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Self-controlled KR schedules: Does repetition order matter?

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ABSTRACT

The impact of an experimenter-defined repetition schedule on the utility of a self-controlled KR context during motor skill acquisition was examined. Participants were required to learn three novel spatial-temporal tasks in either a random or blocked repetition schedule with or without the opportunity to control their KR. Results from the retention period showed that participants provided control over their KR schedule in a random repetition schedule demonstrated superior learning. However, performance measures from the transfer test showed that, independent of repetition schedule, learners provided the opportunity to control their KR schedule demonstrated superior transfer performance compared to their yoked counterparts. The dissociated impact of repetition schedule and self-controlled KR schedules on retention and transfer is discussed.

1. Introduction

Practice contexts organized to challenge the information processing capabilities of the learner are believed to be an important factor facilitating motor skill acquisition (Guadagnoli & Lee, 2004; Lee, Swinnen, & Serrien, 1994; Schmidt & Bjork, 1992). Such practice contexts are referred to as *cognitively effortful* because the processing demands required by the learner to plan, execute, and interpret the outcome of their motor action are heightened (Guadagnoli & Lee, 2004; Lee et al., 1994). Understanding the cognitive mechanisms responsible for the learning advantages associated with cognitively

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effortful practice continues to be a topic of interest in understanding the practice factors facilitating motor skill learning (for reviews see Guadagnoli & Lee, 2004; Lee et al., 1994; Schmidt & Bjork, 1992).

During motor skill learning, the predictability of the repetition schedule (i.e., blocked versus random repetitions) as well as the availability of augmented feedback (frequent vs. infrequent) are two practice variables shown to differentially modulate the cognitive demands imposed on the performer (for reviews see Guadagnoli & Lee, 2004; Wulf & Shea, 2002). Repetition schedules requiring the performer to actively engage in the cognitive processes that are required to *plan* a motor action on each repetition (i.e., random or serial repetition schedule are considered cognitively effortful) have proven superior for learning compared to repetition schedules considered to place predictably lower amounts of motor planning demands on the learner's cognitive processes (i.e., a blocked repetition schedule requires low cognitive effort; see Lee & Simon, 2004 for a review). The learning advantages of cognitively effortful repetition schedules have been attributed to the heightened demands placed on the learner's working memory required for such motor planning processes as inter-task comparisons; (e.g., Shea & Morgan, 1979; Shea & Zimny, 1983, 1988) and construction of motor plans (e.g., Lee & Magill, 1983, 1985). Likewise, providing the learner augmented feedback (i.e., knowledge of results (KR)) on less than 100% of the acquisition trials has been shown to facilitate greater learning compared to providing KR on all trials (see Salmoni, Schmidt, & Walter, 1984; Wulf & Shea, 2004 for reviews). The heightened cognitive processing required by the leaner during the no-KR trials to consciously interpret their intrinsic sources of task related information subsequently strengthens their independence in error detection and correction.

Combining a random repetition schedule with increased no-KR trials (e.g., response interpretation phase) offers a novel method of cognitively challenging the learner in both the *motor planning* and *response interpretation* phases of a motor trial. In fact, the learning benefits associated with both the manipulation of the repetition schedule and provisions of KR have independently proven to be robust. Until recently, the potential *additive* learning advantages of combining these practice contexts has received minimal attention. For example, Wu et al. (2011) examined whether practicing in a random practice schedule combined with a faded-KR schedule (e.g., high cognitive effort) would prove more advantageous to learning compared to receiving faded-KR under a blocked schedule, KR on all trials in a random schedule, and KR on all trials in a blocked schedule (i.e., low cognitive effort). The results showed the characteristics of the repetition schedule (i.e., random repetition schedule) was the practice factor facilitating motor learning, irrespective of the KR schedule. Thus, an additive learning advantage of challenging both the motor planning (i.e., random repetition schedule) and response interpretation (i.e., faded KR) components of a motor trial was not supported. However, an earlier study showed an additive learning advantage when a random repetition schedule was combined with providing KR in a summary format (e.g., Del Rey & Shewokis, 1993). Collectively, the aforementioned results suggest the potential learning advantages of challenging the cognitive processes required to plan a motor action, and those processes required for error detection and correction remains inconclusive.

Understanding the cognitive mechanisms underlying the learning advantages of practice contexts considered cognitively effortful have until recently been attributed to practice contexts defined by the researcher (i.e., externally defined; Guadagnoli & Lee, 2004; Lee et al., 1994; Schmidt & Bjork, 1992). However, an increasing body of literature suggests that providing the learner control over their *repetition schedule* (e.g., Keetch & Lee, 2007; Wu & Magill, 2011) or *KR schedule* (e.g., Chiviacowsky & Wulf, 2002; Hansen, Pfeiffer, & Patterson, 2011; Patterson & Carter, 2010) has a positive impact on skill acquisition. In fact, during multi-task learning, learners have shown a preference for a blocked repetition schedule early in the acquisition period, followed by a preference for a random repetition schedule later in practice, to the advantage of learning (Hodges, Edwards, Luttin, & Bowcock, 2011; Wu & Magill, 2011). Commensurately, learners demonstrate frequent requests for KR early in practice, followed by less-frequent requests for KR as a function of practice trials completed (Chiviacowsky & Wulf, 2002). The learning advantages of a self-controlled practice context are suggested to be the results of a practice context that is individualized to systematically challenge the information processing capabilities of the learner, to the benefit of learning (Chiviacowsky & Wulf, 2002; Patterson & Carter, 2010; Patterson, Carter, & Sanli, 2011; see Wulf, 2007 for review).

The learning advantages associated with a self-controlled practice context have been important in extending our theoretical understanding of the practice variables facilitating motor skill acquisition. However, it is unknown whether these learning benefits would persist, or perhaps be enhanced when combining a self-controlled practice variable (i.e., KR) with an externally defined practice variable, also considered cognitively effortful (i.e., random repetition schedule). Recently, Ali, Fawver, Kim, Fairbrother & Janelle (2012) showed no learning advantages of providing the learner self-control over their KR in a repetition schedule. The authors suggested the simplicity of the to-be-learned motor task (e.g., anticipation timing task) such that it was considered to be learnable independent of KR, undermined a potential additive learning effect of combining self-controlled KR in a random repetition schedule. Thus, Ali et al. (2012) recommend utilizing motor tasks that are considered more complex and require a certain proportion of KR trials to learn the task. The key pressing sequences utilized in the present experiment have previously been shown to vary in perceived complexity and require a certain proportion of KR trials to be learned (see Patterson & Carter, 2010). We believe the results from this inquiry would extend our theoretical and practical understanding of practice contexts that challenge both the *motor planning* and *response interpretation* processes that occur during motor skill learning. Thus, the purpose of the present experiment was to determine whether the learning advantages associated with a self-controlled KR context would be differentially modulated by the structure of the repetition schedule (i.e., externally defined blocked or random repetition schedule). In the present experiment, participants were required to learn three novel spatial-temporal tasks in a researcher defined repetition-schedule (either blocked or random repetition schedule) combined with the opportunity to either self-control their KR schedule or not (i.e., yoked condition). We predicted the following: 1) participants in a random repetition schedule would demonstrate superior learning to those in a blocked practice schedule based on the increased demands on the learner's working memory to plan a motor action (i.e., recall schema; Schmidt, 1975); 2) participants self-controlling their KR schedule would demonstrate superior learning compared to those who do not engage in the increased processing demands used to individualize their KR schedule (i.e., recognition schema; Schmidt, 1975); and 3) based on the temporal dissociation between the cognitive processing events required for motor planning and those required for response interpretation, participants experiencing a *random repetition schedule* (high cognitive effort) combined with *self-controlling* their KR (high cognitive effort) would perhaps demonstrate superior to learning compared to those participants not being cognitively challenged during both motor planning and response interpretation.

2. Method

2.1. Participants

Forty-eight undergraduate students participated in this study (M = 21.3 years, SD = 1.39; 28 females, 20 males; 5 males and 7 females for each experimental condition). All participants provided informed consent prior to commencing the protocol and were provided with course credit upon completion of the experiment. All participants were naive to the purposes of the experiment.

2.2. Apparatus

The apparatus and task were a replication of those employed by Patterson and Carter (2010). Specifically, participants were seated at a table in front of a serial response box (SR box; Model #200A, PsychNet Tools) and a 19 inch LCD monitor. The SR box consisted of five 1 cm^2 buttons that were sequentially labeled one to five from left to right. A Dell OptiPlex GX620 desktop computer ran the LCD monitor, took input from the SR box, and ran a custom made E-Prime 2.0 program (Psychology Software Tools Inc.). The E-Prime program controlled the sequencing of the trials, the presentation of the stimuli, and recorded all the temporal response measures.

2.3. Task

Replicating the key-pressing sequences of Patterson and Carter (2010), participants were required to learn three novel 5-digit key-pressing sequences that had a separate goal movement time (MT). Participants were required to complete the sequences using the index finger of their dominant hand. The key pressing sequence and temporal goal of each sequence was the following: For sequence A, participants were required to depress keys 5-4-3-1-2 in a goal MT of 2550 ms; for sequence B, participants were required to depress keys 1-3-4-2-5 in a goal MT of 1800 ms; and for sequence C, participants were required to depress keys 3-2-5-1-4 in a goal MT of 1050 ms. Participants were asked to complete each sequence as close as possible to the required MT (e.g., depress 1-3-4-2-5 as close as possible to 1800 ms). For the transfer phase, participants were asked to complete a novel 5-digit key pressing sequence (4-5-2-3-1) in a goal MT of 3300 ms.

2.4. Procedure

All participants were tested individually and were quasi-randomly assigned to one of four groups. The four groups resulted from a factorial combination of KR condition (self-control, yoked) and repetition schedule (Blocked, Random). Participants in the self-control conditions were provided with the opportunity to request KR for their most recent attempt. In contrast, participants in the yoked conditions replicated the individualized KR schedule and practice schedule of a self-control counterpart. Participants in the yoked conditions were provided with KR on the same trials as their self-controlled counterpart, yet without the choice (Chiviacowsky & Wulf, 2002; Patterson & Carter, 2010).

Participants in the random practice condition practiced one of the three sequences on a given trial with the requirement that a sequence was not practiced on two consecutive trials. Participants in the blocked condition completed all trials of one sequence, before practicing a subsequent sequence. The practice schedules for the three key pressing patterns were counterbalanced across participants. All participants completed a total of 30 practice trials with each of the sequences for an overall total of 90 acquisition trials.

For the pre-acquisition phase, participants read through a series of instructions slides that outlined the protocol, the goal of the task, and their respective KR condition. Participants in the self-control conditions were informed that they were required to decide whether or not they required KR regarding their most recently completed trial after the completion of each acquisition trial. The response was a verbal "yes" or "no" addressed to the experimenter. Similar to past research (e.g., Patterson & Carter, 2010), participants in the yoked conditions were informed they would receive KR on some trials and not on others. All participants completed one practice trial in their respective experimental condition to ensure understanding of the experimental protocol and the information being presented in the KR display screen. The key-pressing sequence used during the practice trial was novel and was not used during the remainder of the study.

A typical acquisition trial began with participants viewing the required key pressing sequence (e.g., 3-2-5-1-4) accompanied by the required goal MT (e.g., 1050 ms) for 5 s. During this period, participants were instructed to study the to-be-completed key-pressing sequence and goal MT while resting the index finger of their non-dominant hand on the first key in the sequence (e.g., 3). The start key for each sequence on the screen was surrounded by a red square. Following the 5 s display, the key-pressing sequence was replaced by five colored boxes for 3 s and then replaced by the second presentation of the key pressing sequence and its associated goal MT. The presentation of the latter display cued participants to begin their motor response as soon as they were ready. The display remained on the screen until all five keys were pressed on the SR box. Upon trial completion, participants in the self-control conditions were asked to orally state *yes* or *no* regarding their preference to receive KR on the just completed trial. If they responded "yes", KR was displayed for 5 s consisting of the goal MT (e.g., 2550 ms) and their just performed MT (e.g., 2300 ms). On trials where the key pressing sequence was performed incorrectly, subjects were informed the sequence was incorrect and no further KR was provided. Participants then repeated the sequence in a manner that was consistent with their respective repetition condition (i.e., on the following trial for the blocked condition and at the end of acquisition period for the random repetition condition). Participants in the self-control conditions were informed that KR would only be provided when requested and should only be requested when required, as they would eventually be asked to complete the task without KR. Participants in the yoked conditions were also informed they would eventually be asked to perform the task without KR. On the no-KR trials, participants in the self-controlled and respective yoked conditions viewed a blue screen for 5 s equating the duration of the KR and no-KR trials.

Participants in the yoked conditions replicated the repetition and KR schedule of their self-controlled counterpart. All temporal measures (e.g., movement time) and the accuracy of the key pressing sequences during the acquisition, retention, and transfer phases were recorded by the customized software.

Upon completion of the acquisition period, the participants were questioned regarding their preference for KR as a function of feedback type (self/yoked) and repetition schedule (blocked/random). Similar to Chiviacowsky and Wulf (2002) and Patterson and Carter (2010), participants in the self-control conditions were asked to self-report their preferences for KR during the acquisition period (i.e., after perceived good trials, poor trials, randomly, other, etc., as a function of sequence). Similarly, participants in the yoked conditions were asked to report if they received KR after their preferred trials, and if not, when would have they preferred to receive KR (i.e., on good trials, poor trials, good and poor trials, randomly, other). Total completion time for the questionnaire by all participants was approximately 15 minutes.

Learning was assessed at two separate temporal intervals after completion of the acquisition period. The immediate (15 minutes after the last acquisition trial) and delayed retention tests (24 hours after the last acquisition trial) both consisted of five trials of each sequence. The repetition order was counterbalanced across participants with no two trials of the same sequence being repeated on consecutive trials. For the retention tests, participants viewed the key pressing sequence *without* the required goal MT. Thus, participants were required to recall and complete the cued sequence in as close as possible to the associated goal MT. Following the delayed retention test, participants completed a transfer test consisting of five no-KR trials of a novel 5-digit key pressing sequence (4-5-2-3-1) with an associated goal MT of 3300 ms.

2.5. Data analysis

Percent absolute constant error (%|CE|) and coefficient of variation (*CV*) were calculated to measure temporal accuracy and consistency. Consistent with Simon and Bjork (2001, 2002) and Patterson and Carter (2010), |CE| measures were converted to %|CE| to assess performance on three different 5-digit key pressing sequences as function of KR condition and practice schedule. The absolute constant error (|CE|) was defined as the absolute value of the difference between the goal MT and the response MT of an attempt. The %|CE| is calculated by dividing |CE| by the corresponding goal MT and multiplying by 100. Coefficient of variation (*CV*) was utilized as an index of variability of motor performance of participants during the acquisition, retention, and transfer portions of the experiment (Patterson & Carter, 2010).

For the acquisition data, %|CE| and *CV* were grouped into six blocks of five trials, collapsed across sequence. The interaction of KR Condition × Repetition Schedule × Sequence was not statistically significant (p's > .05) for %|CE| or *CV*, and therefore sequence was not included as a within subjects factor during all analyses. The %|CE| and *CV* were submitted to separate 2-KR Condition (self-control, yoked) × 2-Repetition Schedule (blocked, random) × 6-Block mixed analysis of variance (ANOVA) with repeated measures on block. For the immediate and delayed retention test as well as the transfer test, %|CE| and *CV* were each averaged into one block of five trials. Separate 2-KR Condition (self-control, yoked) × 2-Repetition Schedule (blocked, random) × 2-Retention Test (immediate, delayed) mixed ANOVA with repeated measures on the last factor were employed to analyze the retention data. A 2-KR Condition (self-control, yoked) × 2 Repetition Schedule (blocked, random) two-way ANOVA was used to analyze the transfer performance. A 2-Repetition Schedule (Self-Blocked, Self-Random) by 6-Block ANOVA with repeated measures on the final factor was used to analyze the self-controlled feedback requests during the acquisition period. In all analyses, a significance level of $p < .05$ was used. Post hoc comparisons were conducted using a Tukey's HSD where appropriate. We corrected for violations of sphericity by using Greenhouse-Geisser procedures where appropriate.

3. Results

3.1. Acquisition

3.1.1. Feedback requests

Overall, participants in the Self KR-Random condition requested KR on 54.6% of the acquisition trials and the Self-Blocked condition requested KR on 62.9% of the trials (see Table 1). The analysis revealed a significant interaction of Repetition Schedule and Block, $F(5,100) = 4.73$, $p < .05$, $\eta_p^2 = .19$. The post-hoc results indicated that the Self KR-Block participants requested KR less during block 4 ($M = 57.1$, $SE = 16.8$) compared to block 1 ($M = 74.5$, $SE = 13.1$; see Table 1). Overall, the repetition schedule did not differentially affect the proportion of KR requested by participants in the self-controlled conditions during the acquisition period.

3.1.2. Acquisition %|CE|

Only a main effect for block, $F(5,200) = 54.92$, $p < .05$, $\eta_p^2 = 0.58$, was identified for %|CE|. Block 1 and 2 were performed with greater %|CE| compared to blocks 3-6 (see Fig. 1).

3.1.3. Acquisition CV

The analysis revealed main effects of repetition schedule, $F(1,40) = 4.61$, $p < .05$, $\eta_p^2 = .10$, and block, $F(5,200) = 24.1$, $p < .05$, $\eta_p^2 = 0.38$. Participants in a random schedule ($M = 14.17$, $SE = 0.63$) demonstrated greater *CV* than participants with a blocked schedule ($M = 12.87$, $SE = 0.63$). Participants displayed more *CV* in block 1 compared to blocks 2-6. The *CV* in block 2 was also greater compared to the *CV* in blocks 3-6 (see Fig. 2).

3.1.4. Self-reported KR scheduling strategy as a function of experimental condition

During single task learning, previous research has shown that participants in a self-controlled condition prefer requesting KR after what they perceived as good trials rather than poor trials. When the trials are separated post-hoc into KR and No-KR trial groups, the participants are observed to request KR on trials with less error (i.e., lower |CE|) than no-KR trials (e.g., Chiviacowsky & Wulf, 2002). In other words, participants claim to request KR on what they perceive as good performance trials and the post-hoc analysis confirms that the KR performance on KR trials is superior to the No-KR trials.

For the current study, we were interested in determining whether the structure of the repetition schedule differentially impacted self-control of KR strategies. The results of our self-report questionnaire, that was similar to Chiviacowsky and Wulf (2002), showed that 58% (7/12) of participants in the Self KR-Blocked condition and 67% (8/12) of participants in Self KR-Random condition reported a preference for KR after perceived good trials (see Table 2). To determine whether the self-control participants' strategy in requesting feedback for perceived *good* trials were commensurate with their actual motor performance on those trials (e.g., Chiviacowsky & Wulf, 2002; Patterson & Carter, 2010), we analyzed %|CE| on the KR versus no-KR trials with a 2-KR Condition (self-control, yoked) × 2- Repetition

Table 1
Proportion of KR trials during the acquisition period as a function of self-controlled KR condition with mean (ms) and standard error in parenthesis.

	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6
Self-Random						
2550 ms	0.44 (0.08)	0.56 (0.11)	0.69 (0.09)	0.56 (0.11)	0.53 (0.11)	0.62 (0.12)
1800 ms	0.53 (0.09)	0.58 (0.11)	0.65 (0.11)	0.60 (0.10)	0.60 (0.11)	0.58 (0.10)
1050 ms	0.40 (0.10)	0.54 (0.11)	0.53 (0.09)	0.49 (0.11)	0.51 (0.11)	0.41 (0.11)
M	45 (7.5)	56 (9.7)	64 (8.6)	55 (9.7)	54 (10.5)	54 (10.1)
Self-Blocked						
2550 ms	0.80 (0.08)	0.66 (0.11)	0.63 (0.09)	0.58 (0.11)	0.63 (0.11)	0.64 (0.12)
1800 ms	0.76 (0.09)	0.66 (0.11)	0.51 (0.10)	0.59 (0.10)	0.65 (0.11)	0.60 (0.10)
1050 ms	0.67 (0.10)	0.69 (0.11)	0.62 (0.09)	0.55 (0.11)	0.59 (0.11)	0.49 (0.11)
M	75 (7.5)	67 (9.7)	59 (8.6)	57 (9.7)	62 (10.5)	58 (10.1)

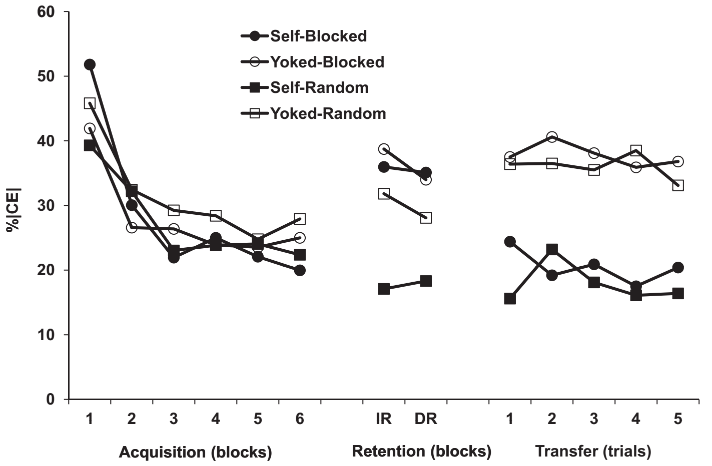

Fig. 1. Percent of absolute constant error (ms) as a function of group, practice schedule, and block (IR = immediate retention; DR = delayed retention). Please note: the transfer data is presented as trial × trial performance to highlight the transfer effects of the respective experimental practice conditions.

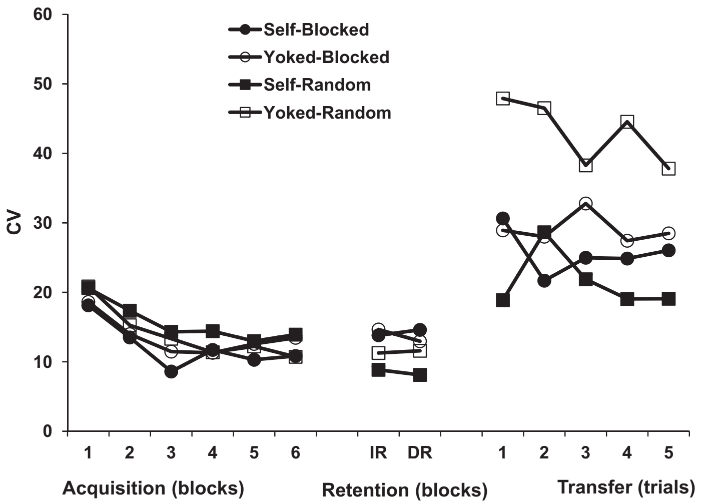

Fig. 2. Coefficient of variation as a function of group, practice schedule, and block (IR = immediate retention; DR = delayed retention). Please note: the transfer data is presented as trial × trial performance to highlight the transfer effects of the respective experimental practice conditions.

Schedule (blocked, random) × 2-Trial Type (KR, No-KR) ANOVA. Similar to Patterson and Carter (2010), the ANOVA failed to reveal significant effects whether for a KR Condition by Repetition Schedule × Trial Type interaction, $F(1,26) = 0.04$, $p = 0.85$, or a KR Condition × Trial Type interaction, $F(1,26) = 0.001$, $p = 0.97$, or a Repetition Schedule × Trial Type interaction, $F(1,26) = 0.10$, $p = .920$.

3.2. Retention

3.2.1. Retention %|CE|

The analysis revealed main effects of KR Condition, $F(1,40) = 4.40$, $p < .05$, $\eta_p^2 = 0.10$, and Repetition Schedule, $F(1,40) = 29.7$, $p < .05$, $\eta_p^2 = 0.43$. In addition, there was a significant interaction of

Table 2
Number of responses (#) to the debriefing questions.

	Self-Random			Self-Blocked				Yoked-Random			Yoked-Blocked		
Sequence	54312	13425	32154	54312	13425	32154		54312	13425	32154	54312	13425	32154
Motor Time Goal	2250	1800	1050	2250	1800	1050		2250	1800	1050	2250	1800	1050
When/Why did you ask for feedback for the above sequence?							*Do you think you received feedback after the right trials?*						
Perceived good trial	6	5	7	6	7	6	YES	2	6	6	7	6	5
Perceived poor trial	2	2	2	1	–	–	NO	10	6	6	5	6	7
Perceived good and poor trials equally	2	2	2	5	5	6							
Randomly	1	2	1	–	–	–							
Other	1	1	–	–	–	–							
When did you not ask for feedback for the above sequence?							*If no, when would you have preferred to received feedback?*						
Perceived good trial	1	2	1	2	7	1		2	1	2	4	3	5
Perceived poor trial	8	6	10	10	–	11		6	3	3	1	–	1
Perceived good and poor trials equally	2	2	–	–	5	–		1	2	1	–	1	–
Randomly	–	1	–	–	–	–		1	–	–	–	1	–
Other	1	1	1	–	–	–		–	–	–	–	1	1

KR Condition and Repetition Schedule, $F(1,40) = 5.5$, $p < .05$, $\eta_p^2 = 0.12$. The Self KR-Random condition ($M = 16.1$, $SE = 2.60$) demonstrated lower %|CE| compared to the Self KR-Blocked ($M = 36.4$, $SE = 2.61$), Yoked KR-Random ($M = 27.7$, $SE = 2.60$), and Yoked KR-Blocked ($M = 35.7$, $SE = 2.61$) conditions. The %|CE| was similar in the latter three conditions (see Fig. 1).

3.2.2. Retention CV

The analysis revealed a main effect for repetition schedule, $F(1,40) = 12.48$, $p < .05$, $\eta_p^2 = 0.24$. Participants under a random schedule demonstrated less *CV* ($M = 9.9$, $SE = 0.81$) compared to the blocked schedule ($M = 14.0$, $SE = 0.811$).

3.3. Transfer

3.3.1. Transfer %|CE|

The analysis revealed a main effect for KR Condition, $F(1,40) = 17.6$, $p < .05$, $\eta_p^2 = 0.31$. The post-hoc test indicated the participants with self-control over KR ($M = 19.6$, $SE = 2.94$ ms) were more accurate in achieving the novel pattern goal compared to the yoked participants ($M = 37.0$ ms, $SE = 2.94$ ms).

3.3.2. Transfer CV

The analysis of CV failed to reveal a main effect for KR Condition, $F(1,40) = 3.17$, $p = 0.08$ or a KR Condition by Repetition Schedule interaction, $F(1,40) = 1.78$, $p = 0.19$. The means for %|CE| and *CV* for the transfer test are located on the far right of Fig. 2.

4. Discussion

The purpose of the present experiment was to determine if cognitively challenging the learner during both the motor planning *and* response interpretation phase of a motor trial would prove superior for learning. To address this question, participants practiced in either a random (i.e., high cognitive demand) or blocked repetition schedule (i.e., low cognitive demand), combined with the opportunity to either control (high cognitive demand) or not control their receipt of KR (e.g., yoked condition; low cognitive demand). Previous research examining the potential learning advantages of combining two practice variables that have *externally* controlled both practice variables (e.g., receipt of KR and repetition scheduling) with subsequent results being inconsistent with each other (Del Rey & Shewokis, 1993; Wu et al., 2011). More recently, Ali et al. (2012) showed no additive learning advantages of providing the learner control over their KR schedule during a random or blocked repetition schedule when learning an anticipation timing task. However, Ali et al. (2012) assessed learning of the practiced sequences in an immediate (10 minutes after practice) rather than a delayed retention test (e.g., 24 hours or more after the last practice trial) recently suggested to provide a more conclusive measure of motor learning (Kantak & Winstein, 2012). Based on the retention results of the present experiment, providing the learner the opportunity to self-control their KR within a random practice schedule did provide an additive and superior motor learning advantage compared to those not challenged in both the motor planning and error detection and correction phase of the motor trial (Self-Blocked, respective yoked conditions). Contrary to Ali et al. (2012), this was the first study to show additive learning advantages of challenging cognitive processing by increasing the demands of both motor planning, through an externally defined repetition schedule, and response interpretation through learner defined KR scheduling. Thus, challenging the motor planning demands of the learner in a random repetition schedule accompanied by the demands to self-control the receipt of KR during the acquisition period facilitated superior learning relative to the other experimental conditions. The results of this study extend the findings of Del Rey and Shewokis (1993) and further suggest that repetition schedules defined externally (i.e., researcher) and KR schedules defined internally (i.e., learner) provide an optimal challenge to the learner's cognitive processes before and after a motor trial, subsequently facilitating skill acquisition.

Our results also showed that decreasing the cognitive demands during motor planning (i.e., blocked practice) in some way modulated the learning advantages previously attributed to a self-controlled KR context (e.g., Self KR-Blocked condition). In fact, the Self KR-Blocked condition did not outperform their respective yoked conditions in the retention period. This finding was rather unexpected since the Self-KR-Blocked participants were expected to experience greater cognitive effort compared to their yoked counterparts based on the fact they were individualizing their KR schedule (Chiviacowsky & Wulf, 2002, 2005) and 'fading' their frequency of KR requests over the duration of the acquisition period (Winstein & Schmidt, 1990). Previous research has unequivocally shown that heightening the cognitive processing demands of the learner during a self-controlled KR context proved superior to learning compared to their yoked counterparts. To account for this finding, we believe the structure of the repetition schedule influenced the meaningfulness and usefulness of the KR being processed by the learner.

The modulating role of the repetition schedule on the learning advantages of a self-controlled KR schedule is rather curious, since the cognitive events to plan (i.e., recall schema) and interpret the outcome of a motor action (i.e., recognition schema) are temporally dissociated. In other words, motor planning and outcome interpretation are suggested to be separate cognitive processing events, occurring sequentially over the repetition, and therefore not expected to interfere with each other during motor skill learning (Schmidt, 1975). To understand the impact of repetition scheduling on the learners' cognitive processing, previous research requiring participants to introspect on their cognitive processing activities as a function of repetition schedule offers some insight. For example, Simon and Bjork (2001) showed that performers who practiced in a random repetition schedule showed a closer association between their perceived and actual learning compared to their blocked counterparts. More recently, Hodges and colleagues (2011) showed that participants self-controlling their repetition schedule during multi-task learning reported higher satisfaction in a random-type repetition schedule, despite being *unaware* of its actual learning advantages. More recently, learners provided the opportunity to control the order of practice repetitions during multi-task learning have also shown a preference for a random repetition later in the acquisition period (Wu et al., 2011). Collectively, the aforementioned research suggests that not only does a random repetition schedule facilitate the learners awareness of their current learning (i.e., Simon & Bjork, 2001), but is a preferred way to practice during multitask learning (i.e., Wu et al., 2011). In fact, motor performance consistency (i.e., *CV*) of participants in the random condition in the acquisition (blocked participants less variable compared to random) and retention period (random participants less variable than blocked) is consistent with previous research (Ali et al., 2012; see Lee, 2012 for review) also showing motor performance stability as a function of repetition scheduling experienced during the acquisition period.

To explain the additive learning advantages of the Self KR-Random condition in the present experiment, we suggest the random repetition schedule increased the meaningfulness and subsequent processing of the requested KR by the performer, and as a result, expedited learning. This notion is consistent with those of Wulf and Schmidt (1994), who suggested that during a randomized repetition schedule, the KR received about a recent trial cannot be used immediately to update a subsequent motor action, therefore KR is processed more meaningfully in reference to the just completed motor action, and a subsequent dependency on KR is avoided (see Wulf & Shea, 2004 for review). Del Rey and Shewokis (1993) further suggest that decreasing the frequency of KR trials in combination with a random repetition schedule enhances the learner's independence in error-detection and correction. The results of the present study are commensurate with the aforementioned research and further suggest that for participants in the Self KR-Random condition, the randomized repetition schedule increased the meaningfulness and processing of the requested KR to the benefit of learning. Although the Yoked-Random condition experienced a similar repetition and KR schedule as their Self counterparts, providing the learner *choice* over their KR, not the relative KR frequency as experienced by the yoked participants was the factor determining learning. In fact, a majority of participants in the Self-Random condition reported a preference for requesting KR after perceived *good* trials. Thus, a KR trial would require the learner to engage in the cognitive processes required to interpret their response produced feedback to formulate a prediction in regards to whether or not their 'perceived' motor performance matched their criterion for requesting KR. Because of the randomized repetition schedule, we suggest the learner's choice of whether or not to receive KR was heightened based on the fact they would experience a temporal delay, based on interleaving practice trials of the other sequences, between receiving KR and having the opportunity to utilize this KR to modify their movement. Thus, a preference for receiving KR after perceived good trials was perhaps a strategy utilized by a majority of learners in the random repetition schedule to confirm the success of their motor planning for a particular task goal, therefore alleviating the associated heightened cognitive demands associated with correcting a motor plan on a subsequent trial (see Koehn, Dickenson, & Goodman, 2008). Consistent with Wulf and Schmidt (1994), we suggest that although participants in the Self KR-Blocked condition had the opportunity to utilize their requested KR on an upcoming motor trial, this immediate usefulness of the KR seemingly alleviated: 1) the cognitive processes required by the performer to detect and correct their own errors and, 2) the cognitive processes required to update a motor plan as a function of availability of KR.

Based on the %|CE| data for the retention period, the relationship between the structure of the repetition schedule and KR schedule was reciprocal. Specifically, the benefits of a random repetition schedule were based on whether the learner had control over their KR; and the utility of a self-controlled context were most advantageous in a random repetition schedule. To determine whether the structure of the repetition schedule differentially modulated performer's frequency of KR requests, and subsequent learning, we examined the proportion of KR trials for the self-controlled conditions as a function of the repetition schedule over the duration of the acquisition period. Our results showed that frequency of KR requests were irrespective of the repetition schedule. In fact, when queried upon completion of the acquisition period, a majority of participants in both self-controlled KR conditions reported a preference for requesting KR after perceived 'good' rather than 'poor' trials. This finding extends the findings of other experiments utilizing self-controlled KR schedules during single task (Chiviacowsky & Wulf, 2002, 2005) and multitask learning (Patterson & Carter, 2010).

Although the structure of the repetition schedule modulated the effectiveness of a self-controlled KR schedule and subsequent performance in the retention period, this was not the case for the transfer period. In contrast, having the opportunity to control KR during acquisition, independent of repetition schedule, was the practice factor facilitating superior transfer performance relative to the yoked conditions. This finding is consistent with other studies showing superior transfer performance of participants self-controlling their KR during single task (Chiviacowsky & Wulf, 2005) and multitask learning (Ali et al., 2012; Patterson & Carter, 2010). Thus, the cognitive processes engaged in by the learners during a self-controlled KR context seemingly proved advantageous to a novel variation of the practiced motor tasks. In fact, a majority of participants in both self-controlled KR conditions reported a preference for requesting KR after perceived 'good' trials rather than 'poor trials'. We suggest the shared cognitive processing experiences of participants in the self-controlled conditions was a factor underlying superior transfer performance of these conditions relative to the yoked condition, not expected to be engaged in similar cognitive processing. In fact, the transfer results of the present experiment are contrary to the previously shown advantages of a random over a blocked repetition schedule (see Lee, 2012 for review). Thus, we suggest that providing the learner self-control over their KR schedule during the acquisition period in fact superseded and were independent of the repetition schedule experienced by the learner during this period. However, we suggest that further research is required to delineate the cognitive mechanisms underlying the modulating effects of repetition scheduling on self-controlled KR schedules and subsequent motor performance during retention and transfer.

4.1. Conclusion

In conclusion, the results of the present study suggest the learning advantages of a self-controlled KR context were directly modulated by the structure of the repetition schedule. However, consistent with previous research, performers provided with the opportunity to self-control their KR schedule demonstrated superior transfer of their behavior to a novel motor task that was independent of the repetition schedule. The results of the present study suggest further research is required to delineate the cognitive mechanisms underlying the dissociated benefits of a self-controlled KR context as a function of repetition schedule and the characteristics of the learning test (i.e., retention versus transfer). Future research should also determine whether the learning advantages associated with a self-controlled practice context are attributed to: a) the information being requested by the learner is perceived as having greater *informational* value (Wulf, 2007); b) providing control to the learner enhances their subsequent *motivation* to learn the motor task (Lewthwaite & Wulf, 2010); or c) a contribution of both. For example, a recent review by Sanli, Patterson, Bray, and Lee (2013) recommend utilizing the self-determination theory (SDT; Ryan & Deci, 2007) as a theoretical framework for understanding the *motivational* advantages of a self-controlled practice context. Alternatively, Hansen et al. (2011) recently suggested the learning advantages demonstrated by a yoked condition provided control over their receipt of KR, is consistent with other findings in the motor learning literature that suggest the perceived *informational* value of KR is increased when self-controlled by the learner. Other potential factors are expected to modulate the learning advantages associated with the characteristics of the repetition schedule and self-controlled KR context such as complexity of the motor task, movement expertise, and neurological status of the performer. The findings from these additional lines of inquiry will augment our understanding of other practice variables modulating skill acquisition in a self-controlled practice context.

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