overlap (M = 2.5%) condition,

$F(1, 23) = 6.53$, $p < .05$, $\eta_p^2 = .22$ – indicating a partial repetition cost and no speed-accuracy tradeoff.

These results replicate past research (Mattson & Fournier, 2008; Stoet & Hommel, 1999; Wiediger & Fournier, 2008). The size of the partial repetition cost in this experiment was 11 ms and this cost is comparable to past research that has shown partial repetition costs ranging from 9 ms to 33 ms (e.g., Fournier et al., 2010; Stoet & Hommel, 1999). In this experiment, 24 out of 24 participants reported representing Action A with features corresponding to the key presses (proximal features).

EXPERIMENT 2

The purpose of this experiment was to determine whether a partial repetition cost could be obtained for two action plans based on stimulus discrimination when the goals corresponding to Action A could be represented by proximal features and/or distal features and Action B was represented by only proximal features. All stimuli and procedures were similar to Experiment 1 except that when executing Action A white boxes appeared on the computer screen, and participants were instructed to plan Action A in terms of moving a white box on the screen (distal features), not the keys that needed to be pressed (proximal features). As a result, Action A could be represented by proximal features corresponding to key presses and/or distal features corresponding to white box movements. The proximal and distal features for Action A partially overlapped or did not overlap with the proximal features for Action B (see Figure 1, in Experiment 2 panel). If Action A was represented by only proximal features (key presses), a partial repetition cost was expected (similar to Experiment 1 and past research). If Action A was represented by both proximal and distal features that share a representational domain, a larger partial repetition cost was expected for this experiment than Experiment 1 due to the redundancy between the proximal features (key presses) and the distal features (white box movements) for Action A (see Figure 1, in Experiment 2 panel). If Action A was represented by only distal features (white box movements) and these distal features were represented in a different cognitive domain than the proximal features for Action B (as suggested by Herwig et al., 2007), then no partial repetition cost was expected.

Methods

Participants. Participant characteristics and compensation were identical to Experiment 1. A total of 30 students participated and five participants were dropped for not following instructions (*n*=4 used strategies that they were explicitly told not to use) or low accuracy (*n*=1 was less than 80% accurate to Action A and Action B). One participant was dropped for an extreme speed-accuracy tradeoff (i.e., 23 ms slower on feature overlap trials compared to no feature overlap trials, but 5% more accurate on feature overlap trials). Data were analyzed for the remaining 24 participants.

Apparatus, Stimuli, and Procedure. The apparatus and stimuli were the same as Experiment 1, except that the key presses for Action A elicited spatially compatible white boxes on the computer screen. The procedure was similar to Experiment 1 except for the following. Participants were instructed to create their action plan for Stimulus A in terms of the white box movements (distal features) and not the motor movements required to execute the key presses (proximal features) (see Table 1). For example, if Stimulus A was a right arrowhead with an asterisk above it (>*), then participant planned to move the white box from the right center of the screen to the upper right portion of the screen then back to the right center of the screen. Thus, the white box movements spatially corresponded to the key presses (i.e., use the right hand to press the center key, the key above the center key, and then the center). See Figure 5. The white boxes (duration = 100 ms) directly followed the key presses for Action A so that they served as perceptual effects (distal features) for the movements required across the keypads (proximal features). The action plan for Stimulus B (Action B) was represented by the proximal features corresponding to the key presses and had no white box movements.

---insert Table 1 about here ---

---insert Figure 5 about here ---

The manipulated factor was feature overlap between proximal features for Action A and Action B. Either the proximal features (key presses) had partial feature overlap (i.e., both action plans shared a proximal feature) or no feature overlap (i.e., both action plans did not share proximal features) (see Figure 1, in Experiment 2 panel). To determine whether the plan for Action A was represented by proximal or distal features, participants were asked if they represented their action plans with key presses (proximal features) or white box movements (distal features) during debriefing.

Results and Discussion

A repeated measures ANOVA with the factor of feature overlap (partial feature overlap or no feature overlap) was conducted separately on Action B correct RT and Action B error rate. The correct RT and error analyses for Action B were restricted to trials where responses to Action A were accurate. Additionally, correct RT data were restricted to trials that were 3 standard deviations from the mean of each participant (approximately 0.05 % of trials from each participant were lost). Figure 4(B) shows the Action B correct RTs and error rate for the partial feature overlap and no feature overlap conditions. As evident in Figure 4(B), a partial repetition cost was found for partial proximal feature overlap when the proximal and distal features for the action maintained in memory were spatially compatible.

Action A. The average error rate was 7.1% indicating that participants accurately recalled Action A 92.9% of the time.

Action B. Similar to Experiment 1, mean correct RT was significantly slower for the partial feature overlap (M = 524 ms) compared to the no feature overlap (M = 503 ms) condition, $F(1,23) = 25.55$, $p < .0001$, $\eta_p^2 = .53$ – indicating a partial repetition cost. Consistent with mean correct RT, mean error rate was significantly higher for partial feature overlap condition (M = 3.0%) compared to no feature overlap condition (M = 1.8%), $F(1, 23) = 6.20$, $p < .05$, $\eta_p^2 = .21$.

These results are consistent with Experiment 1 and past research (e.g., Mattson & Fournier, 2008; Stoet & Hommel, 1999; Wiediger & Fournier, 2008), and suggest that a partial repetition cost can be obtained when proximal and distal features were available for the representation of Action A. In this experiment, 15 out of 24 participants reported representing Action A with features corresponding to the key presses (proximal features) – not the white box movements (distal features). When spatially compatible proximal and distal features were available for the representation of Action A, a 21 ms partial repetition cost was obtained compared to an 11 ms cost obtained in Experiment 1 when only proximal features were available for the representation of Action A. The relatively larger partial repetition cost between experiments suggests that proximal and distal features were represented in a similar cognitive domain. However, a 2 (experiment: 1, 2) X 2 (feature overlap: partial feature overlap, no feature overlap) mixed ANOVA showed that the cost found in this experiment was not significantly greater than that found in Experiment 1; there was no significant interaction (but a trend) between experiment and feature overlap [$F(1, 46) = 2.76$, $p = .10$, $\eta_p^2 = .06$].

This experiment found that the partial repetition costs originally found in Experiment 1 were not compromised when Action A could be represented by the features corresponding to the perceptual effects of an action (distal features) and/or the features for the motor movements of that action (proximal features). However, this experiment cannot determine whether proximal features, distal features, or both were incorporated into an action plan when both features were available. In order to address this question, Experiment 3 was conducted.

EXPERIMENT 3A, 3B, and 3C

These experiments examined whether a partial repetition cost occurred when the goals corresponding to the action plan for Action A was based on proximal features (key presses) or distal features (white box movements) that were spatially incompatible and Action B was based on proximal features (key presses). That is, these experiments used spatially incompatible proximal and distal features for the action maintained in memory (Action A) to determine if distal or proximal features dominate when representing an action. Similar to Experiment 2, participants were instructed to move a white box based on the identity of Action A, and maintain this action plan in memory. However, the key presses (proximal features) required to move the white box were spatially incompatible with the locations of the white box (distal features). For example, a left-up white box movement in Experiment 3A (i.e., move the white box from the left center of the screen to the upper left portion of the screen then back to the left center of the screen), required participants to use their the right hand to press the center key, the key below the center key, and then the center key. Therefore, there were trials where the key presses (proximal features) for Action B partially overlapped with the key presses (proximal features) for Action A – but did not overlap with the white box movements (distal features) for Action A; conversely, there were trials where the key presses (proximal features) for Action B partially overlapped with the white box movements (distal features) for Action A – but did not overlap with the key presses (proximal features) for Action A (see Table 1).

If Action A was represented by only proximal features (key presses) - not distal features (white box movements) - then a partial repetition cost was expected for overlapping proximal features (key presses), consistent with previous research. In contrast, if Action A was represented by only distal features – and not proximal features – and these action features share a cognitive domain, then a partial repetition facilitation was expected for partially overlapping proximal features (key presses; see Figure 1, in Experiment 3 panel) because the distal features for Action A will be primed (or activated) by the proximal features for Action B. Additionally, if Action A was represented by only distal features and Action B was represented by proximal features and these action features were represented in separate cognitive domains (Herwig et al., 2007), then no significant partial repetition cost was expected between the partial feature overlap and no feature overlap conditions because if proximal and distal features were represented in different cognitive domains the features for Action A would not interfere with the features for Action B. However, if Action A was represented by proximal features and there was no significant partial repetition cost, this null result may suggest that proximal features were explicitly used to represent Action A but distal features were implicitly used to represent Action A. In accordance with Herwig et al. (2007), if proximal and distal features were represented in different cognitive domains and participants represented Action A with proximal features, a partial repetition cost was expected because the partially overlapping proximal features between Action A and Action B were represented in the same cognitive domain.

Experiments 3B and 3C were conducted as manipulation checks for Experiment 3A. Experiment 3B examined whether the results of Experiment 3A were due to the difficulty of the task. That is, Action A may be too difficult when both of the movements (i.e., left-right and up-down) for the key presses (proximal features) and the white boxes (distal features) were spatially incompatible. In Experiment 3B, only the left and right key presses (proximal features) were spatially incompatible with the left and right locations of the white box on the screen (distal features), the other key presses (up and down) were spatially compatible with the up and down locations of the white box.

Experiment 3C examined whether the stimuli used in Experiments 3A and 3B (i.e., the left and right arrowhead) had a directional influence on Action A. That is, the left and right arrowheads used for Action A can represent an arrowhead pointing towards the direction of the white box movements (distal features) or an open mouth indicating the direction of the key presses (proximal features). This can be problematic if we want participants to represent their action plans with distal features (when both proximal and distal features were available) because the arrowhead stimuli can indicate proximal or distal features. Therefore, the arrowheads were replaced with the outline of a red or green box. Additionally, Experiment 3C examined whether the plan for Action A would be represented with distal features (white box movements) – not proximal features – if there was a previously established relationship between spatially incompatible key presses (proximal features) and white box movements (distal features) due to a training session.

Methods

Participants. Participant characteristics and compensation were identical to Experiment 1. A total of 92 students participated; 37 in Experiment 3A, 30 in Experiment 3B, and 25 in Experiment 3C. In Experiment 3A, 13 participants were dropped for not following instructions (*n*=3 used strategies that they were explicitly told not to use) or low accuracy (*n*=9 were less than 80% accurate to Action A and Action B). And one participant was dropped for an extreme speed-accuracy tradeoff (i.e., 27 ms slower on partial feature overlap trials compared to no feature overlap trials, but 9% more accurate on partial feature overlap trials). In Experiment 3B, six participants were dropped for not following instructions (*n*=1 used strategies that they were explicitly told not to use) or low accuracy (*n*=5 were less than 80% accurate to Action A and Action B). In Experiment 3C, one participant was dropped for an extreme speed-accuracy tradeoff (i.e., 304 ms slower on partial feature overlap trials compared to no feature overlap trials, but 8% more accurate on partial feature overlap trials). Data were analyzed for the remaining 72 participants (24 participants per experiment).

Apparatus, Stimuli, and Procedures. All stimuli and equipment were identical to Experiment 2 except that when participants executed Action A, their key presses (proximal features) elicited spatially incompatible white boxes on the screen (distal features). Participants were instructed to create their action plan for Stimulus A in terms of white box movements (distal features) and not key presses (proximal features). In Experiment 3A, the key presses (proximal features) required to move the white box for the planned action to the arrowhead and asterisk (Stimulus A) were the opposite of the white box movements (distal features; see Table 1). For example, to make a left-up white box movement (i.e., move the white box from the left center of the screen to the upper left portion of the screen then back to the left center of the screen), participants needed to use their the right hand to press the center key, the key below the center key, and then the center key.

In Experiments 3B, all other procedures and stimuli used were similar to Experiment 3A except the left and right white box movements (distal features) – not the up and down movements – required spatially incompatible key presses (proximal features) for the planned action to the arrowhead and asterisk (Stimulus A). For example, to make a left-up white box movement (i.e., move the white box from the left center of the screen to the upper left portion of the screen then back to the left center of the screen), participants used their the right hand to press the center key, the key above the center key, and then the center key.

In Experiments 3C, only the left and right movements for the key presses (proximal features) and white boxes (distal features) were spatially incompatible. All other procedures were similar to Experiment 3B except participants responded to the outline of a red or green box instead of a left or right arrowhead for Stimulus A. Half of the participants responded left for the red box and right for the green box, and the other half of participants had the opposite stimulus-response mapping. Additionally, participants completed a 10 minute training session (180 trials) before the experiment to teach them the relationship between the key presses (proximal features) and the white box movements (distal features). Previous research (Elsner & Hommel, 2004; Herwig et al., 2007; Herwig & Waszak, 2009) had participants practice making responses (e.g., left or right key presses) and experience the effects of those responses (e.g., a high or low tone). Perhaps practice might lead to participants representing their plan for Action A with white box movements (distal features).

For each experiment, the manipulated factor was feature overlap between proximal features for Action A and Action B. Either the proximal features (or key presses) for Action A and Action B had partial feature overlap (i.e., both action plans shared a proximal feature) or these actions had no feature overlap (i.e., both action plans did not share proximal features). To determine whether the plan for Action A was represented by proximal or distal features, participants were asked if they represented their action plans with key presses (proximal features) or white box movements (distal features) during debriefing.

Results and Discussion

For each experiment (3A, 3B, and 3C), a repeated measures ANOVA with the factor of feature overlap (partial feature overlap or no feature overlap) was conducted separately on Action B correct RT and Action B error rate. The correct RT and error analyses for Action B were restricted to trials where responses to Action A were accurate. The correct RT data were restricted to trials that were 3 standard deviations from the mean of each participant (approximately 0.07 % of trials from each participant were lost). Figure 6 shows the Action B correct RTs and error rate for the partial feature overlap and no feature overlap among key presses (proximal features) for each experiment (3A, 3B, and 3C). As evident in Figure 6, no partial repetition cost was found for partially overlapping key presses (proximal features).

---insert Figure 6 about here ---

Experiment 3A.

Action A. The average error rate was 12.8% indicating that participants accurately recalled Action A 87.2% of the time.

Action B. Unlike Experiments 1 and 2, mean correct RT did not differ between the partial feature overlap (M = 517 ms) and no feature overlap (M = 514 ms) conditions, $F < 1$; JZS Bayes Factor = 6.32.[1] Also, mean error rate did not differ between the partial feature overlap (M = 1.8%) and no feature overlap (M = 1.5%) conditions, $F(1, 23) = 1.21$, $p > .28$, $\eta_p^2 = .05$, power = 1.00; JZS Bayes Factor = 2.36.

Overall, these results did not replicate Experiments 1 and 2 because no partial repetition cost was found (i.e., mean difference = 3 ms). Adding spatially incompatible distal features to an action plan eliminated the partial repetition costs. While the data appears to support the prediction that distal and proximal features are presented in different domains (as suggested by Herwig et al., 2007), this would only be the case if participants reported representing their plan to Action A with only distal features. However, 19 out of 24 participants reported representing Action A with features corresponding to the key presses (proximal features) – not the white box movements (distal features). Therefore, the majority of participants did not consciously represent their Action A responses with the white boxes (distal features). Unexpectedly, no partial repetition costs were obtained - despite most participants consciously representing their action plans with proximal features. These results do not support the idea that responses based on stimulus discrimination cannot be represented with distal features (Herwig et al., 2007). This suggests that the distal features may have had an implicit influence on the action plan representation of participants.

The failure to find a significant partial repetition cost could have been due to the difficulty of Action A. That is, thirty-five percent (13 out of 37) of the participants in this experiment were dropped (this is a higher rate of attrition than other experiments) and the error rate for Action A was relatively high (compared to previous experiments). It is possible that the difficulty of the task for Action A (i.e., both the left-right and up-down movements for the key presses and white boxes were spatially incompatible) placed a greater demand on working memory [although recent evidence from our lab suggests increasing cognitive load can increase partial repetition costs]. To ensure that the failure to obtain a partial repetition cost was not due to the difficulty of Action A, Experiment 3B was conducted. In Experiment 3B, the task was simplified by making only the left-right movements of the key presses (proximal features) spatially incompatible with the white box movements (distal features) for the action maintained in working memory (Action A); while, the up-down movements were spatially compatible.

Experiment 3B.

Action A. The average error rate was 7.5% indicating that participants accurately recalled Action A 92.5% of the time.

Action B. Similar to Experiment 3A, mean correct RT was not significantly different between the partial feature overlap (M = 517 ms) and the no feature overlap (M = 510 ms) conditions, $F(1,23) = 3.26$, $p > .08$, $\eta_p^2 = .12$, power = 1.00; JZS Bayes Factor = 0 – indicating a trend but no partial repetition cost. Also, mean error rate did not differ between the partial feature overlap ($M = 2.6\%$) and no feature overlap ($M = 1.5\%$) conditions, $F(1, 23) = 2.37$, $p > .13$, $\eta_p^2 = .09$, power = 1.00; JZS Bayes Factor = 0.

These results replicated Experiment 3A. Also, 21 out of 24 participants reported representing Action A with features corresponding to the key presses (proximal features) – not the white box movements (distal features). The previous attempts to have participants explicitly represent the goal of their action plans in terms of the white box movements (distal features) appeared to be unsuccessful. To examine the role of experience with the key presses and white boxes and to rule out any possible directional influence from the arrowhead stimuli, Experiment 3C was conducted.

Experiment 3C.

Action A. The average error rate was only 7.2% indicating that participants accurately recalled Action A 92.8% of the time.

Action B. Similar to Experiments 3A and 3B, mean correct RT was not significantly different between the partial feature overlap ($M = 518$ ms) and the no feature overlap ($M = 513$ ms) conditions, $F(1,23) = 1.29$, $p > .26$, $\eta_p^2 = .05$, power = 1.00; JZS Bayes Factor = 1.80 – indicating no partial repetition cost. Also, mean error rate did not differ between the partial feature overlap ($M = 2.0\%$) and no feature overlap ($M = 2.1\%$) conditions, $F < 1$; JZS Bayes Factor = 6.38.

The results from this experiment suggest that the results from Experiments 3A and 3B were not due to the stimuli used (i.e., the arrowhead). Also, the training session did not succeed in getting participants to explicitly represent Action A with distal features. Twenty out of 24 participants reported representing Action A with the key presses (proximal features) – not the white box movements (distal features). Therefore even with a training session, participants reported representing their action plan maintained in working memory (Action A) with key presses (proximal features).

Across all three experiments (3A, 3B, and 3C), if participants only used proximal features to represent their action plans maintained in working memory (when spatially incompatible proximal and distal features were available for its representation) and proximal and distal features were represented in different cognitive domains, then partial repetition costs should have been obtained similar to Experiments 1 and 2. However, the results from these experiments failed to find a significant partial repetition cost suggesting proximal and distal features were represented in a similar cognitive domain. Although participants may have explicitly represented their action plans for Action A with proximal features (key presses), their action plans were implicitly influenced by distal features (white box movements) creating no partial repetition costs.

COMPARISONS AMONG EXPERIMENTS 1, 2, 3A, 3B, and 3C

Although the results of Experiments 3A, 3B, and 3C (i.e., spatially incompatible features) may appear different than Experiments 1 and 2 (i.e., no distal features or spatially compatible distal features, respectively), a mixed design ANOVA was conducted to determine if these experiments were significantly different. The within-subjects factor was feature overlap between proximal features (partial feature overlap and no feature overlap and the between-subjects factor was experiment (experiment 1, 2, 3A, 3B, and 3C). The purpose of these analyses was to examine if spatially incompatible proximal and distal features (Experiments 3A, 3B, and 3C) were responsible for failing to find significant partial repetition costs. If so, then the Action B RT difference between partial feature overlap and no feature overlap among proximal features (key presses) for spatially compatible features (Experiment 2) was expected to be significantly different than spatially incompatible features (Experiment 3A, 3B, and 3C). That is, we should observe an experiment by feature overlap interaction.

Action B. There was a significant interaction found for mean correct RT between feature overlap and experiment [$F(4,115) = 3.11$, $p < .05$, $\eta_p^2 = .10$]. As a follow-up to this significant interaction, a between-subjects ANOVA was conducted on the mean difference for feature overlap (i.e., no feature overlap minus partial feature overlap) with the between-subjects factor of experiment (i.e., Experiment 1, 2, 3A, 3B, and 3C). There was a significant difference among experiments in terms of the mean difference for feature overlap, $F(4,115) = 3.11$, $p < .05$. Least significant difference (LSD) post-hoc analyses revealed that Experiment 2 had a larger partial repetition cost than Experiment 3A ($p = .002$), Experiment 3B ($p = .015$), and Experiment 3C ($p = .007$) but this cost was not significantly larger than Experiment 1 ($p = .089$). These results, along with the statistical analyses conducted separately on each experiment, suggest that when the proximal and distal features were compatible (Experiment 2), a partial repetition cost was obtained; however when the proximal and distal features were incompatible (Experiment 3A-C), no significant partial repetition cost was obtained.

If only proximal features were used for responses based on stimulus discrimination and distal features were represented in a different cognitive domain (as suggested by Herwig et al., 2007), then partial repetition costs should have been obtained in all experiments. However when there were spatially incompatible proximal and distal features available for the representation of Action A (as in Experiments 3A, 3B, and 3C), we failed to find a significant partial repetition cost despite the majority of participants reporting that they explicitly used proximal features for the representation of their action plans. The significant interaction for mean correct RT extends previous research (e.g., Cattaneo & Rizzolatti, 2009; Hommel, 1993) by demonstrating that, when the proximal and distal features of an action were available, the proximal and distal features of an action were incorporated into a single action plan. Therefore, if there were two action control systems (stimulus-based and intention-based) as proposed by Herwig et al. (2007) and Herwig and Waszak (2009), then actions can be represented by both distal features (intention-based action control system; ideomotor learning) and proximal features (stimulus-based action control system; sensorimotor learning) in a similar – not different – cognitive domain. The Theory of Event Coding assumes that action plans based on stimulus discrimination can be represented by both proximal and distal features in a similar cognitive domain. It is possible that the spatially incompatible proximal and distal features created code confusion (Hommel, 2004; 2005; Mattson et al., 2012) in the partial feature overlap and no feature overlap conditions leading to no significant difference between these conditions.

GENERAL DISCUSSION

This study was conducted to determine if an action plan based on stimulus discrimination could be represented by distal features, and if so, to determine whether proximal and distal features were represented in a similar cognitive domain. A partial repetition paradigm (Stoet & Hommel, 1999) was used because partial repetition costs indicate that partially overlapping action features were represented in a similar cognitive domain. When the action plan held in memory could be represented by only proximal features (Experiment 1) or spatially compatible proximal and distal features (Experiment 2), partial repetition costs were observed. However when the action plan held in memory could be represented by spatially incompatible proximal and distal features and participants reported representing their action plan held in memory with proximal features (explicitly), we failed to obtain a significant partial repetition cost. Across all experiments, 99 out of 120 participants (24 out of 24 in Experiment 1, 15 out of 24 in Experiment 2, and 60 out of 72 in Experiment 3) consciously represented their plans to Action A with features corresponding to the key presses (i.e., proximal features) and not features corresponding to the perceptual effects of those key presses (i.e., distal features or white box movements). Therefore, if only proximal features were used to represent Action A (as suggested by Herwig et al. 2007), then partial repetition costs should have be obtained in all experiments. However, we failed to obtain a significant partial repetition cost for spatially incompatible proximal and distal features. Taken together, the results from the current study demonstrate that an action plan representation based on stimulus discrimination can be represented by proximal features (explicitly) and distal features (implicitly) when both features were available and these features were represented in a similar cognitive domain. This finding is consistent with the

Theory of Event Coding (Hommel et al., 2001) which assumes that the proximal and distal features of an action plan are represented in a similar cognitive domain. Additionally, this finding is consistent with hierarchical action control (i.e., automatic actions, Logan & Crump, 2009) and Perception-Action model (i.e., online and offiline actions, Goodale, 2010; Goodale & Westwood, 2004) that assume separate but interacting systems.

The distal features having an implicit influence on an action plan explicitly represented by proximal features is consistent with other findings (e.g., Simon, 1969 or Stürmer, Aschersleben, & Prinz, 2000) showing that responses based on stimulus discrimination were influenced by response irrelevant features. For example in Stürmer et al. (2000), participants performed a spreading or grasping response with their hand and started their responses from a neutral, half-open hand posture. For half of the trials, participants were shown a hand on the computer screen that was in a closed posture (i.e., the end state for the grasping response) and the other half of trials participants were shown a hand on the screen that was in an open posture (i.e., the end state for the spreading response). However, the posture of the hand was not relevant to the task and participants performed a grasping or spreading response depending on the skin color of the hand on the computer screen. When the skin turned blue, participants executed one response (e.g., a grasping action) and when the skin turned red, participants executed another response (e.g., a spreading action). This created a task where the hand postures on the screen and the responses of participants were either compatible (i.e., they indicated the same action like grasping) or not compatible (i.e., they indicated different actions like spreading and grasping). Stürmer et al. (2000) found that features not relevant to the response (i.e., the posture of the hand on the computer screen) influenced the time it took for participants to start their response (i.e., a spreading or grasping action). That is, grasping and spreading responses were initiated faster when the posture of the hand that signaled the response was compatible with the end state of the response compared to not compatible. Past research and the current study suggest that response relevant features and response irrelevant features can prime each other to influence response selection.

One model of action learning, the Action Control Model, explains "how voluntary actions can emerge in adults meeting new environmental conditions and action possibilities" (Hommel & Elsner, 2000). According to the Action Control Model, arbitrary movements occur that produce perceptual effects in the environment. When there is temporal overlap between the motor movements and the perceptual effects of those movements, an automatic association is created between the motor movements and the perceptual effects of those movements forming an "action concept." Once formed, the links between perceptual effects and motor movements can activate one another in a bidirectional manner. That is, perceptual effects and motor movements can both activate each other through the activation of their common action concept. The automatic acquisition of perceptual effect and motor movement associations would provide a continually expanding knowledge base for action-effect associations, or action goals (Hommel & Elsner, 2000).

Results from our study suggest that proximal and distal features were concurrently represented in an action plan implying that sensorimotor and ideomotor learning might co-occur when learning a new action sequence. Perhaps ideomotor learning and sensorimotor learning are at opposing ends of action learning (see Hommel & Elsner, 2009) where ideomotor learning is implicitly (automatic processing) used to acquire an association between an action sequence and its effects (distal features; white box movements), and sensorimotor learning is explicitly used to acquire the specific steps of an action sequence (proximal features; key presses). It is possible that action plans are initially represented by the features for the motor movements needed to execute an action (proximal features; sensorimotor learning) and through Hebbian learning actions are represented by the features for the perceptual effects of an action (distal features; ideomotor learning). As an action becomes proceduralized (or automatic), it could be explicitly represented by the perceptual effects of the action (distal features; ideomotor learning) and implicitly represented by the motor movements needed to execute the action (proximal features; sensorimotor learning). This transition between proximal and distal representations could be related to actions moving from declarative memory to procedural memory.

Across all of the experiments in the current study, participants consistently preferred to explicitly represent their action plans with proximal features - not distal features. Past research has shown that action plans can be represented with proximal or distal features depending on the goal of the task (Cattaneo & Rizzolatti, 2009; Hommel, 1993; Janczyk et al., 2012). When learning an action sequence (i.e., before proceduralization), maybe proximal features are explicitly represented because proximal features could be closely aligned with the expected action goals. Or perhaps this lack of utilizing distal features could be related to the salience of the distal features (e.g., see Experiment 2 in Janczyk et al., 2012) and how close in time the action (key press) and effect (white box) were coupled. Previous research (Janczyk et al., 2012; Koch & Kunde, 2002) suggested that linking the action and effect closely in time was a critical factor for measuring action effects (distal features). In the current study, key presses caused white boxes to immediately appear on the screen and the white boxes remained visible for 100 ms, but this could have created small gaps between the appearances of the white boxes (not fluid motion). This could explain why participants did not explicitly represent their action plans with white box movements (distal features). Future research could try linking the action and the effect closer in time (i.e., eliminate the small gaps between the appearances of the white boxes) to encourage participants to explicitly represent their action plans with distal features. Additionally, the white box movements (distal features) were not relevant to the task (Action A). That is, the task could be completed by representing the action maintained in working memory with proximal or distal features so participants may have used the easiest (or most convenient) action features (i.e., proximal features) for representing their action plan to a new action sequence. However, if distal features were highly relevant to the task, then it is possible that distal features may be explicitly used for representing an action plan based on stimulus-discrimination when learning a new action sequence. Future research may consider using a more salient distal goal (e.g., an airplane or car display) for the action maintained in memory, or cue responses with tones, to encourage the explicit use of distal features for action plan representations.

The current study examined whether action plans were represented by action features corresponding to the motor movements needed to execute an action (proximal features) or the perceptual effects of an action (distal features) when both types of action features were available. Past research (Cattaneo et al., 2009; Hommel, 1993; Janczyk et al., 2012) suggests that an action plan can be represented by features corresponding to the motor movements needed to execute an action (proximal features) and the perceptual effects of an action (distal features) depending on the goal of the action. The current study extends previous research by demonstrating that an action plan representation can include the action features corresponding to the motor movements of an action (explicitly; proximal features) and the perceptual effects of an action (implicitly; distal features), and both of these action features were represented in a similar cognitive domain. Furthermore the explicit and implicit representation of proximal and distal features (respectively), extends the idea that ideomotor learning is an automatic process (Hommel & Elsner, 2000) and suggests that ideomotor and sensorimotor learning might co-occur when learning an action. It is also likely that implicit and explicit memory can prime each other to influence action selection. Improving our understanding of action planning and how actions are represented may benefit from examining both sides of action learning (i.e., ideomotor and sensorimotor learning).

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Footnotes

1. The JZS Bayes Factor (Rouder, Speckman, Sun, Morey, & Iverson, 2009) is a measure of how much more likely the null hypothesis is true compared to the alternative hypothesis. According to Jeffries (1961), a value of 3 provides “some evidence” for favoring the null. A value of 6.32 suggests that the null hypothesis is 6.32 times more likely to be true than the alternative hypothesis.

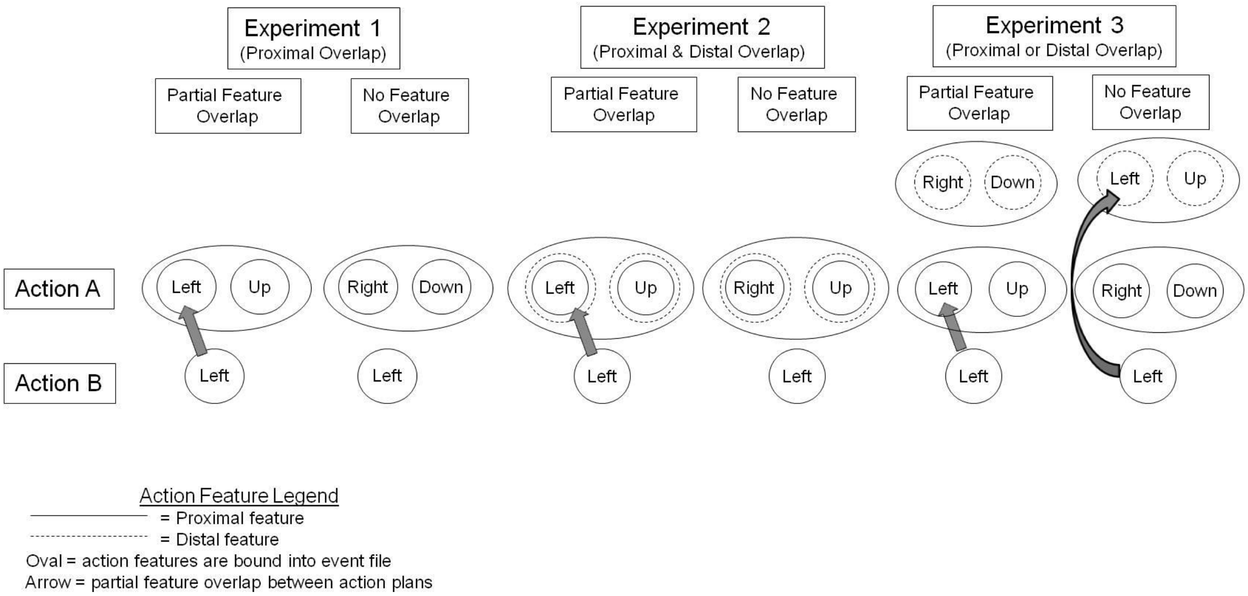


Figure 1. The diagram above depicts the predicted activation patterns between Action A and Action B for each experiment that can result in code confusion, and hence a partial repetition cost. Action features are represented by “Left”, “Right”, “Up”, and “Down” encased by a solid (proximal) or dashed (distal) circle. In Experiment 1, if the features for Action A are bound together into an action plan (represented by an oval) and both action plans (Action A and B) share a feature (e.g., Left), then this shared feature will activate the features for Action A (the grey arrow). As a result, the irrelevant Action A features (or action plan) need to be inhibited to correctly execute Action B creating a delay in executing Action B, or a partial repetition cost. In Experiment 2, if proximal (encased in solid lines) and/or distal features (encased in dashed lines) for Action A were bound into an action plan and these features were represented in a similar cognitive domain, then Action B will be delayed when both action plans share a feature (i.e., partial feature overlap) compared when they do not share a feature (i.e., no feature overlap).

Experiment 3 had spatially incompatible proximal (encased in solid lines) and distal (encased in dashed lines) features available for the representation of Action A. If Action A was represented with only proximal features, then a partial repetition cost was expected for partially overlapping proximal features (grey arrow under Partial Feature Overlap). If Action A was represented with only distal features and both features were represented in a similar cognitive domain, then faster responses are expected for the intervening action when both action plans share a proximal feature (Partial Feature Overlap) compared when they do not share a proximal feature (the curved grey arrow under No Feature Overlap). However, if Action A was represented by only distal features and both features were represented in separate domains, then no significant difference was expected between partial feature overlap and no feature overlap conditions.

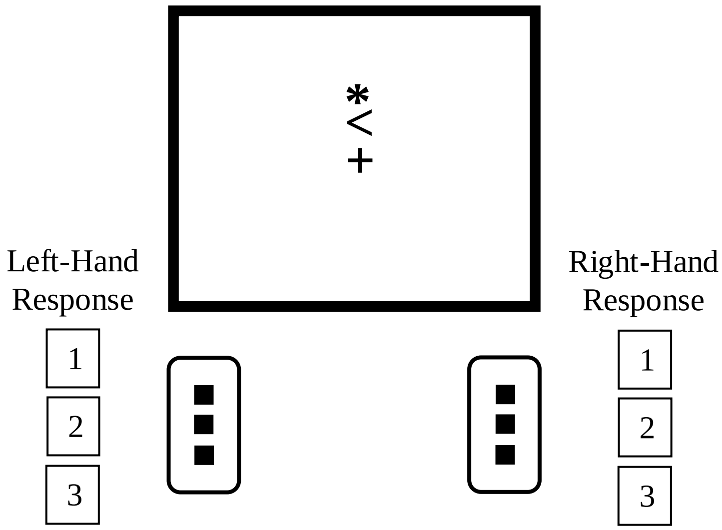


Figure 2. Above is a diagram of the keypads that were used to input responses for Action A and Action B. The keys on the left and right of the keypads are magnified to the left and right, respectively, and numbered to help describe the different response sequences for Stimulus A and Stimulus B. The direction of the arrowhead indicated which response hand to use (left or right) and the location of the asterisk relative to the arrowhead (above or below) indicated the correct key sequence to press. The response for each symbol set were as follows: an asterisk above a left arrowhead required a left hand key press of 2-1-2; an asterisk below a left arrowhead required a left hand key press of 2-3-2; an asterisk above a right arrowhead required a right hand key press of 2-1-2; and an asterisk below a right arrowhead required a right hand key press of 2-3-2.

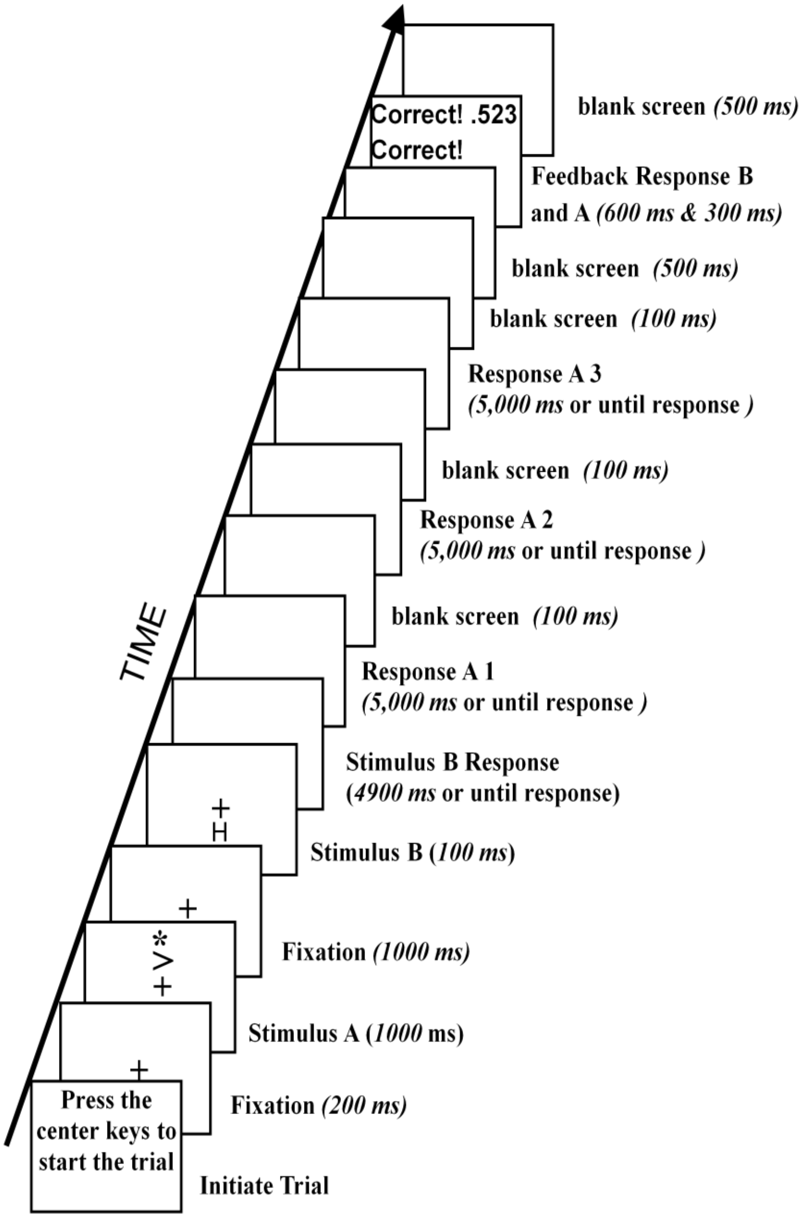
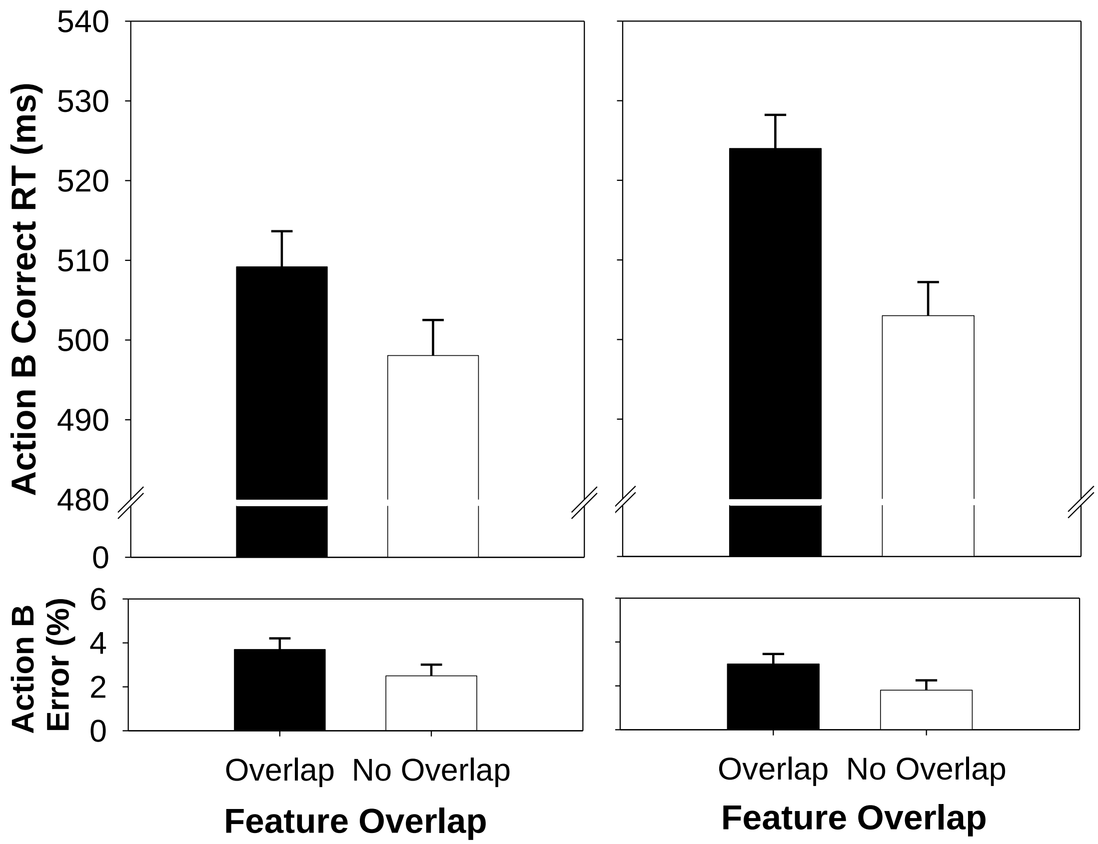


Figure 3. Above is a diagram of the sequence and duration of frames within a trial for Experiment 1. All frames were black with white letters and/or symbols on them, except the text for the feedback slide which used green text if correct and red text if incorrect. The responses for Stimulus A were recorded across three frames (A1, A2, and A3) to be consistent with Experiment 2 and Experiment 3 that displayed white box movements.



(A) **(B)**

Figure 4. Action B correct reaction time and percent error for partial feature overlap and no feature overlap for Experiment 1 (A) and Experiment 2 (B). Error bars represent the within-subjects standard error of the mean. For each experiment, the action features available to represent Action A are as follows: Experiment 1 (A) had only proximal features and Experiment 2 (B) had spatially compatible proximal and distal features.

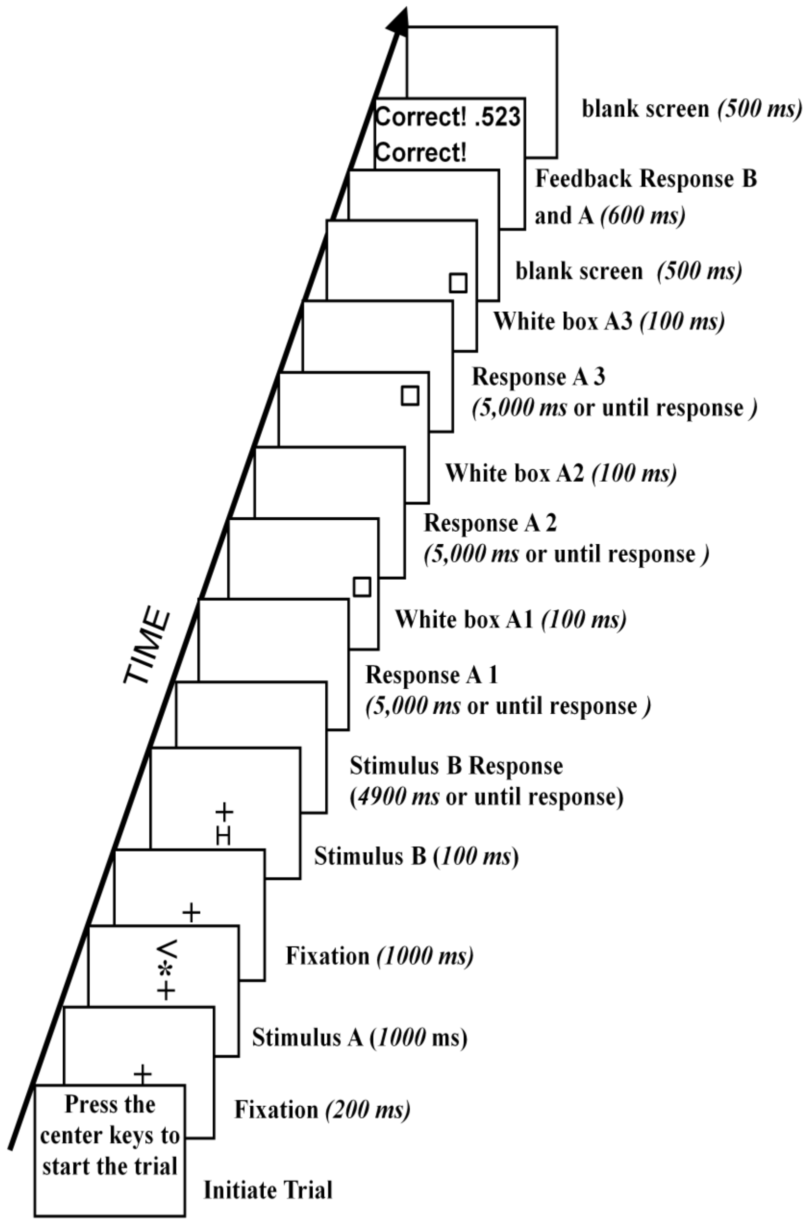


Figure 5. Above is a diagram of the sequence and duration of slides within a trial for Experiments 2 and 3 In Experiment 2, the location of the white boxes was spatially compatible with the location of the key presses. In Experiment 3, the location of the white boxes was incompatible with the location of the key presses. To create white box movements, the responses for Stimulus A were recorded across three separate frames (A1, A2, and A3) and frames displaying white boxes directly followed each key press.

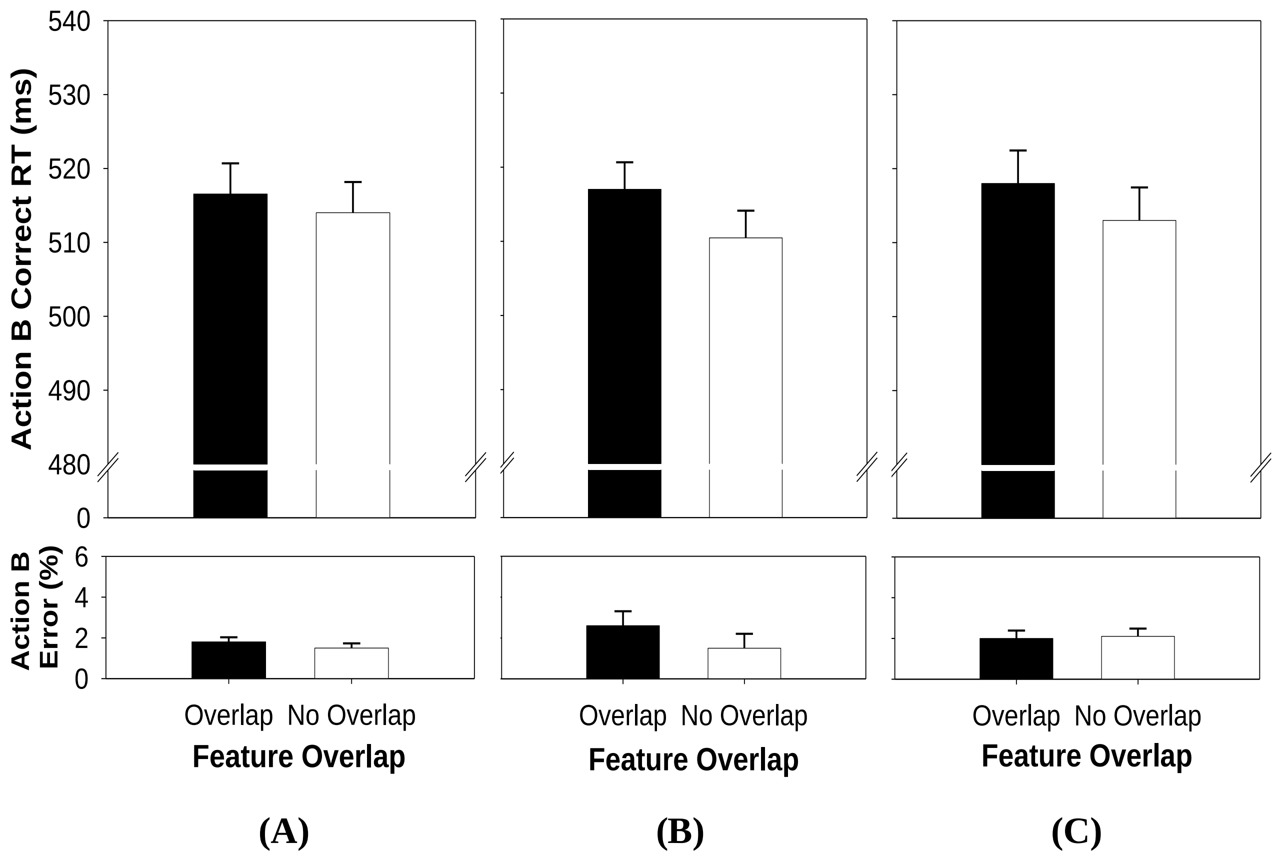


Figure 6. Action B correct reaction time and percent error for partial feature overlap and no feature overlap for Experiment 3A (A), Experiment 3B (B), and Experiment 3C (C). Error bars represent the within-subjects standard error of the mean. Experiments 3A (A), 3B (B), and 3C (C) had spatially incompatible proximal and distal features available to represent Action A.

Table 1

Mapping of key presses to white box movements for each experiment.

Experiment	Key Presses	White Box Movements
1	Left hand: Center-Up-Center	No white box
	Left hand: Center-Down-Center	No white box
	Right hand: Center-Up-Center	No white box
	Right hand: Center-Down-Center	No white box
2	Left hand: Center-Up-Center	Left side: center, up, center
	Left hand: Center-Down-Center	Left side: center, down, center
	Right hand: Center-Up-Center	Right side: center, up, center
	Right hand: Center-Down-Center	Right side: center, down, center
3A	Left hand: Center-Up-Center	Right side: center, down, center
	Left hand: Center-Down-Center	Right side: center, up, center
	Right hand: Center-Up-Center	Left side: center, down, center
	Right hand: Center-Down-Center	Left side: center, up, center
3B and 3C	Left hand: Center-Up-Center	Right side: center, up, center
	Left hand: Center-Down-Center	Right side: center, down, center
	Right hand: Center-Up-Center	Left side: center, up, center
	Right hand: Center-Down-Center	Left side: center, down, center