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Two Routes to the Same Action: An Action Repetition Priming Study

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ABSTRACT. Action selection can be influenced by preceding movements. The authors investigated how retrospective factors may interact with plan versus rule based action selection. Participants completed 2 tasks, both of which involved selecting a pronated or supinated posture. In the plan task, they chose the most comfortable hand orientation. In the rule task, they followed a learned prescription. Trials in both tasks comprised prime probe pairs that were identical, or differed in the visual stimulus or required motor response. Both tasks showed a response time advantage for probes that were preceded by identical primes. This effect was greater for the plan task suggesting that plan based action selection is especially susceptible to recent history, fortifying the idea that differential mechanisms underlie a rule versus plan based approach to the same action.

Keywords: action planning, action repetition priming, action selection, motor history, rule based action

There is evidence demonstrating that the probability of selecting a given action is increased when that same action or aspects of the action have been performed prior (repetition effect, action priming): for example, action repetition priming can lead to faster response times (RTs; Craighero, Fadiga, Rizzolatti, & Umilta, 1999; Valyear & Frey, 2014). Another resulting effect may be the tendency to perseverate previously executed postures (Dixon, McAnsh, & Read, 2012; Glover & Dixon, 2013), or movement trajectories (Jax & Rosenbaum, 2007). Reduced RTs because of repetition suggest that repeating action parameters results in advantages in action selection. This advantage is important because the existence and specificity of action priming provides a window into the way that actions are represented and accessed in the brain. The source(s) of this retrospective influence are not yet well explained.

In a previous study (Randerath, Martin, & Frey, 2013) we have shown that for certain tool-manipulations, grip selection can be solved using different approaches: based on a rule (following a learned stimulus response association) versus based on planning (choosing the most comfortable hand orientation to complete the task). In the previous study, we demonstrated differential priming effects of prior tool use on rule- versus plan-based tool grip selection. For grasping tools based on a rule (grasp only), RTs were modulated in terms of interference effects: Participants responded slower when the responding hand was opposite from the tool's handle (e.g., right hand grasping a left-oriented tool). The effect was apparent only when the tools have been extensively used shortly beforehand. This reflects a tool use carryover effect, and supports the hypothesis that prior activated tool use processes in the brain can remain effective over time. Importantly, RTs are not modulated by preceding tool use when, instead of simply grasping based on a rule, participants have to plan a grasp and then subsequently rotate the tool. This suggests that despite relatively similar (although not entirely identical) motor outputs, rule- versus plan-based selection may rely on different mechanisms in the brain. However, it remains unclear whether differential effects of history for these two approaches to action selection are generalizable (i.e., toward tasks that do not involve familiar tools and that involve entirely identical motor outputs). The latter was investigated in the present study.

Studies over the past century have shown that simple rule- and plan-based action selection can be influenced by prior trial history leading to repetition effects. But there has been no comparison between the two approaches to selecting the very same action. For tasks involving action planning, such as selecting a comfortably oriented grasp, it has been argued that retrospective effects reflect reduced computational demands (e.g., Rosenbaum, Chapman, Weigelt, Weiss, & van der Wel, 2012). The idea is that response priming reflects the recycling of recently used movement parameters that persist for some time in the system (Jax & Rosenbaum, 2007; Valyear & Frey, 2014). One idea is that the major source for action priming represents response selection based on previously acquired stimulus response mappings. From an ecological perspective, stimulus-bound action units make sense to allow adapted responses to object related actions the environment may afford, allowing for efficient action selection when stimuli or stimulus features (e.g., form, shape, weight) are repeated versus changed. In line with these arguments, the theory of event coding argues that stimulus and response features are integrated, meaning that perception and action representations interact, whereby representations are thought of as feature composites in widely distributed feature networks (Hommel, 2009; Hommel, Muesseler, Aschersleben, & Prinz, 2001).

Studies investigating rule-based action selection using speeded choice tasks with simple response movements

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similarly point out the importance of the link between stimulus and response for action priming (Bertelson, 1965; Pashler & Baylis, 1991). Pashler and Baylis ran a series of experiments with learned stimulus-response mappings to address whether repetition effects on RT are based on a speedup of perceptual processing of the repeated stimulus, response selection based on the repeated stimulus-response association, or whether the repetition facilitates the execution of the response itself. They found that same responses only show a response time benefit, when they were associated with a repeated stimulus or when the stimulus was grouped into the same category as the one presented previously. Pashler and Baylis concluded that RT reductions due to repetition arise from a speed-up of the response selection, based on stimulus code (when mentally translating between stimulus and response), not perceptual identification or repetition of movement parameters.

To date, it is uncertain what role computational demands on action selection may play for action repetition priming as measured by RTs. It remains to be elucidated whether rule- and plan-based action selection make use of the same repetition mechanisms or whether priming-effects based on repetition have to be distinguished for the two approaches. Here, we vary the demands on action selection by measuring priming-effects in two different tasks, a task that involves prospective planning to select an action (plan task), and a rule task that introduces a simple rule to get to the very same actions using similar stimuli. We make use of an action repetition priming design, which can be viewed as a specific form of testing immediate effects of retrospective factors, by presenting two events in a row within a trial (first: prime, second: probe). RT can be modulated for the probe depending on its congruency with the prime. Congruent information can, for example, consist of repeating features of the stimulus, or the movement. Congruent or repeated events can accelerate the response to the probe, whereas incongruent or differing events can prolong responses to the probe.

To further explore whether movements themselves are susceptible to recent action history, Experiment 1 included three conditions, defined by the relationship between prime and probe events: (a) both the stimulus and motor output are the same, (b) both the stimulus and motor output are different, or (c) the stimuli are different but evoke the same motor output (see Figure 1). Experiments 2 and 3 were conducted as control experiments.

Predictions

> Hypothesis 1: We predicted that both tasks would show the fastest RTs for the probe event when the stimulus and response are repeated. To the extent that priming is specific to the actual selection process (as opposed to perception or motor execution), these effects would be larger for the plan versus the rule task.

> Hypothesis 2: If action repetition priming is attributable to the repetition of movement parameters, we would also pre dict faster RTs in our action repetition priming design, when movements are repeated but perceptual stimuli differ compared to when both differ.

Remarkably, to our knowledge only a few studies have investigated RTs in action repetition priming by manipulating the repetition of manual responses (Cant, Westwood, Valyear, & Goodale, 2005; Valyear & Frey, 2014). By use of a novel action repetition priming design, the present study provides information about how the repetition of movements or visual stimuli contribute to action repetition priming, and, most importantly, how these effects interact with different approaches to the same action: plan-based action selection versus rule retrieval. The results shed new light on how actions are cognitively processed.

EXPERIMENT 1

Method

Participants

Volunteers who participated in the experiment either received course credits or were paid for the 90-min experiment. Out of 34 participants, two were discarded from further analysis because the percentage of missing values (caused by errors and response time outliers) exceeded the group mean by more than two standard deviations, suggesting noncompliance. Of the 32 included participants, 18 were women and 14 men. The mean age was 23 years ($SD = 3.3$ years). Participants were right-handed, which was assessed with the Edinburgh Inventory (Oldfield, 1971). The work of Experiments 1 and 2 received approval by the local ethics committee (Institutional Research Board) at the University of Oregon.

Material and Procedure

Stimuli. Stimuli were images of plates with a diagonal slot and an orange and a pink circle at the slot's ends, as well as one orange- or pink-colored arrow cue displayed in the upper left or lower right corner of the plate. Stimuli were presented as displayed in Figure 1, by use of the Superlab Software (www.cedrus.com) on a 32.5 × 51.8 cm iMac Screen (OS X Lion, Apple, Cupertino, CA). Tasks were cued by the form of the fixation point, present in the center of each stimulus. In Experiment 1, for 15 participants, a diamond cued the plan task and a cross indicated the rule task, for the other 17 participants the cueing was reversed. Within one trial two events (prime and probe) of the same task, rule or plan was presented. One trial consisted of 15-s fixation point. A flicker of the fixation point indicated that a prime-stimulus was presented in 0.5 s. The prime-stimulus stayed for 2.5 s. After an additional 2.5 s

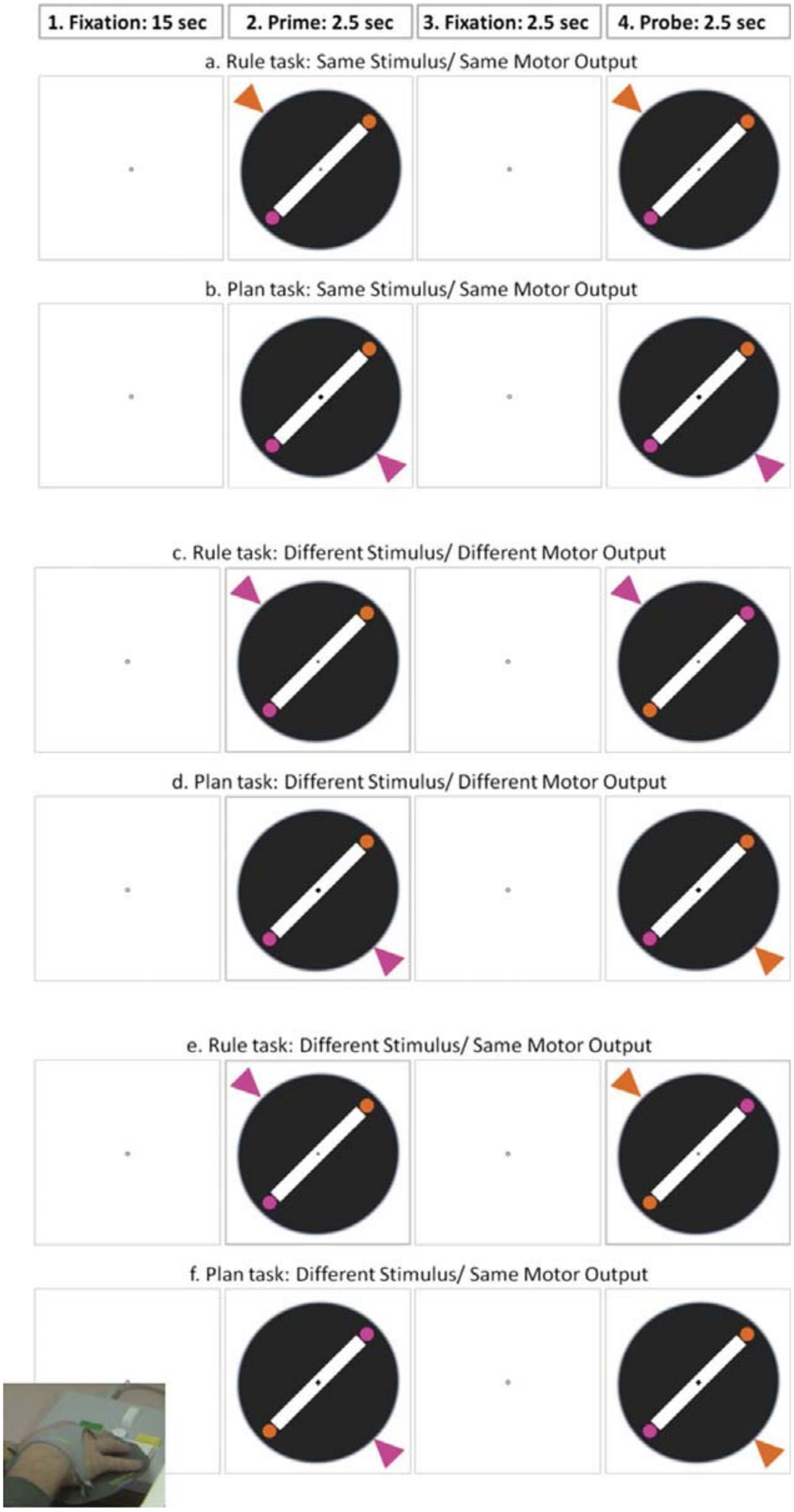

FIGURE 1. The figure displays example trials. The plan and rule tasks were presented intermixed within six blocks of 18 trials. Within one trial two stimuli of the same task were presented. The task was indicated by the form of the fixation point presented centrally within the stimulus (e.g., a diamond indicated the plan task and a cross the rule task). In the rule task, participants had to pantomime inserting their hand with the thumb toward the same colored circle as the arrow. They then rotated the plate to align

interstimulus interval with a fixation point, the probe stimulus occurred for 2.5 s. In Experiment 1, it was varied within a trial whether the prime and probe event had (a) the same stimulus evoking the same motor response, (b) a different stimulus evoking the same motor response, or (c) the prime and probe had different stimuli requesting different motor responses. The experiment consisted of six runs with 18 trials each, resulting in six trials per condition in one run. Tasks were presented intermingled in a fixed random order, with a maximum of three trials of the same task in a row.

Tasks. The introduced plan task is based on the so called end-state comfort effect, because it is robust and offers a simple way of monitoring the outcomes of action planning. A wide range of studies have shown that the intention to achieve a biomechanically comfortable end position is taken into account before the execution of a movement, meaning that action selection is based on planning (e.g., Johnson, 2000a, 2000b; Randerath, Goldenberg, Spijkers, Li, & Hermsdorfer, 2010; Randerath, Li, Goldenberg, & Hermsdorfer, 2009; Rosenbaum et al., 1990; Short & Cauraugh, 1997; Weigelt & Schack, 2010). In the present plan task, participants were told to choose the most comfortable way to pantomime inserting the paddle and rotating the plate into a specific end position (e.g., if the arrow cue was pink, then the object was rotated in such a way that the end with the pink circle was aligned with the arrow). Insertion and rotation movements were executed with the lower right arm only. In the rule task, participants followed a rule for pantomiming a hand-posture. They were asked to pantomime inserting the paddle into the slot in such a way that the thumb was directed toward the circle that had the same color as the arrow cue. For example, if the arrow cue was pink, then the thumb had to be directed toward the pink circle. Participants then rotated the plate so that the same colored circle was aligned with the arrow. Both tasks involved the exact same motor outputs: Participants had to either produce overhand (palm down), or underhand (palm up) postures for the insertion, and then they rotated the plate involving the exact same path length. Based on awkwardness rating results by Johnson (2000b), a slot angle was chosen that was comfortable for both underhand and overhand insertion postures produced with the right hand, reflecting a diagonal plane at 315°. Experiments were videotaped to determine type of selected posture (see also Randerath et al., 2013).

A button device was used to measure RT (Cedrus, RB350). Participants wore a swim paddle on their right hand while their elbow rested on a Styrofoam block. To facilitate holding the button down with the paddle, a piece of cardboard (8 × 3 cm) was attached to the button's surface. The participants' default position was to press the button unless they were responding. RTs were measured from the moment a stimulus was displayed until the participant released the button. The form of the fixation point informed the participant about which task they had to perform. The instructions ended with the following information:

> Please begin with the task as soon as you see the picture of the object. Continue focusing your eyes on the fixation cross. It is important that you demonstrate the movement accurately. Please do not leave any part of the movement out. Return to the default position after you completed the movement. Respond as quickly but also as accurately as you can.

Training. Before being exposed to the experimental tasks, participants were trained with a cardboard plate attached to a rotatable device. The cardboard included a slot and two circles at the slot's ends. Colored arrow cues were attached to the device and were exchanged using a Velcro mechanism. Training involved actual insertion and rotation of the paddle to train accurate movements. After that, participants were trained to pantomime the same movement in front of the screen. Participants were given feedback, when pantomime movements were inaccurate or sloppy and were prompted to produce the accurate movements such as in the training with the real plate.

Data Analysis

The dependent variable was RTs. Trials with errors or outliers in prime or probe were not considered for further statistical analysis. Errors were defined through video analysis (i.e., awkward movements, change of response, no response) and RT outliers were defined by the $M \pm 2$ *SD*. For the group of participants analyzed ($n = 32$), in the plan task the error percentage was 5.8 (*SD* = 4.2) and the outlier percentage was 4.2 (*SD* = 1.4). In the rule task, the participants' error percentage was 1.9 (*SD* = 2.0) and the outlier percentage was 4.5 (*SD* = 1.2). This affects 16.6% (*SD* = 6.7%) of the trials in the plan task and 11.6% (*SD* = 3.7%) in the rule task.

← **FIGURE 1.** *(Continued)* the same colored circle with the arrow cue. In the plan task, participants had to choose the most comfortable way to rotate the plate and align the same colored circle with the arrow cue. Per task there were three trial conditions for which prime and probe either varied or were the same: same stimulus, same output (SS/SO; a./b.: stimuli evoke a repeated underhand posture as motor output); different stimulus, same output (DS/SO; c.: prime overhand/probe underhand d: prime underhand/probe overhand); and different stimulus, different output (DS/DO; e./f.: switch in stimulus, but both the prime and probe stimuli evoke an overhand posture). Participants wore a swim paddle on their hand to reduce sloppiness of pantomime movements (see bottom left). Please note for grayscale prints: light gray colors correspond to orange, dark gray colors correspond to pink.

First with a repeated measures analysis of variance (ANOVA) probe-only method (traditional): per task and condition probe RTs were analyzed. To investigate the nature of the task by condition interaction, and better illustrate the differences between conditions according to task, post hoc, we used paired-samples *t* tests for group probe mean difference scores between conditions per task.

To obtain difference scores for the probes between conditions we computed the following subtractions separately for each task: (a) different stimulus, different output same stimulus, same output, (b) different stimulus, different output different stimulus, same output, and (c) different stimulus, same output same stimulus, same output.

Reported values reflect Greenhouse-Geisser correction results. Post hoc paired-samples *t* tests were applied. The significance of results is reported with respect to Bonferroni corrections for multiple comparisons (Bf-*p*: .05/number of comparisons).

Results and Discussion

History Effects

The repeated measures ANOVA was based on comparing probe RTs. For descriptions, see Figure 2 and Table 1. Main effects of task, $F(1, 31) = 32.44$, $p < .001$, and condition, $F(1.5, 46.1) = 87.76$, $p < .001$, as well as an interaction between the two variables, $F(2.0, 60.9) = 4.41$, $p = .017$, were found. The task by condition interaction reflects greater history effects for the plan versus rule task, consistent with the hypothesis that dissociable neural mechanisms underlie plan- versus rule-based action selection. RTs in the plan task were significantly slower than in the rule task. The same pattern of differences between conditions were evident for either task the repetition of both stimulus and response (same stimulus, same output) resulted in the fastest RTs, repetition of the motor response only (different stimulus, same output) resulted in intermediate RTs, while changing both the stimuli and motor response (different stimulus, different output) resulted in the slowest RTs (Bf-$p = .017$), $t(31) > 5.07$, $p < .001$. The task by condition interaction reflects the fact that these differences were more pronounced for the plan task.

To further investigate the nature of the task by condition interaction, and to better illustrate the differences between conditions according to task, Figure 2b shows the group mean probe difference scores between conditions per task. Although condition differences are more pronounced for the plan task for all comparisons, only the differences between the two extreme conditions (different stimulus, different output) > (same stimulus, same output) were found to be greater for the plan task compared with the corresponding difference scores for the rule task (see Table 1). Please note that this result also remains significant, when calculating the proportional difference per task (different stimulus, different output same stimulus, same output/mean of different stimulus, different output + same stimulus, same output) and then comparing the resulting ratios between tasks (Plan: $M = .10$, $SD = .06$; Rule: $M = .08$, $SD = .05$), $t(31) = 2.30$, $p = .029$.

These findings demonstrate differential sensitivity to recent motor history for RTs to initiate hand actions depending on whether or not those actions were selected based on arbitrary stimulus-defined rules (rule task) versus prospective planning (plan task). Repeating the stimulus or response between first (prime) and second (probe) actions had a greater impact on RTs for the plan task. In other words, these results indicate that plan-based selection is more sensitive to the effects of recent motor history. Importantly, these differences emerged even though the motoric characteristics of the hand actions that participants produced were the same for each task; only the means by which these movements were selected differed. These findings indicate that differences in RTs to execute probe actions according to condition (i.e., recent motor history effects) for the plan task cannot be explained entirely based on repeating versus changing the motoric aspects of successive actions (otherwise history effects would be the same for both tasks). Instead, we interpret greater history effects for the plan task as evidence that the mechanisms underlying prospective action planning and selection (e.g., in accordance with predictions about forthcoming task demands) are influenced by recent action selection history.

We recognized a potentially confounding factor that complicates interpretations of conditional differences, independent of task. Namely, the experiment comprised an equal number of trials per condition, however, two thirds of our conditions involved repeated motor responses (same stimulus: same output, different stimulus: same output). As such, participants might have anticipated response repeats, which might have accounted for (or exaggerated) differences in RTs across conditions. For example, the imbalance may have elicited prolonged RTs for the probe when a different output had to be planned, caused by an unfulfilled expectation to produce the same movement twice. To test for this possibility, we conducted Experiments 2 and 3, which each had only two conditions: Experiment 2: same stimulus, same output and different stimulus, different output and Experiment 3: different stimulus, different output and different stimulus, same output.

EXPERIMENT 2

Method

The majority of the methods including the approach to analyze the data are the same as in Experiment 1. Here we describe the few points (participants and trials) that differed.

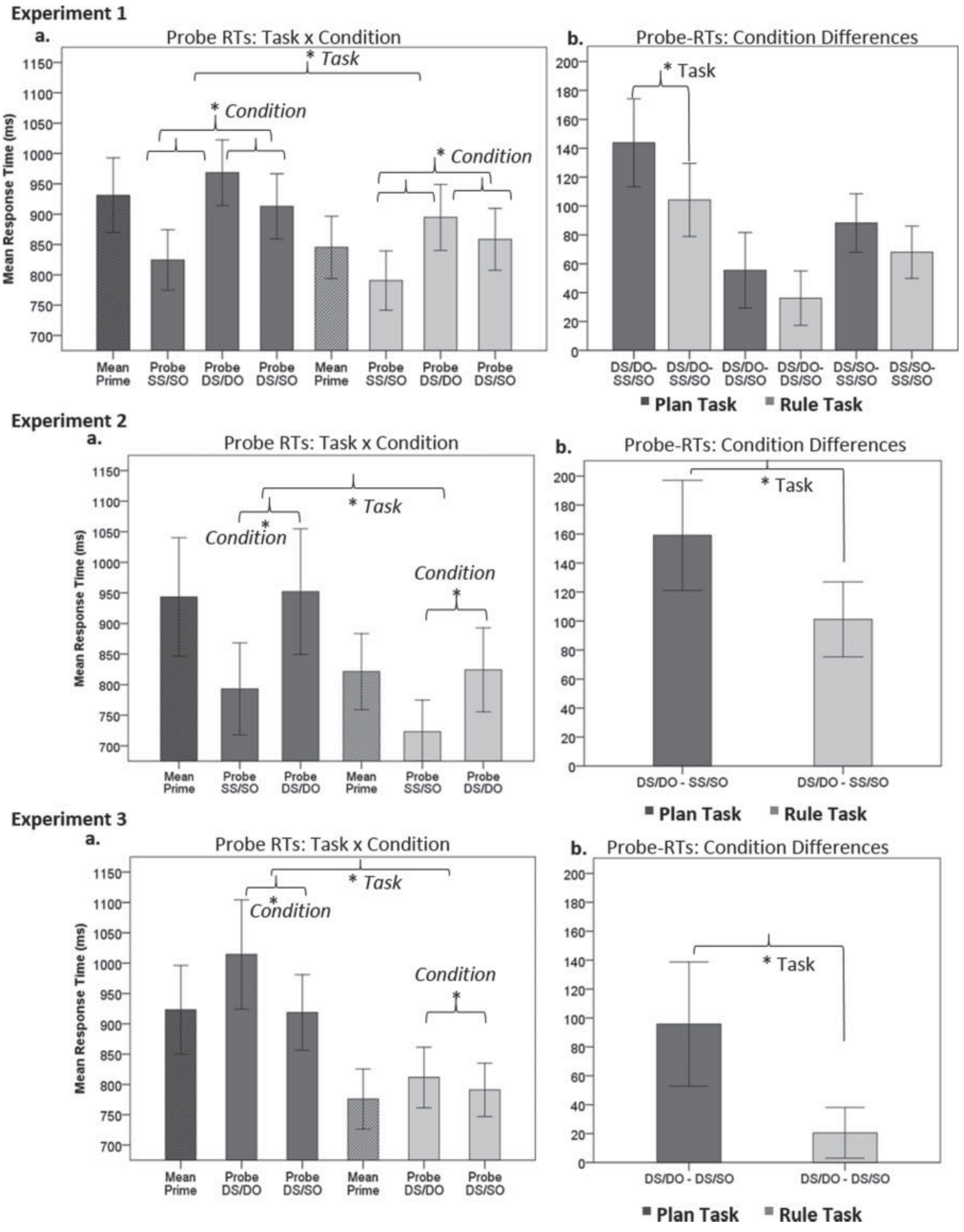

FIGURE 2. The results of the three experiments. (a) The mean probe RTs per task and condition: the main effect of task and condition as well as their interaction. Asterisks represent significant differences ($p < .05$). Probe RTs are fastest for repeated events (same stimulus, same output [SS/SO]) and slowest for completely different events (different stimulus, different output [DS/DO]). (b) The group mean difference scores between conditions per task. Differences between the two extreme conditions Experiment 1/2: different stimulus, different output versus same stimulus, same output were found to be greater for the plan task compared with the corresponding difference score for the rule task. Error bars represent 95% confidence intervals.

TABLE 1. Probe RT (ms) and Probe RT Differences Between Conditions (ms)

		Task					
		Plan		Rule		Condition average	
EXPERIMENT 1		*M*	*SD*	*M*	*SD*	*M*	*SD*
Condition	SS/SO	824.6	138.5	790.5	135.3	807.5	132.9
	DS/DO	968.3	150.1	894.6	151.0	931.5	146.5
	DS/SO	912.8	148.9	858.5	141.7	885.6	140.7
Task average		901.9	139.9	847.9	138.8		
PROBE DIFFERENCES	Task	*M*		*SD*		*t*(31)	*p*
DS/DO SS/SO	Plan	143.8		84.5		2.79	.009*
	Rule	104.2		70.3			
DS/SO SS/SO	Plan	88.3		56.2		1.48	.148
	Rule	68.0		50.2			
DS/DO DS/SO	Plan	55.5		72.3		1.59	.121
	Rule	36.2		52.1			
		Task					
		Plan		Rule		Condition average	
EXPERIMENT 2		*M*	*SD*	*M*	*SD*	*M*	*SD*
Condition	SS/SO	793.0	146.5	723.0	100.7	758.0	115.6
	DS/DO	952.1	199.6	824.1	133.4	888.1	160.3
Task average		872.6	171.1	773.6	115.5		
PROBE DIFFERENCES	Task	*M*		*SD*		*t*(16)	*p*
DS/DO SS/SO	Plan	159.1		73.9		4.82	<.001*
	Rule	101.1		50.3			
		Task					
		Plan		Rule		Condition average	
EXPERIMENT 3		*M*	*SD*	*M*	*SD*	*M*	*SD*
Condition	DS/DO	1014.3	186.8	811.4	103.6	912.9	183.3
	DS/SO	918.6	129.4	790.9	91.6	854.8	107.0
Task average		966.5	154.4	801.2	96.1		
PROBE DIFFERENCES	Task	*M*		*SD*		*t*(18)	*p*
DS/DO DS/SO	Plan	95.8		89.1		4.25	<.001*
	Rule	20.5		36.4			

Note. RT = reaction time; SS/SO = same stimulus, same output; DS/DO = different stimulus, different output; DS/SO = different stimulus, same output. Asterisks represent significant differences ($p < .05$).

Participants

This experiment included eighteen students. One was removed from further analysis because the percentage of missing values (errors + response time outliers) exceeds the group mean by more than two standard deviations in at least one of the two tasks. Of the 17 participants, 10 participants were women, 7 men. The mean age was 23 years (*SD* = 3.8 years). For nine participants, the task cue for the plan task was a diamond formed fixation point, and for the rule task, it was a cross. For the other participants task-cueing was reversed.

Material and Procedure

Similar to Experiment 1, within one trial two stimuli of the same task (rule or plan) are presented. However, Experiment 2 only included two conditions: prime and probe were exactly the same stimuli and requested the same motor output (same stimulus, same output) or the prime and probe had different stimuli and required a different motor output (different stimulus, different output). The experiment consisted of six runs with 16 trials each, which meant that there were eight trials per condition in one run.

Data Analysis

In the plan task, the participants' ($n = 17$) error percentage was 3.6 (*SD* = 4.4) and the outlier percentage was 4.4 (*SD* = 1.7). In the rule task, the participants' error percentage was 1.9 (*SD* = 2.5) and the outlier percentage was 4.5 (*SD* = 1.6). On average, 14.3% (*SD* = 7.0) of the plan task trials and 12.1% of the rule task (*SD* = 5.5) were removed from analyses.

Results and Discussion

History Effects

Results of Experiment 1 were replicated. Please see Figure 2 and Table 1. The repeated measures ANOVA revealed significant main effects of task, $F(1, 16) = 15.81$, $p = .001$, and condition, $F(1, 16) = 85.03$, $p < .001$, as well as the interaction, $F(1, 16) = 23.22$, $p < .001$. Differences between conditions were in the same direction for either task, responses for repeated events were fastest.

RT differences for the repeated versus the different condition were significantly more pronounced for the plan versus rule task (see also Table 1). The difference remained significant, when comparing the ratios between tasks (plan: $M = .11$, $SD = .04$; rule: $M = .08$, $SD = .03$), $t(16) = 3.63$, $p = .002$. These findings replicate those of Experiment 1, and demonstrate that plan- versus rule-based selection is more susceptible to recent motor history. These effects are easily visualized as the group-mean difference scores between conditions per task (Figure 2b). Also consistent with the results of Experiment 1, a main effect of task reflects faster RTs for the rule versus plan task independent of condition.

A third experiment was conducted to test for potential effects of the disproportionate number of same-output trials included in Experiment 1 on the RTs for the condition different stimulus, same output.

EXPERIMENT 3

Method

The work received approval by the local ethics committee (Institutional Research Board) at the University of Missouri.

Participants

This experiment included 21 University of Missouri students. Two were removed from further analysis because the percentage of missing values (errors + response-time outliers) exceeds the group mean by more than two standard deviations in at least one of the two tasks. Out of the 19 participants, seven participants were women, 12 were men. The mean age was 19 years ($SD = 1.4$ years).

For 10 participants, the task cue for the plan task was a diamond formed fixation point, and for the rule task, it was a cross. For the other participants task cueing was reversed.

Material and Procedure

Experiment 3 only included two conditions: prime and probe had different stimuli and required a different motor output (different stimulus, different output), or, the prime and probe had different stimuli and requested the same motor output (different stimulus, same output). The experiment consisted of six runs with 16 trials each; this meant that there were eight trials per condition in one run.

Data Analysis

Data of 19 participants was analyzed. In the plan task, the participants' error percentage was 10.0 ($SD = 5.6$) and the outlier percentage was 3.6 ($SD = 1.4$). In the rule task, the participants' error percentage was 2.1 ($SD = 2.1$) and the outlier percentage was 4.4 ($SD = 1.6$). On average, 16.1% ($SD = 6.1\%$) of the trials were removed from the plan task, and 10.5% from the rule task ($SD = 3.6\%$).

Results and Discussion

History Effects

The repeated measures ANOVA is based on comparing probe RTs. For descriptions, see Figure 2 and Table 1. Main effects of task, $F(1, 18) = 63.67$, $p < .001$, and condition, $F(1, 18) = 20.41$, $p < .001$, as well as the interaction, $F(1, 18) = 18.09$, $p < .001$, were significant. RTs in the plan task were significantly slower than in the rule task. Responses for repeated motor outputs are faster compared to different motor outputs.

The task by condition interaction reflects greater history effects for the plan versus rule task, consistent with the hypothesis that dissociable neural mechanisms underlie plan- versus rule-based selection. Figure 2b shows the task by condition interaction expressed as the group-mean difference scores between conditions per task. In contrast to Experiment 1, this further analysis showed that condition differences between different stimulus, different output and different stimulus, same output conditions are significantly more pronounced for the plan task compared with the corresponding difference score for the rule task (see also Table 1). Compared to the rule task, plan-based selection is more sensitive to these history effects. This result remains significant, when calculating the proportional difference per task (different stimulus, different output different stimulus, same output/mean of different stimulus, different output + different stimulus, same output) and then comparing the ratios between tasks (Plan: $M = .06$, $SD = .05$; Rule: $M = .02$, $SD = .03$), $t(18) = 4.50$, $p < .001$. Thus, whether motor responses are repeated or changed has significantly differential effects depending on the task in Experiment 3, but although tendencies are similar in Experiment 1 the task-differences do not reach significance for Experiment 1. Based on this observation, it has to be concluded that a frequency-imbalance of repeated versus changed motor responses could have influenced the results observed in Experiment 1 by way of shaping participants' expectations. Alternatively, the combination of different conditions may play a role in shaping participants' response tendencies.

Independent from these differences between Experiments 1 and 3, it can be concluded that it matters whether the same action is selected via a rule or plan based: the strength of repetition effects on action selection can be modulated by the approach.

GENERAL DISCUSSION

Previous research indicates that decision processes for action selection influence the time needed for response-initiation. RTs can furthermore be modulated by experience in prior trials (e.g., Valyear & Frey, 2013). When selecting actions the system tends to make use of previously activated components. Our goal was to shed light on whether action selection is affected differently by history depending on the route to solve the action. We present a novel paradigm introducing two different instructions to achieve the same action, namely inserting the hand (pronated vs. supinated) into a slot in order to rotate a wheel to a cued location. The solution for the rule task lies in simply following the rule for color cues. The solution for the plan task involves selecting an action through planning ahead, by taking the subsequent action into account. With our rule/plan paradigm, (see also Randerath et al., 2013) we introduce a way to manipulate computational demands for action selection. The main interest was in comparing history effects between tasks. In addition, by using a repetition priming design we manipulate within a trial (that includes two events of the same task: 1. prime, 2. probe) whether stimuli and response completely differ or whether they are repeated or whether stimuli differ but the response is still the same. In the present study, we show how plan- versus rule-based action selection interacts with repetition priming.

Approach to Action Selection

Both the rule and the plan task require solving a problem to achieve an appropriate action and only differ in the approach to get there.

The task effect across all experiments shows that RTs in the plan task are prolonged compared to the rule task. In line with these results, most participants report that the plan task was more demanding. Thus, the plan task's prolonged RTs can be attributed to higher computational demands caused by prospective planning: the approach to select the appropriate action is based on knowledge about the biomechanical properties of the right upper limb with respect to the prospective comfort of the action's end state. Whereas the rule task provides a prescription on how to select the appropriate action. A task main effect has been reported previously, in a study using the rule plan paradigm investigating effects of prior tool use on grasping (Randerath et al., 2013). Here, using a repetition priming approach we show in accordance with our predictions, that both tasks show fastest RTs for the probe event when the stimulus and the required response are the same as for the prime, thus a complete repeat. While rule-based repetition effects may be explained as related to changes in the efficiency of processes underlying the retrieval of rules (identification of stimuli and the retrieval of learned arbitrary stimulus response associations), plan-based repetition effects are interpreted as related to changes in the efficiency of processes underlying action planning and selection. Three experiments support the main finding that recent motor history has a greater impact on plan-based selection compared to solving the same action based on a rule. We predicted that the extent of priming is specific to the actual selection process (as opposed to perception or motor execution). It could be argued that when repeating the same action, the selection process based on the stimulus and task is uncalled for. Thus, the priming effect is defined by the reduction of the action selection process, which appears to be significantly more elaborate for planning. Furthermore, based on the idea that the selection process is omitted for repeated actions, one could speculate the following: if the two tasks used similar routes or mechanisms then probe responses for repeated events should be similarly fast; but if the two tasks show different probe RTs for repeated events, then at least partly distinct routes or mechanisms are used for either task. In the present study, the main effect of task supports the latter. Therefore, the idea of differentially involved mechanisms in rule- versus plan-based action selection is strengthened by the present study showing that (a) action repetition priming occurs in both tasks, but plan-based action selection appears to be particularly susceptible to history-effects, and (b) even for completely repeated events, probe RTs are slower for plan-based actions.

Priming of Perceptual or Motor Output Components

A limitation of our study with respect to disentangling priming due to perceptual or motor parameter repetition is that we cannot completely isolate stimulus and motor parameter repetition, because our tasks do not enable different motor outputs for the same stimulus. Our study does show that compared to completely differing events, repetition priming effects for RTs are strongest when the stimulus and motor response are both repeated, and intermediate when only the motor parameter but not the stimulus is repeated. Nevertheless, the present and other evidence support the idea that the underlying mechanisms for action repetition priming are not merely a summation of perceptual grounded or motor parameter repetition. First, with their rule-based action selection task, Pashler and Baylis (1991) drew a similar conclusion based on a same stimulus, different response condition. The response was either manual or vocal toward the same stimuli. Manual responses in the probe were not facilitated when the prime involved the same stimulus but a vocal response. On the other hand, these authors did find only little repetition benefit for the production of same responses when elicited by differing stimuli. Explanations for finding a lesser degree of priming-effects for repeating movement parameters could be related to the Bernstein problem or online adaptation of movements. The Bernstein (1965) problem is based on a traditional view by Nikolai Bernstein (1896 1996), who argued that absolute movement repetition is not possible because of the numerous degrees of freedom (Bongaardt, 2001; Latash, 1998; Sporns & Edelman, 1993; Stuart, 2005). In no situation can it be assumed that two successive responses are the same. Another, although not contradictory explanation why movement repetition effects could be expected to be reflected to a lesser degree in RT measurements is that, in visual guided actions, effector-specific movement parameters are adapted on-line while the movement is executed (Cant et al., 2005).

However, instead of attributing it to single aspects, repetition priming-effects are more likely predominantly induced by the facilitation of action selection through reactivation of stimulus bound action units. In line with this, and following the cognitive effort account in the motor learning literature, practice through repetition is viewed as an attempt to solve a goal related movement problem, given previous experience with the same problem (process of solving) rather than through repeating the same movements over and over again (means of solution; Bernstein, 1967; Lee, Swanson, & Hall, 1991; Sherwood & Lee, 2003). A close link between visual stimuli and actions has been described in other studies including elements of priming. Experiments testing visuomotor priming for example show that presenting stimuli features that are congruent with aspects of the subsequent action can induce action preparation and accelerate RTs (Craighero, Bello, & Fadiga, 2002). Other studies investigating history effects found that grasp posture perseveration across trials appear to be tied to object identity instead of to the most recent postural kinematics (Dixon et al., 2012). In the present study, both of our tasks required the participants to resolve a puzzle to achieve the correct action, for which the solution was bound to the stimulus. This likely explains why repetition priming was strongest for completely repeated events. Importantly and advancing, our study underlines by means of a novel point that action repetition priming is neither solely based on perceptual priming nor mere repetition of the motor output: although both tasks used similar stimuli and responses, plan-based action selection showed stronger history effects compared to the rule-based approach to the same actions.

Our results fit with the theory of event coding (TEC) for action control (Hommel, 2009). It assumes an interaction and integration of perception and action, with cognitive representations thereof being composed by feature codes in widely distributed feature networks. According to TEC, action control specifies only those parameters that are essential for achieving the action goal, and thereby it distinguishes cognitive representations as part of the feedforward component of action control from online adaptation of motor outputs to the physical environment. TEC claims binding operations are necessary to relate the codes to the same event. Registering a stimulus should then suffice to spread activation to the associated response. Applied to the present study, rule- versus plan-based action repetition priming may be based on binding operations in partly distinctive networks defined by the task.

Conclusions

Evident in all experiments was the common result that recent motor history had the greatest impact on plan-based compared to rule-based action selection. In other words, these results indicate that plan-based selection is more sensitive to the effects of recent motor history. Importantly, these differences emerge even when the motoric characteristics of the hand actions that participants produced were the same for each task; only the means by which these movements were selected differed. These findings indicate that differences in RTs to execute probe actions according to condition (i.e., recent motor history effects) for the plan task cannot be explained entirely by repeating versus changing the motoric aspects of successive actions (otherwise history effects would be equivalent for both tasks). Instead, we interpret greater history effects for the plan task as evidence that the mechanisms underlying prospective action planning and selection (e.g., in accordance with predictions about forthcoming task demands) are uniquely influenced by history-effects. To say the same thing differently, differential priming for rule- versus plan-based action selection supports the argument that these tasks involve distinct routes to the same action.

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