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# Learner regulated knowledge of results during the acquisition of multiple timing goals

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ABSTRACT

The purpose of the present experiment was to examine the advantages of a learner controlled KR schedule during the acquisition of three novel sequential timing tasks. The self-regulated group requested KR when necessary during the acquisition period while participants in the yoked condition replicated the KR schedule of a self-regulated counterpart, without the choice. The self-regulated condition demonstrated superior performance in retention and transfer, with a relative KR frequency similar for all three sequences. Similar to Chiviacowsky and Wulf (2002), learners also demonstrated a preference for KR after perceived good trials, independent of defined task difficulty. Thus, the results extend previous research by suggesting a generalized learning strategy by performers acquiring multiple motor task goals.



## 1. Introduction

Understanding the practice factors facilitating expeditious motor skill acquisition is a fundamental tenet of motor learning inquiry. Of particular interest are those practice factors providing learning advantages generalizing across differing motor tasks and practice contexts. Recently, there has been an identifiable surge in understanding the learning advantages associated with performers afforded the opportunity to individualize a portion of their practice context during the acquisition of a novel motor skill (Chiviacowsky & Wulf, 2002, 2005, 2007; Chiviacowsky, Wulf, Laroque de Medeiros, Kaefer, & Tani, 2008; Chiviacowsky, Wulf, Laroque de Medeiros, Kaefer, & Wally, 2008; Huet, Camachon,

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Fernandez, Jacobs, & Montagne, 2009; Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Janelle, Kim, & Singer, 1995; Patterson & Lee, in press; Sanli & Patterson, 2009; Wrisberg & Pein, 2002; Wulf, 2007; Wulf, Clauss, Shea, & Whitacre, 2001; Wulf, Raupach, & Pfeiffer, 2005; Wulf & Toole, 1999). Intriguingly, performers have demonstrated learning advantages when scheduling their frequency of receiving KR (Chiviacowsky & Wulf, 2002, 2005; Chiviacowsky, Wulf, Laroque de Medeiros, Kaefer, & Tani, 2008; Chiviacowsky, Wulf, Laroque de Medeiros, Kaefer, & Wally, 2008; Janelle et al., 1995), the order of practice repetitions during the acquisition of multiple motor tasks (Keetch & Lee, 2007; Sanli & Patterson, 2009), and the frequency of observing a skilled model or use of an assistive device (Janelle et al., 1997; Wrisberg & Pein, 2002; Wulf & Toole, 1999; Wulf et al., 2005). The superiority of a learner controlled practice context is confirmed when compared to the movement performance of participants who replicate the practice schedule of a self-regulated participants' practice schedule, however without the choice (e.g., yoked condition). The learning advantages of a learner regulated practice condition have been extended to children (Chiviacowsky, Wulf, Laroque de Medeiros, Kaefer, & Tani, 2008; Chiviacowsky, Wulf, Laroque de Medeiros, Kaefer, & Wally, 2008; Sanli & Patterson, 2009) and are predicted to have important implications for retraining functional movement in a rehabilitation context (Wulf, 2007). The underlying mechanisms contributing to the advantages of a learner regulated practice context have been attributed to increased motivation of the participant to learn (Boekaerts, 1996; Winne, 1995), the practice context is individualized to the needs of the learners (Chiviacowsky & Wulf, 2002), and task information is requested only when necessary, resulting in a deeper and more meaningful processing of the task information (Boekarts & Corno, 2005; Chiviacowsky & Wulf, 2002; Winne, 2005; Zimmerman, 1989).

Our particular interest in the present experiment was to further examine the strategies of performers controlling the proportion of KR trials while learning *multiple* motor task goals, a factor not previously examined. Knowledge of results (KR) is referred to as the information provided to a learner regarding the results of their performed movement (e.g., spatial or temporal) relative to the desired movement goal (Schmidt & Lee, 2005; Wulf & Shea, 2004). Providing the learner KR for a portion of their acquisition trials is unequivocally a requisite factor facilitating motor skill acquisition (for reviews, see Salmoni, Schmidt, and Walter (1984) and Wulf and Shea (2004)). A copious amount of research provides support for the primary tenet of the guidance hypothesis predicting that KR is advantageous during motor skill acquisition only to a point where the learner does not develop a reliance on KR to guide their performance (Salmoni et al., 1984). However, KR too readily available during skill acquisition is predicted to guide the learner to the requisite motor response, at the expense of circumventing the cognitive processes required for independent error detection and correction, critical when KR is no longer available (Bjork, 1998; Guadagnoli & Kohl, 2001; Salmoni et al., 1984; Schmidt, 1991; Schmidt & Bjork, 1992; Wulf & Shea, 2004). One of the most ubiquitous KR manipulations in the motor learning literature is the associated learning advantage for performers experiencing a reduced relative frequency of KR (e.g., less than 100%) during acquisition (for reviews see Salmoni et al. (1984) and Wulf and Shea (2004)). However, the learning advantages associated with frequent provisions of KR during skill acquisition have been attributed to such factors as task complexity (Wulf, Shea, & Matschiner, 1998; also see Wulf and Shea (2002, 2004) for reviews) and the integrity of the central nervous system (Guadagnoli, Leis, van Gemmert, & Stelmach, 2002). Evidence from a learner controlled context of KR also suggests that learners prefer not to have KR on all trials during acquisition. For example, research investigating the relative frequencies of KR during motor skill learning have demonstrated learners preferences for KR on 95% (Chen, Hendrick, & Lidor, 2002; sequential timing task), 35% (Chiviacowsky & Wulf, 2002; sequential timing task) to as low as 11% and 7% (Janelle et al., 1995, 1997; ball throwing task) of the acquisition trials subsequently facilitating learning. The results from these experiments extend the fundamental tenet of the guidance hypothesis by showing learning advantages in a context of decreased KR frequency under direct control of the learner.

Based on the existing theoretical understanding of KR, the learner has revealed an interesting and counterintuitive strategic preference for KR during motor skill acquisition. Specifically, Chiviacowsky and Wulf (2002) found that participants who were queried upon completion of the acquisition period of a novel sequential key pressing pattern, a preference for KR on perceived good trials compared to perceived poor trials. In fact, indexes of movement error on KR trials (perceived good trials by participants) were lower compared to the no-KR trials (perceived as poor trials by participants)

(Chiviacowsky & Wulf, 2002). Although these findings confirm the notion that learners are actively engaged in their learning as evidenced by their deliberate and strategical choices of KR, they do however challenge the historical role of KR during the acquisition of goal behavior (Chiviacowsky & Wulf, 2002; Salmoni et al., 1984). These findings have led to the speculation that perhaps the effort to repeat a successful response is perceived by the learner as less effortful and more motivating compared to the effort required to update a perceived less successful motor response (Chiviacowsky & Wulf, 2002; Lewthwaite & Wulf, 2009). This notion is substantiated by more recent evidence demonstrating increased demands on the performers cognitive processes (e.g., working memory and attention) during interpretation of feedback delivered for an unsuccessful motor response compared to a successful motor response (Koehen, Dickinson, & Goodman, 2008). Collectively, the results of the aforementioned studies suggest learners engage in a deliberate strategy to economize their investment of cognitive and physical effort during motor skill acquisition. Although expeditious motor learning has proven to be a function of the degree of cognitive effort invested by the learner during motor skill acquisition (Lee, Swinnen, & Serrien, 1994; Schmidt & Bjork, 1992), the results from Chiviacowsky and Wulf (2002) suggest that learners have a definite strategy in regards to their preference of how they mobilize their cognitive effort during skill acquisition.

Independent of the degree of cognitive effort invested during motor skill acquisition, the cognitive demands of learners controlling a portion of their learning environment have also been determined to be exceptionally effortful (Kanfer & Ackerman, 1989). However, the utility of a learner-regulated schedule of KR, inherently considered effortful, during the acquisition of multiple motor task goals, also varying in difficulty, is currently unknown. To address this limitation in the current literature, the purpose of the present experiment was to examine the relative frequency of the KR schedules as well as the strategic preferences of learners regulating their KR during the acquisition of three novel motor task goals. Participants were required to learn three novel 5-key-pressing sequences, each with a respective overall movement time goal and sequence order. A serial key-pressing task was utilized based on its sensitivity to capturing the utility of a learner controlled practice context (Chen et al., 2002; Chiviacowsky & Wulf, 2002, 2005), and the relative ease of manipulating sequence difficulty based on the interaction of the key pressing pattern (e.g., the total amount of left to right, or right to left directional changes) and the overall timing goal (1050, 1800, or 2550 ms). A pre-test confirmed the spatial and motor task goals of each respective sequence were perceived to vary in difficulty (from this point on, referred to as intertask difficulty). Thus, distinguishing intertask difficulty was essential in examining the interaction between learner controlled KR schedules and the acquisition of multiple motor task goals, varying in intertask difficulty. We believed the results from this experiment would have important theoretical and practical implications. Theoretically, the results would extend our understanding of a learners' strategical choice for KR and the relative frequency preferences during the acquisition of multiple motor task goals, not yet examined in the motor learning literature. We also believed the results from this experiment would have important practical implications for performers acquiring multiple motor task goals commonly found in a rehabilitative, vocational, and recreational context.

Based on the extant self-regulation motor learning research, we generated the following experimental predictions. First, we predicted the proportion of KR to no-KR trials would be a function of intertask difficulty, such that the greater the established difficulty, the more frequently KR would be requested. This prediction is based on the notion learners are sensitive to the cognitive and motor complexities of a motor task, and as a result, KR would be requested accordingly: more frequent KR for greater cognitive and/or motor demands and less frequently for motor tasks placing minimal motor and/or cognitive demands on the performer (Wulf et al., 1998; see Wulf and Shea (2004) for recent review). Second, the strategic preferences of when to receive KR during the acquisition period (e.g., after perceived good or poor trials, see Chiviacowsky & Wulf, 2002) would be independent of intertask difficulty, but consistent with a generalized preference for KR after perceived good trials as a method of economizing and strategically mobilizing their effort for replicating a good trial, compared to calibrating a motor response for a perceived poor trial. We believed a strategical preference for perceived good trials would be especially appealing in the present experiment whereby participants were required to learn multiple motor task goals varying in intertask difficulty.

## 2. Method

### 2.1. Participants

Twenty-four, right-handed participants (18 women and 6 men, *M* = 21.4 years, *SD* = 0.84) from Brock University participated in the study. All participants provided informed consent and were naïve to the purposes of the experiment. Participants received course credit upon completion of the experiment.

### 2.2. Apparatus and task

All participants were seated at a standardized desk containing a desktop computer (Dell OptiPlex GX620 with an Intel Pentium IV 3.20 GHz processor and 3 GB of RAM) and a serial response (SR) box (Model #: 200A, PsychNet Tools). On each trial, all experimental stimuli were presented on a 19 in. flat screen Dell monitor. The total display size was 9.5 cm in length and 7 cm in width. The SR box was positioned directly in front of the participant and consisted of five 1 cm × 1 cm buttons sequentially labeled one to five from right to left. The SR box was 17 cm in length and 19.8 cm in width. The software program E-prime (version 1.1, Psychology Software Tools, Inc., Pittsburg, PA, USA) was customized to control all temporal components of the experiment, the presentation of the experimental stimuli, and collect the dependent variables of interest.

The experimental stimuli consisted of three novel 5-key sequences each with an accompanying goal movement time. On each trial during acquisition, retention, and transfer, participants were required to produce the visually cued key-pressing sequence along with its associated movement time goal (e.g., 5-4-3-1-2 in 2550 ms). For sequence A, participants were required to depress keys 5-4-3-1-2 in a goal time of 2550 ms; sequence B required participants to depress keys 1-3-4-2-5 in a total movement time of 1800 ms, and finally, sequence C required participants to depress keys 3-2-5-1-4 in a total movement time of 1050 ms. A pre-test determined perceived intertask difficulty between the respective sequences. Specifically, 10 participants who did not participate in the experiment (5 males and 5 females, mean age = 21.6 years, *SD* = 0.92) practiced two trials of each sequence with KR. The practice orders of the sequences were counterbalanced across all participants such that no two trials of the same sequence were repeated on consecutive trials. Upon completion of these trials, participants were visually presented via E-Prime, three separate screens requesting an estimation of their perceived difficulty in collectively satisfying the temporal and spatial goals of each respective sequence. Participants read the following statement for each of the three sequences: "Please select a number between 1 (easy) and 5 (difficult) to describe your perceived difficulty in achieving the task goals (correct sequence and timing goal) of the following sequence...". Each participant was required to depress any number between 1 and 5 on a standard keyboard that best represented their level of difficulty in achieving the sequence goals. The results of this pre-test showed that participants perceived sequence A (5-4-3-1-2, 2550 ms) as being less difficult to complete the sequence goal (*M* = 1.6, *SD* = 0.84) compared to sequence C (3-2-5-1-4, 1050 ms) perceived as the pattern having the highest intertask difficulty (*M* = 4.1, *SD* = 1.37). Sequence B was perceived as having intermediate difficulty (*M* = 3.00, *SD* = 1.70). A one-way analysis of variance (ANOVA) with repeated measures on sequence showed a main effect for sequence, $F(2, 18) = 12.88$, $p \leqslant .05$. A Tukey post-hoc test indicated a significant difference between sequence A and C, with sequence B not being statistically different from A or C. Based on these results, we classified sequence A as easy, sequence B as moderate difficulty, and sequence C as being perceived as difficult by participants to complete the defined spatial and temporal goals. Our classification of task complexity is consistent with the methodological approach utilized by Patterson and Lee (2005) who classified the complexity of novel typographical script as being low, moderate, or high difficulty to the user.

### 2.3. Procedure

Participants were randomly assigned to either a self-regulated KR or yoked condition. The important distinction between experimental conditions was a function of their KR schedule. Participants in the self-regulated condition determined, after every trial during acquisition whether or not they required KR about their just completed response. Whereas participants in the yoked condition replicated the relative frequency KR schedule from a self-regulated counterpart; however, these participants were not afforded control over their KR schedule. The yoked participants were gender matched to a self-regulated participant. All participants completed a total of 90 trials, 30 acquisition trials of each sequence. Importantly, the orders of the practice trials were counterbalanced across participants, with the requirement that a particular sequence would not be repeated on two consecutive trials.

Before beginning the experimental protocol, all participants were informed of the goals of the task, debriefed on the experimental protocol and practiced one typical trial in their respective experimental condition. Importantly, the sequence utilized in the practice trial was not used during the experimental protocol. A typical experimental trial began with the participants viewing the required sequence pattern (e.g., 5-4-3-1-2) with the associated goal time (e.g., 2550 ms) for 5 s. During this temporal period, participants were instructed to orient and place the index finger of their dominant hand on the first key of the sequence (e.g., the number 5). The starting key was outlined with a red square to obviate for the participant the location of the start key. After 5 s, the cued pattern was replaced by five colored boxes for a total of 3 s. Following this screen, participants viewed for a second time, the goal sequence and its associated movement time goal signaling participants to begin their movement as soon as they were ready. This display remained on the screen for the duration of the trial. Upon completion of the trial, participants in the self-regulated condition were asked if they wished to receive KR regarding their just completed trial. The participant would orally state either *yes* or *no* to the research assistant. If the participant indicated *yes*, KR was presented consisting of the sequence timing goal, the participant's movement time and whether or not the key-pressing sequence was completed correctly or incorrectly. The screen displaying KR was presented for a total of 5 s. Importantly, participants in the self-regulated condition were informed that KR would only be presented when requested and should only be requested when required, as they would eventually be asked to produce the required temporal goal without KR. Participants in the yoked condition were instructed that KR would be available on some trials and not on other trials. On the no-KR trials, all participants viewed a blank screen for 5 s, equated to the duration of the KR display screen. The key-pressing patterns performed incorrectly (e.g., pushing keys in the incorrect order) were subsequently repeated at the end of the acquisition period. The temporal measures and success of the key-pressing sequences during the acquisition, retention, and transfer periods were determined exclusively by E-Prime.

Upon completion of the acquisition phase, similar to Chiviacowsky and Wulf (2002), all participants were asked to complete a paper and pencil questionnaire requiring them to introspect on their preferences for requesting KR on some trials and perhaps not on others during the acquisition period. Similar to Chiviacowsky and Wulf (2002), participants in the self-regulated condition responded to questions that required them to circle the most appropriate response in regards to their preference for KR, individually for each of the three sequences. Participants in the yoked condition were asked to introspect on whether they received KR after the right trials, and if not, when would they have preferred to receive KR. Completion of this questionnaire was approximately 15 min.

To assess learning as a function of KR condition, all participants were required to participate in an immediate (15 min) and delayed (approximately 24 h) retention test after the final acquisition trial. The immediate and delayed retention test both consisted of 15 trials, five trials of each sequence, with the repetition order counterbalanced across participants, with no two trials of the same sequence being repeated on consecutive trials. The experimental stimuli during the retention test consisted of the key-pressing sequence without its associated movement time goal. Thus, as a function of viewing the cued sequence, participants were required to recall and reproduce the associated movement time goal. The purpose of the transfer test in the present experiment was to determine if the motor performance advantages, commonly demonstrated by participants in a self-regulated condition would transfer to superior performance of a novel 5-key-pressing sequence and movement timing goal (4-5-2-3-1 in a goal movement time of 3300 ms). The purpose of the transfer test in the present experiment was to determine whether the motor performance advantages commonly demonstrated by participants in a self-regulated condition during the retention period would transfer to superior performance of a novel 5-key-pressing sequence and movement timing goal (4-5-2-3-1 in a goal movement time of 3300 ms). Previous research has demonstrated superior motor performance of participants in a self-regulated condition compared to the yoked counterparts transferring from a practiced sequential pattern, to a novel unpracticed sequential key pressing pattern (Chiviacowsky & Wulf, 2002). All participants were required to complete five trials of the novel sequence. The transfer portion of the experiment was completed after the delayed retention test. Importantly, no KR was presented during the retention or transfer tests.

### 2.4. Data analyses

The dependent variables of interest were percent absolute constant error (%|*CE*|) and the coefficient of variation (*CV*) utilized to index changes in motor performance during the acquisition, retention, and transfer periods of the experiment. |*CE*| is used as a measure of absolute timing bias and computed as an average of the absolute average of the errors. To accurately compare the differences between the three key-pressing patterns, as a function of practice condition, |*CE*| measures were converted to a percent absolute constant error (%|*CE*|) by dividing |*CE*| by the corresponding target movement time and multiplying by 100. This equation is consistent with the analytical methods of Simon and Bjork (2001, 2002) who also assessed performance of participants on three-5-key-pressing patterns, each associated goal movement time. 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.

For acquisition, mean (% |*CE*|) and *CV* were grouped into six blocks of five trials for each respective sequence (sequence A, 2550 ms; sequence B, 1800 ms; sequence C, 1050 ms). The %|*CE*| and *CV* dependent variables were submitted to a separate 2 (Practice condition: yoked, self-control) × 3 (sequence: A: 2550 ms, B: 1800 ms, C: 1050 ms) × 6 (Block) analysis of variance (ANOVA) with repeated measures on the last two factors. For the immediate and delayed retention test, mean (% |*CE*|) and *CV* scores were each averaged into one block of five trials for each of the three sequences. For the transfer test, (%|*CE*|) and *CV* were analyzed from one block of five trials. For the retention tests, each dependent variable was analyzed separately in a 2 (Practice condition: yoked, self-control) × 3 (Sequence: A: 2550 ms, B: 1800 ms, C: 1050 ms) × 2 (Retention test: immediate, delayed) ANOVA with repeated measures on the last two factors. A one-way repeated measures ANOVA was computed to analyze the transfer performance (%|*CE*| and *CV*) for the experimental conditions (self-control, yoked). In all analyses, a significance level of $p < .05$ was used. Post hoc comparisons were conducted using a Tukey's HSD. We corrected for violations of sphericity by using the Greenhouse-Geisser procedures, where appropriate.

## 3. Results

### 3.1. Acquisition

#### 3.1.1. Feedback requests

During the acquisition period (blocks 1–6), participants in the self-control condition requested KR on 65%, 63%, 67%, 63%, 48%, and 62% of the acquisition trials for sequence A (2550 ms); 67%, 68%, 65%, 58%, 65%, and 55% of the acquisition trials for sequence B (1800 ms); and 55%, 68%, 65%, 60%, 65%, and 60% of the acquisition trials for sequence C (1050 ms) pattern. Overall, participants requested KR on 61.3% of the acquisition trials for sequence A (2550 ms); 63% of practice trials for sequence B (1800 ms) goal and 62.2% of the acquisition trials for sequence C (1050 ms). A repeated measures ANOVA for blocks (1–6) and sequence (A: 2550, B: 1800, and C:1050 ms) for the self-control condition during acquisition did not evidence a main effect for block, $F(5, 55) = .75$, $p > .05$; sequence, $F(2, 22) = 0.29$, $p > .05$, or an interaction, $F(10, 110) = 1.06$, $p > .05$, for proportion of trials with feedback.

#### 3.1.2. Acquisition %|*CE*|

The means for %|*CE*| for the experimental conditions are displayed on Fig. 1. There was a main effect for block, $F(5, 110) = 50.58$, $p < .05$, and sequence, $F(2, 44) = 21.25$, $p < .05$. The main effects were superseded by a Block × Sequence interaction, $F(3.78, 83.18), = 25.17$, $p < .05$. The results of the post hoc test indicated that sequence A and B were performed with less %|*CE*| compared to sequence C on blocks 1–4, whereas as sequence B was performed with less %|*CE*| on block 5. No differences amongst the sequences were identified for block 6.

#### 3.1.3. Coefficient of variation (CV)

*CV* for participants over the course of the acquisition period is located on Fig. 2. There was a main effect for block, $F(5, 110) = 20.59$, $p < .05$. The results of the post hoc indicated block 1 had greater variability ($M = 22.37$) compared to blocks 2 ($M = 14.1$), 3 ($M = 13.11$), 4($M = 12.46$), 5 ($M = 11.86$), and 6 ($M = 10.70$). All other block comparisons were not statistically significant.

#### 3.1.4. Self-reported KR scheduling strategy as a function of sequence

Our primary interest in the present experiment was to determine whether participants in the self-control condition would individualize a KR schedule differently as a function of the three sequence goals. To capture these strategies, we utilized the questionnaire presented by Chiviacowsky and Wulf (2002). The results of the questionnaire are displayed in Table 1. Consistent with Chiviacowsky and Wulf (2002), none of the participants requested feedback after they perceived a poor trial. Interestingly, 67% (8 of 12) of participants requested feedback after they perceived a *good trial* for sequence A and C, and 58% (7 of 12) of participants requested feedback after perceived *good trials* for sequence B. Twenty-five percent (3 of 12) of participants requested feedback after perceived *good and poor trials* for sequence B and C, respectively, whereas 16.7% (2 of 12) of participants utilized this strategy for sequence A. One participant selected a *random strategy* of feedback for sequence B and C, whereas 2 participants for sequence A and one participant for sequence B and C adopted a strategy not listed on the questionnaire. Such individualized strategies reported were "always" and "at the beginning then again at the end".

For the yoked condition, 42% of participants (5 of 12) reported they received feedback after the correct trials for sequence A; 50% of participants reported receiving feedback after the correct trials for sequence C; and 58% of participants (7 of 12 participants) reported receiving feedback after correct trials for sequence B. For those participants who reported not receiving feedback after the appropriate trials, 43% of participants for sequence A, 60% of participants for sequence B and 67% of participants for sequence C reported they would have requested feedback after perceived good trials. Only one

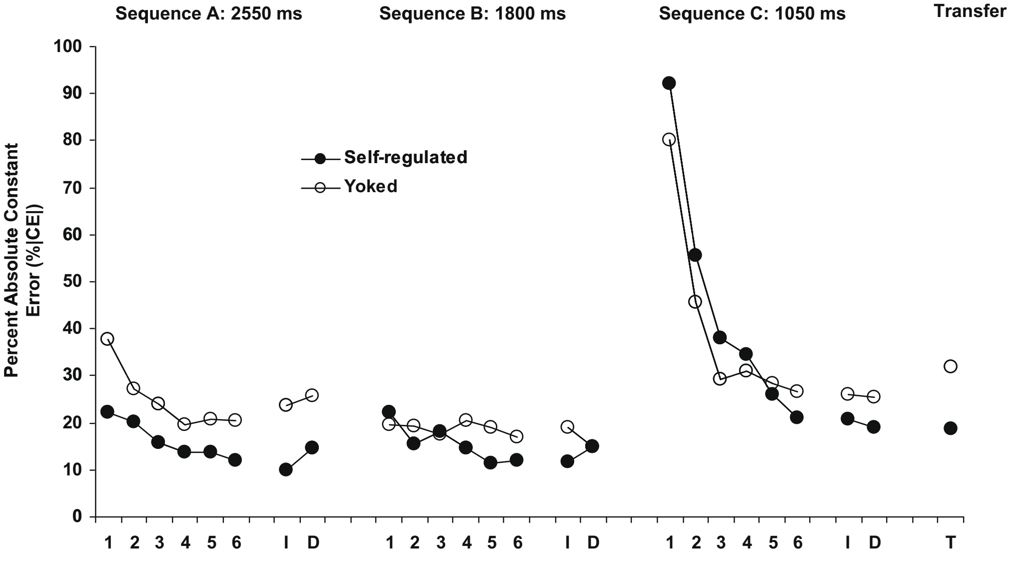


**Fig. 1.** Percent absolute constant error (%|*CE*|) for experimental conditions as a function of sequence goal for acquisition, retention and transfer.

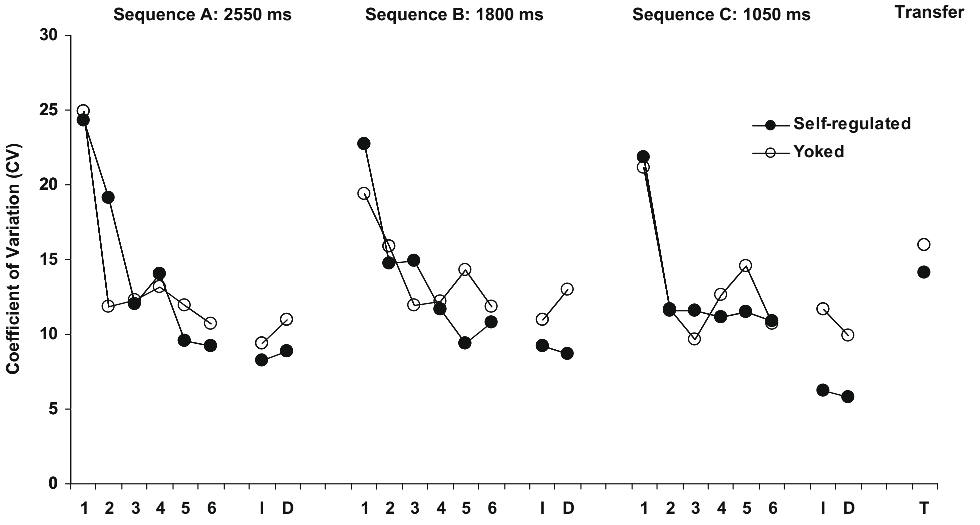


**Fig. 2.** Coefficient of variation (*CV*) for experimental conditions as a function of sequence goal for acquisition, retention and transfer.

participant reported they would have requested feedback after perceived poor trials for sequence A. In summary, the results from the questionnaire data indicated that most participants had a preference for feedback after perceived *good* trials, independent of the differing pattern goals.

**Table 1**
Introspective responses of self and yoked participants to questions regarding feedback scheduling.

| Group | Spatiotemporal pattern | | |
|---|---|---|---|
| | 2550 ms | 1800 ms | 1050 ms |
| Self-control | Number of responses | | |
| *When/why did you ask for feedback?* | | | |
| Mostly after a perceived good trial | 8 | 7 | 7 |
| Mostly after you perceived a poor trial | 0 | 0 | 0 |
| After perceived good trials and poor trials equally | 2 | 3 | 3 |
| Randomly | 0 | 1 | 1 |
| Other | 2 | 1 | 1 |
| *When did you not ask for feedback?* | | | |
| After perceived good trials | 2 | 2 | 2 |
| After perceived bad trials | 8 | 6 | 9 |
| After perceived good trials and poor trials equally | 0 | 2 | 0 |
| Randomly | 0 | 1 | 0 |
| Other | 2 | 1 | 1 |
| Yoked condition | Number of responses | | |
| *Do you think you received feedback after the right trials?* | | | |
| Yes | 5 | 7 | 6 |
| No | 7 | 5 | 6 |
| *If the answer to the above question was NO, when would you have preferred to receive feedback?* | | | |
| After perceived good trials | 3 | 3 | 4 |
| After perceived bad trials | 1 | 0 | 0 |
| After good trials and poor trials equally | 2 | 1 | 2 |
| Randomly | 1 | 1 | 0 |
| Other | 0 | 0 | 0 |

To determine if the self-control participant's strategy in requesting feedback for perceived *good* trials were commensurate with their actual motor performance on those trials, we analyzed %|*CE*| on the feedback versus no feedback trials for the first and second half of practice (similar to Chiviacowsky and Wulf (2002)). Since the three pattern goals did not interact with the experimental groups during the acquisition blocks, we performed analysis on the feedback and no feedback trials for the first (acquisition blocks 1–3) and second half (blocks 4–6) of practice blocks, collapsed across sequence. To determine the statistical significance of the identified differences between the KR and no-KR trials for the self-control condition, a 2 (Experimental Group: self-control, yoked) × 2 (Trial Type: KR, no-KR) × 2 (Block: First half, second half of acquisition) ANOVA was performed. Although there was a trend for the self-control participants to demonstrate less %|*CE*| on KR trials compared to no-KR trials, similar to the findings of Chiviacowsky and Wulf (2002), the ANOVA failed to show a Group × Trial Type interaction, $F(1, 15) = 1.51$, $p = .23$, or a Group × Trial Type × Block interaction, $F(1, 15) = 0.76$, $p = .39$.

### *3.2. Retention*

#### *3.2.1. Proportion absolute constant error*

The %|*CE*| measures for the retention period are presented on Fig. 1. There was a main effect for group, $F(1, 22) = 5.11$, $p < .05$, The post hoc analysis indicated the self-control condition were more accurate in achieving the overall timing goals ($M = 15.15$ ms, $SE = 2.29$ ms) compared to the yoked condition ($M = 22.48$ ms, $SE = 2.29$ ms).

#### *3.2.2. Coefficient of variation (CV)*

*CV* for the experimental conditions during the retention period as a function of sequence are located on Fig. 2. The results of the ANOVA indicated a main effect for group, $F(1, 22) = 7.29$, $p < .05$ showing the self-control condition with less *CV* ($M = 7.84$, $SE = 0.82$) compared to their yoked counterparts ($M = 10.99$, $SE = 0.82$).

### *3.3. Transfer*

#### *3.3.1. Proportion absolute constant error: %|CE|*

The means for %|*CE*| for the experimental conditions transfer performance is located on the far right on Fig. 1. There was a main effect for experimental condition, $F(1, 22) = 5.37$, $p < .05$. The post hoc analysis indicated the self-control condition ($M = 18.58$, $SE = 4.09$ ms) were more accurate in achieving the novel pattern goal compared to the yoked condition ($M = 31.98$ ms, $SE = .4.09$ ms).

#### *3.3.2. Coefficient of variation (CV)*

Analysis of *CV* for the experimental conditions as a function of pattern did not reveal a statistically significant main effect for experimental condition, $F(1, 22) = 0.21$, $p = .653$. The experimental conditions means for the transfer test are located on the far right of Fig. 2.

## 4. Discussion

The purpose of the present experiment was to examine the relative frequency and strategic preferences of KR for performers required to learn three sequence goals determined to differ in intertask difficulty (easy, moderate difficulty, difficult). Thus, the results from this experiment extend the findings of previous research utilizing a single motor task goal during the acquisition of a sequential timing task (e.g., Chen et al., 2002; Chiviacowsky & Wulf, 2002, 2005). To our knowledge, this was the first experiment to examine this void in the motor learning literature. To answer this research question, we predicted the following: first, we expected performers to request KR most frequently during the acquisition period for sequence C (difficult) followed by sequence B (moderate difficulty) and finally, less frequently for sequence A (easy) (Wulf & Shea, 2002, 2004). Second, learners would show a preference for KR after perceived good trials, independent of intertask difficulty, based on research evidencing a preference and motivation for learners to repeat the cognitive and motor processes required for a successful response, compared to the effort required to update an unsuccessful motor response (Chiviacowsky & Wulf, 2002, 2005). The results of the experiment suggest that independent of intertask difficulty, the relative frequency of KR requests was similar across the three sequences, failing to support our first prediction. These finding are consistent with the results from other studies demonstrating the learning advantages for practice conditions requiring an increased investment in their cognitive effort, independent of task difficulty (Patterson & Lee, 2005, 2008). Although the self-regulated participants demonstrated a preference for KR more frequently on perceived good trials, independent of task complexity, with a trend for %|*CE*| to be lower on KR compared to no-KR trials, the differences between the KR and no-KR trials were not statistically significant. As a result, our second prediction was not supported. A discussion of our findings follows.

### 4.1. KR Scheduling strategies as a function of sequence goals

One of our primary interests in the present experiment was to examine if performers would be sensitive to intertask difficulty and as a result, individualize a KR schedule differently for each of the three sequence goals. Our prediction was derived from the extant research suggesting the optimal relative frequency of KR during motor skill acquisition is a function of the complexity of the to be learned motor task, such that the more complex the motor task, the more frequently KR would be required to resolve the discrepancy between the produced and the required motor response, with the exact opposite predicted for simpler motor tasks (Guadagnoli & Lee, 2004; Wulf & Shea, 2002, 2004). As well, evidence from the cognitive self-regulation literature suggest that learners demonstrate an ability to individualize an effective learning context as a function of differing levels of task difficulty (Son, 2004). The results from the present experiment were not commensurate with the extant research, or our first prediction. In fact, the relative KR frequencies for participants in the self-regulated condition were relatively similar for the three to-be-learned sequences, suggesting a generalized KR scheduling strategy during the acquisition period. The relative proportion of KR to no-KR trials in the present experiment are less than Chen et al. (2002), where participants requested KR on 95% of the acquisition trials and greater than Chiviacowsky and Wulf (2002) where participants asked for KR on 35% of the acquisition trials during the acquisition of a sequential timing task. We offer two alternative hypotheses that perhaps contributed to participants adopting a generalized relative frequency KR schedule. First, independent of established intertask difficulty, a bias towards a generalized KR strategy appears consistent with the research suggesting that learners prefer a strategy that economizes the effort invested in learning the task (Chiviacowsky & Wulf, 2002). Thus, the cognitive effort required to simultaneously individualize more than one relative frequency KR schedule and the processing requirements inherent in self-regulation (e.g., Kanfer & Ackerman, 1989) are expected to interact, perhaps in a disadvantageous way, by creating an overloading context to the cognitive processes of the learner at the expense of learning.

Another possible contributing factor for the learners' preference for a generalized relative KR frequency schedule may be related to the amount of practice participants experienced with each of the sequences. Specifically, the established intertask difficulty in the pre-test was perhaps ameliorated as a function of practice repetitions. However, recent research has also evidenced a generalized frequency of receiving augmented information during the acquisition of a novel handwriting task, with varying levels of task difficulty (Patterson & Lee, in press). Thus, the novelty of the present findings suggests that independent of task difficulty, learners preferred a generalized KR schedule during multiple task learning.

### 4.2. Performance-contingent self-regulation strategies

Consistent with the findings of Chiviacowsky and Wulf (2002), participants in the self-regulation condition in the present experiment reported a preference for KR on *perceived* good trials. This finding lends support to the notion that learners are deliberate and strategical in their choice of KR that is seemingly *performance-contingent* (Chiviacowsky & Wulf, 2002). These results are also consistent with the findings from other learner controlled practice contexts, such as the scheduling of practice repetitions (Keetch & Lee, 2007). In fact, previous research has demonstrated that participants' preference for KR on *perceived good trials* was commensurate with their actual movement error (e.g., |*CE*|) on those trials compared to trials in which KR was not requested (Chiviacowsky & Wulf, 2002). Examination of the (%|*CE*|) for the KR trials (perceived as *good trials* by participants) and no-KR trials in the present experiment demonstrated a trend for KR trials having less (%|*CE*|) than the no-KR trials; however, this difference was not statistically significant at the $p < .05$ level. Regardless, the importance of these results suggest that in addition to perceived movement error, learners are engaged in other possible metacognitive strategies to inform their decision in regards to whether or not they require KR. However, further research is required to delineate these exact metacognitive strategies utilized by the learner individualizing their KR schedule as a function of learning multiple motor task goals.

Identifying *when* the learner prefers to receive feedback challenges the preexisting notion on the informational role of KR during motor skill acquisition (Salmoni et al., 1984). However, understanding *why* participants prefer KR on perceived good trials is inconclusive. One possible explanation suggests an increased motivation and decreased effort required by the learner to replicate a correct response compared to the processing demands required to update a less than successful motor response (Chiviacowsky & Wulf, 2002). Further support for this hypothesis can be found in the verbal learning literature suggesting that learners receiving feedback on a correct trial resolves a metacognitive discrepancy (e.g., low confidence in response correctness) in regards to whether or not their response was in fact correct (Butler, Karpicke, & Roediger, 2007). Therefore, feedback on *correct trials* seemingly strengthens the learners' memory association between the planned and the actual target response. Evidence from the education literature suggests extrinsic feedback during self-regulated learning confirms for the learner their knowledge of the task requirements is consistent with the actual task requirements (Butler & Winne, 1995). Other research efforts have demonstrated that learners spent more time studying the feedback display from a correct response compared to the feedback display of an incorrect response (Kulhavy, Yekovich, & Dyer, 1979). As well, there is evidence to suggest that learners who are required to learn multiple items simultaneously utilize feedback on correct trials to strengthen their *inhibition* of the incorrect responses, and strengthen the association between the cue and the target response.

Further, the impact of *error trials* have been demonstrated to come at an increased cost to the learners' cognitive processes (e.g., working memory; attention) compared to interpreting the feedback from a successful motor trial (Koehen et al., 2008). Thus, participants' motivation for preferring feedback after "good trials" is seemingly consistent with their attempt to economize their invested effort in the cognitive and motor processes attributed to motor planning during skill acquisition (Koehen et al., 2008; Chiviacowsky & Wulf, 2002, 2005). More recently, Lewthwaite and Wulf (2009) showed that augmenting KR with additional motivational information in regards to suggesting superior performance relative to others, resulted in enhanced motor proficiency of the motor task. Motivation has also recently shown to have a biological impact on the performer showing that performers motivated to learn actually increased the activity levels of the dopaminergic cortical pathways during practice resulting in superior learning advantages (Declerck, Boone, & de Brabander, 2006; Kühn et al., 2008). In summary, the results of the present study suggest learners are engaged in a deliberate and resourceful strategy during the individualization of their learning context. This notion is confirmed based on the degraded retention and transfer performance of the yoked condition that were not afforded the opportunity to individualize a learning strategy during acquisition.

### *4.3. Learning benefits of learner controlled KR schedules*

To our knowledge, this was the first experiment to show learning advantages for performers controlling their KR schedule while learning multiple motor task goals. In addition, the results of the present experiment provide additional support for the existing research demonstrating learning advantages for performers controlling a portion of their practice context. The results of our experiment extend previous research in three important ways. First, the results suggest that learners can effectively individualize a KR schedule during the acquisition of multiple motor task goals. Interestingly, the KR relative frequency was generalized across, and not dependent upon, the established intertask difficulty between the motor task goals. These results are similar to recent research demonstrating the relative frequency of augmented information was independent of task difficulty (Patterson & Lee, in press). Second, the preference for KR after *perceived* good trials, independent of intertask difficulty, extends previous research (e.g., Chiviacowsky & Wulf, 2002, 2005) showing similar preferences for learners practicing a motor task of one degree of difficulty. Thus, the preference for a generalized strategy is suggested to be a function of the cognitive effort required to reproduce a correct motor response compared to the effort required to calibrate an unsuccessful motor response (Chiviacowsky & Wulf, 2002). Interestingly, the learning advantages of a learner controlled practice context share similarities to and add to the growing support for practice factors facilitating the active engagement of the learner in their practice context (Guadagnoli & Lee, 2004; Lee et al., 1994; Schmidt & Bjork, 1992). Finally, the efficiency of a learner regulated practice has been evidenced in their ability to generalize and transfer their acquired motor behavior to novel task parameters (Chiviacowsky & Wulf, 2002, 2005). Importantly, learners in the present experiment, despite having to learn three motor task goals, demonstrated a superior ability in their performance of the transfer portion of the experiment.

## 5. Conclusion

In conclusion, the learning advantages evidenced from performers afforded the opportunity to individualize a portion of their learning context has unequivocally advanced our understanding of the practice factors facilitating motor learning. The results of the present experiment provide additional support for, and extend the efficacy of a learner controlled practice context. However, many questions still remain in regards to the utility of a learner controlled practice context. For example, further research is required to delineate the metacognitive strategies utilized by learners individualizing their practice context while learning multiple motor task goals. Also, during practice contexts where multiple motor skills are being practiced, it is unknown whether the order of the repetitions (e.g., blocked or random) interacts differently with performers strategical preferences for KR. Current motor learning theory would predict such an interaction exists, also to be influenced by the complexities of the motor task and the characteristics of the performer (e.g., skill level, age, neurological status) (see Guadagnoli & Lee, 2004). Future research is required to examine this potential interaction. As well, further research is required to examine the interaction of a learner controlled practice context with persons who have experienced changes to their central nervous system as a function of typical aging (e.g., older adults), as well as those participants who have experienced (e.g., cerebrovascular accident), or are experiencing (e.g., Parkinson disease) changes to the integrity of their central nervous system (see Wulf, 2007, for review). Finally, the robustness of a self-regulated learning context is attributed to performers acquiring a motor skill previously untrained. Curiously, it is unknown whether the performance advantages evidenced from novice performers, would in fact prove advantageous to performers already demonstrating cognitive and perceptual-motor expertise at the motor skill to be practiced. In fact, is well accepted in the expertise literature that continued movement expertise advancement is a function of performers deliberately challenging their current level of cognitive and motor ability with effortful practice contexts (e.g., Ericsson & Lehman, 1996). A Self-regulated practice context offers the expert the opportunity to individualize a practice context of optimal challenge and effort. Recently, Patterson and Lee (2008) predicted the cognitive effort required for performers to self-regulate their practice environment would have important practical implications for the movement expert advancing their cognitive expertise in regards to movement planning and error correction. Findings from these future investigations will have important theoretical implications as well as direct practical implications for persons learning motor skills in vocational, recreational, and rehabilitative settings.

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