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Decreasing the Proportion of Self-Control Trials During the Acquisition Period Does Not Compromise the Learning Advantages in a Self-Controlled Context

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The present experiment examined the learning effects of participants self-controlling their receipt of knowledge of results (KR) on all or half of their acquisition trials (50%). For participants who were provided 50% self-control, the first half of their acquisition period consisted of receiving KR on all trials, or according to a faded-KR schedule. Participants practiced a sequential timing task. The results showed that independent of practice condition, participants who self-controlled their KR during the acquisition period demonstrated superior performance compared to the respective yoked conditions in the retention and transfer portion of the experiment. These results extend previous research by suggesting that decreasing the proportion of self-control trials does not compromise learning in a self-controlled context.

Key words: knowledge of results, perceptuomotor processes, sequence learning

Understanding the practice factors that facilitate expeditious motor skill acquisition is a fundamental objective of motor learning inquiry. It is interesting that the theoretical understandings of motor skill acquisition have been extrapolated from practice contexts under direct control of the experimenter (e.g., Adams, 1971; Guadagnoli & Lee, 2004; Schmidt, 1975). Recently however, the learning advantages demonstrated by individuals controlling a portion of their practice context have rejuvenated a theoretical interest in further understanding the processes facilitating motor skill acquisition. The advantages of a self-controlled practice context can be seen in its generalization across several practice variables, such as augmented feedback (Chiviacowsky & Wulf, 2002, 2005; Chiviacowsky, Wulf, de Medeiros, Kaefer, & Tani, 2008; Huet, Camachon, Fernandez, Jacobs, & Montagne, 2009; Janelle, Kim, & Singer, 1995; Patterson & Carter, 2010; Patterson & Lee, 2010), the order of practice repetitions during multitask learning (Keetch & Lee, 2007; Sanli & Patterson, 2009), and the frequency of observing a skilled model or using an assistive device (Hartman, 2007; Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Wulf, Raupach, & Pfeiffer, 2005; Wulf & Toole, 1999).

The initial explanations for the self-control effects seen in motor skill learning were largely based on ideas from research in the verbal domain (Butler & Winne, 1995; Zimmerman, 1989). Currently, learning advantages have been attributed to an increased motivation to learn (Boekaerts, 1996; Winne, 1995), the practice context being strategically individualized to the learner's perceived performance (Chiviacowsky & Wulf, 2002, 2005), and task information being processed in a deeper and more meaningful way (Boekaerts & Corno, 2005; Janelle et al., 1997; Janelle et al., 1995; Winne, 2005; Zimmerman, 1989). The process of individualizing a practice context is considered cognitively effortful (Kanfer & Ackerman, 1989), as evidenced by self-report measures from individuals who indicated deliberate and strategic behavior when controlling a specific practice variable (Chiviacowsky & Wulf, 2002, 2005). In fact, practice contexts that engage the performer in the processes required for motor plan-

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ning and error detection, although considered cognitively effortful, have been acknowledged as a factor facilitating motor skill acquisition (Guadagnoli & Lee, 2004; Lee, Swinnen, & Serrien, 1994; Schmidt & Bjork, 1992). Providing learners control over an aspect of their practice context offers an alternative method of organizing cognitively effortful practice and lends further credence to the notion that motor skills are highly cognitive in nature (Starkes & Allard, 1993).

It is interesting that practice contexts individualized by performers have revealed consistencies, as well as inconsistencies, in our theoretical understanding of the practice factors that facilitate motor skill learning. For example, a schedule of frequent requests for knowledge of results (KR) early in the acquisition period, followed by a systematic reduction in KR requests later in the acquisition period (Chiviacowsky & Wulf, 2002; Patterson & Lee, 2010), is consistent with the learning advantages demonstrated in externally defined faded-KR schedules (e.g., Winstein & Schmidt, 1990), and is also consistent with the predictions of the guidance hypothesis (Salmoni, Schmidt, & Walter, 1984; see Wulf & Shea, 2004 for a review). However, an individual's preference for KR after a perceived *good* trial challenges previously held theoretical views regarding the primary role of KR in resolving the discrepancy between an actual and desired response (e.g., Adams, 1971; Schmidt 1975). In fact, individuals receiving feedback after successful trials have shown an increased motivation to learn (Chiviacowsky & Wulf, 2002, 2005), a decreased demand on information processing by repeating a successful response (Koehn, Dickinson & Goodman, 2008), and increased activity levels of the dopaminergic cortical pathways considered essential for learning (Declerck, Boone, & De Brabander, 2006; Kühn et al., 2008). Collectively, the findings from a self-controlled KR practice context suggest the role of KR during motor skill acquisition is not completely understood.

Curiously, in a self-controlled practice context, the individual's preference to systematically reduce the use of KR over the course of the acquisition period (e.g., Chiviacowsky & Wulf, 2002) raises an important question: does the learner in fact require self-control for the duration of the acquisition period? Theoretically, if individuals who were afforded control over a portion of their acquisition trials demonstrated learning equivalent to individuals who were given self-control on all acquisition trials, one could conclude that the factor facilitating learning was the cognitive processes that were facilitated by the self-control KR trials, rather than the *amount* of self-control KR trials (Butler & Winne, 1995). To address this gap in knowledge, individuals in the present study either self-controlled their receipt of KR on all (100%; similar to Chiviacowsky & Wulf, 2002), or a portion (50%), of their acquisition trials. For individuals afforded self-control of KR for a portion of their acquisition trials, we wanted to determine whether an externally defined KR schedule, preceding the self-control trials, would differentially affect the individuals' preference for and frequency of KR requests during their self-control trials, leading to either an advantage or disadvantage in their skill learning.

The purpose of the present experiment was to examine directly the effects on learning when combining an externally defined practice context for the first half of acquisition trials, with a learner-defined practice context for the second half. We expected that the structure of this self-controlled practice context would either add to or compromise the existing benefits attributed to a self-controlled practice context. Based on the guidance hypothesis (e.g., Salmoni et al., 1984), the structure of the externally defined KR schedule experienced during the first half of practice trials was expected to differentially affect individuals' preference for and frequency of requests for KR during the second half of practice and subsequent learning. In the present experiment, individuals during the first half of practice experienced one of two dichotomous KR schedules: one considered beneficial for skill acquisition (i.e., faded-KR schedule; Winstein & Schmidt, 1990), and the other considered suboptimal (i.e., KR after all trials; see Wulf & Shea, 2004 for a review). In a faded-KR schedule, individuals are believed to increase their independence in error detection and correction by using intrinsic information from their just-completed trial to guide upcoming responses on the no-KR trials, evidenced by fewer KR requests during the self-controlled trials (Winstein & Schmidt, 1990; Salmoni et al., 1984). However, providing KR on all trials is believed to circumvent the processing of intrinsic feedback, resulting in a dependency on KR to guide upcoming responses, evidenced by frequent KR requests during the self-control trials at the expense of independent error detection and subsequent learning (for a review, see Wulf & Shea, 2004).

Method

Participants

Sixty students from Brock University (34 women and 26 men; *M* age = 22.3 years, *SD* = 1.79) participated in the study. All participants provided informed consent before their participation and were naïve to the purposes of the experiment, and none had prior experience with the task. On completion of the experimental protocol, all participants received course credit.

Apparatus and Task

Participants sat at a standardized desk containing a desktop computer (Dell OptiPlex GX620) and a serial response (SR) box (Model #200A, PsychNet Tools). The

SR box (17 cm by 19.8 cm) was positioned directly in front of the participant and consisted of five 1 x 1 cm buttons sequentially labeled one to five from left to right. On each trial, all experimental stimuli were presented on a 19-inch LCD Dell monitor.[1] The total display size was 9.5 cm high and 7 cm wide.

The experimental task required participants to depress five keys (3-2-5-1-4) sequentially on the SR box using the index finger of their self-reported nondominant hand. The goal was to complete the sequence in as close as possible to a goal movement time (MT) of 2,550 ms. For the transfer portion of the experiment, participants completed a novel five-key pressing sequence (4-5-2-3-1) with an overall goal MT of 3,300 ms.

Procedure

Participants were assigned randomly to the self-controlled and yoked conditions. Participants in the self-controlled conditions (from this point on, referred to as a Self condition) were randomly assigned to the Self-Self, the All-Self or the Faded-Self condition. Two important distinctions differentiated the three Self conditions. First, participants were given the opportunity to control their receipt of KR on all (termed Self-Self) or a portion (50%; termed All-Self or Faded-Self) of the acquisition trials. Second, the first half of the acquisition trials was distinct for each Self condition. In the Self-Self condition, participants individualized their KR schedule for all 90 acquisition trials, consistent with the existing literature (Chiviacowsky & Wulf, 2002; Patterson & Carter, 2010). In the All-Self condition, KR was provided on all trials for the first 45 trials, then self-controlled by the participant for the remaining 45 trials. For the Faded-Self condition, the frequency of KR was reduced over the first 45 practice trials, followed by 45 trials in which the performer self-controlled the receipt of KR. The Faded-Self group, on Trials 1 through 15, received KR on all trials, followed by every third trial (33%) for Trials 16 to 30, and finally every fifth trial (20%) for Trials 31 through 45. The relative KR frequency for this condition was 51% for the first half of the acquisition period. Participants in each respective yoked condition (Yoked-Yoked, All-Yoked and Faded-Yoked) replicated the KR schedule from a self-controlled counterpart, but without the element of choice (see Table 1).

Before beginning the formal acquisition period, all participants read through a series of instruction slides, generated through E-Prime (version 1.1, Psychology Software Tools, Inc., Pittsburgh, PA), that explained the task goal and structure of their practice condition. All participants practiced one trial of the motor task to familiarize themselves with its demands as well as the information contained in the KR display. Both the key-pressing sequence and its associated MT goal used in the practice trial were not used during the experimental protocol.

A typical experimental trial began with participants viewing the required key-pressing sequence (3-2-5-1-4) and MT goal (2,550 ms) for 5 s. During this period, participants were instructed to familiarize themselves with both the sequence and its MT goal as well as to rest the index finger of their nondominant hand on the first key of the sequence (i.e., 3). To clearly distinguish the first key of the sequence from the remaining four keys, the starting key was outlined with a red border. After 5 s, the key-pressing sequence was replaced by a solid blue screen for 3 s, followed by the sequence being presented a second time, serving as a cue for participants to begin their key-pressing movements as soon as they were ready. On trial completion, participants in the Self-Self, All-Self and Faded-Self conditions viewed a screen prompting them to decide whether or not they required KR on their just-completed trial. If *yes*, participants pressed the 1 key, clearly labeled on the SR box. If *no*, participants pressed the 5 key, clearly labeled on the SR box. The KR display consisted of both the goal MT and the participant's MT for 5 s. On the no-KR trials, a blue screen was displayed for 5 s to control the intertrial interval during the experiment. All participants then viewed a "Ready?" screen for 5 s before beginning the next trial. Participants in the Self conditions were informed that KR would be presented only when requested and should be requested only when absolutely needed, as they would eventually be asked to produce the goal MT without KR. Participants in the yoked condition received the same information (i.e., they would eventually be asked to produce the goal MT without KR), with the difference that sometimes they would receive feedback and sometimes they would not, similar to the instructions provided by Chiviacowsky and Wulf (2002, 2005). For participants in the All-Self and Faded-Self conditions, KR was initially presented based on a predefined KR schedule for the first half of the acquisition period (45 trials), and subsequently based on the participants' requests for KR during the second half of the practice period. Participants in the three yoked conditions replicated the KR schedule

Table 1. Summary of the knowledge of results schedules for the experimental conditions for the first half (Blocks 1–5) and second half (Blocks 6–10) of acquisition trials

Experimental group	First half of acquisition (45 trials)	Second half of acquisition (45 trials)
Self-Self	Self	Self
All-Self	KR on all trials	Self
Faded-Self	Faded KR	Self
Yoke-Yoke	Yoked to Self	Yoked to Self-Self
All-Yoke	KR on all trials	Yoked to All-Self
Faded-Yoke	Faded KR	Yoked to Faded-Self

Note. KR = knowledge of results.

of their self-regulated counterpart, but without the choice. The difference in length of the KR-delay interval between the Self-participants required to make a decision and the Yoked participants not required to make a decision regarding receipt of KR were minimal and, therefore, did not differentially impact the results of the present experiment. All incorrect trials (i.e., incorrect sequence) were immediately repeated. Participants did not receive MT KR on incorrect trials. All participants completed 90 acquisition trials. The software program E-prime was customized to control the presentation of the experimental stimuli and collect the dependent variables of interest.

On completing the acquisition phase, all participants filled out a questionnaire about their preference for receiving KR. The questionnaire was identical to that used by Chiviacowsky and Wulf (2002). Those in the Self conditions were asked to circle the most appropriate response in regard to their preference for KR (e.g., after good trials, poor trials, randomly, etc.), while those in the Yoked condition were queried as to whether they believed they received KR after the right trials, and if not, when they would have preferred to receive KR. Completion of the questionnaire took approximately 10 min.

To examine learning, participants completed 5 trials of the practiced sequence from the acquisition period in an immediate (10 min) and a delayed (approximately 24 hr) no-KR retention test. Participants then completed a no-KR transfer test consisting of 5 trials of a novel five-digit key-pressing sequence (4-5-2-3-1) with associated MT goal (3,300 ms). The delayed retention test always preceded the transfer test.

Data Analyses

The dependent variables absolute constant error (|CE|) and variable error (VE) were used to index changes in motor performance of the participants as a function of their respective practice condition, during the acquisition, retention, and transfer periods of the experiment. Absolute constant error is defined as the absolute mean deviation from the goal MT and the participant's MT (Schmidt & Lee, 2005). Variable error (VE) was used as an index of movement consistency, defined as the standard deviation of a block of scores in reference to the participant's average score (Schmidt & Lee, 2005).

For the acquisition period, mean |CE| and VE were grouped into 10 blocks of nine trials. Both dependent variables were analyzed in separate analyses of variance (ANOVAs). To examine potential experimental group differences during the first half of trials in the acquisition period, |CE| and VE were submitted to separate 6 (experimental group: All-Self, All-Yoked, Faded-Self, Faded-Yoked, Self-Self, Yoked-Yoked) x 5 (blocks) ANOVAs with repeated measures on blocks. To examine potential changes in motor performance during the second half of the acquisition period, as a function of the KR schedule experienced by the Self conditions during the first half of the acquisition period, |CE| and VE were submitted to separate 3 (experimental group: All-Self, Faded-Self, Self-Self) x 5 (Blocks: 6–10) ANOVAs with repeated measures on blocks. To examine the frequency of KR requests as a function of the Self condition, the mean proportion of KR trials for Blocks 6–10 were submitted to a 3 (experimental group: All-Self, Faded-Self, Self-Self) x 5 (Blocks: 6–10) ANOVA with repeated measures on blocks.

For the immediate and delayed retention tests and the transfer test, mean |CE| and VE measures were each averaged into one block of five trials. To determine whether learning was a function of the Self condition experienced during acquisition, |CE| and VE were submitted to separate 3 (experimental group: All-Self, Faded-Self, Self-Self) x 2 (retention test: immediate, delayed) ANOVAs with repeated measures on retention. It was of further interest to determine whether the performance of the Self conditions were superior to their respective yoked counterparts, consistent with the extant literature (Chiviacowsky & Wulf, 2002; Patterson & Carter, 2010; Patterson & Lee, 2010). Thus, we submitted |CE| and VE to a series of separate one-way ANOVAs to compare Self-Self to Yoked-Yoked, Faded-Self to Faded-Yoked, and All-Self to All-Yoked. In all analyses, the alpha level was set at $p < .05$. Estimated effect sizes are reported as partial eta squares (η_p^2). Post hoc comparisons were conducted using Tukey's HSD.

Results

Acquisition

Feedback Requests. During Blocks 6–10, participants in the Self-Self condition requested KR on 69, 71, 76, 63, and 78% ($M = 71.3$, $SE = 0.09$) of the acquisition trials, whereas participants in the All-Self condition requested KR on 41, 46, 42, 43, and 49% ($M = 44$, $SE = 0.009$) of the acquisition trials. Participants in the Faded-Self condition requested KR on 39, 44, 41, 36 and 38% ($M = 39$, $SE = 0.09$) of the acquisition trials. The ANOVA revealed a significant main effect for Self condition, $F(2, 27) = 3.40$, $p < .05$, $MSE = 43{,}326$, $\eta_p^2 = .20$. The post hoc test indicated the Self-Self condition requested KR more frequently during the second half of the acquisition period compared to the All-Self and Faded-Self conditions. No differences were noted between the All-Self and the Faded-Self conditions.

Absolute Constant Error. The |CE| scores in the acquisition period for the experimental conditions are displayed on the left side of each panel in Figure 1 for the self-control and yoked conditions, respectively. For the first phase of the acquisition period (Blocks 1–5), there was a significant main effect for block, $F(4, 216) = 16.71$, $p < .05$, $MSE = 25{,}355$, $\eta_p^2 = 0.24$. The results of the post hoc test indicated that Block 1 was performed with more |CE| compared to Blocks 2, 3, 4, and 5.

For the second half of the acquisition period (Blocks 6–10), the KR schedule experienced during the first half of the acquisition period (Self or experimenter-defined) did not differentially affect |CE|. This finding was supported by the absence of a main effect for group or a Group x Block interaction.

Variable Error. VE for experimental conditions are located on the left side of each panel in figure 2. For the first phase of the acquisition period (Blocks 1–5), the ANOVA indicated a main effect for group, $F(5, 54) = 4.83$, $p < .05$, $MSE = 15{,}795$, $\eta_p^2 = .31$, and block, $F(4, 216) = 13.26$, $p < .05$, $MSE = 12{,}954$, $\eta_p^2 = 0.20$. The post hoc results of the group main effect indicated that the Self-Self ($M = 204.7$, $SE = 23.5$), All-Self ($M = 211.5$, $SE = 37.5$), and Faded-Self ($M = 222.7$, $SE = 38.7$) conditions demonstrated less VE compared to the All-Yoked condition ($M = 303.8$, $SE = 17.7$). The post hoc results from the block main effect indicated that Block 1 had greater VE compared to Blocks 2, 3, 4, and 5. No other block differences were identified. For the second half of the acquisition period (Blocks 6–10), the KR condition experienced during the first half of the acquisition period did not differentially affect participants' VE.

Participant-Reported KR Preference as a Function of Self Condition. Similar to Chiviacowsky & Wulf (2002) and more recently Patterson & Carter (2010), we examined participants' preference for KR during the acquisition period. Thus, to examine the impact of a predetermined KR schedule experienced by participants during the first half of trials in the acquisition period (Blocks 1–5), we were interested in examining participants' preferences for KR during the second half of the acquisition period (see Table 2). It is interesting that 30% of participants in the Self-Self condition, 50% of participants in the All-Self condition, and 60% of participants in the Faded-Self condition reported a preference for requesting KR after they perceived a *good trial.* One participant in each of the Self-Self and All-Self conditions reported that they re-

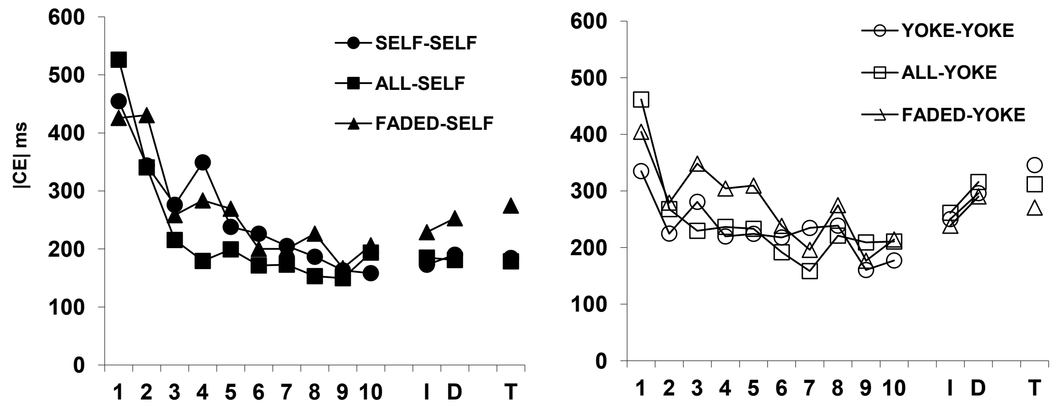

Figure 1. Absolute constant error (|CE|) for experimental conditions for acquisition, retention and transfer.

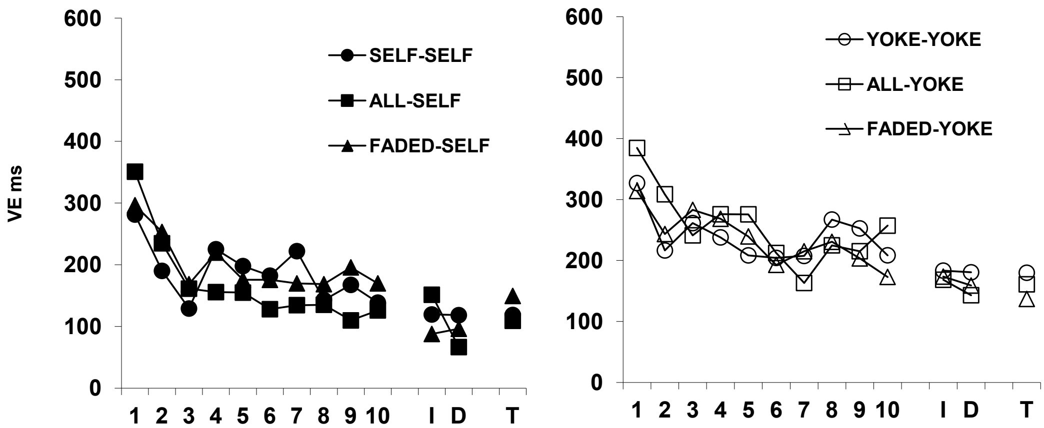

Figure 2. Variable error (VE) for experimental conditions for acquisition, retention and transfer.

quested KR after a perceived *poor trial*. In addition, 60% of participants in the Self-Self condition and one participant in the All-Self condition reported that they requested KR after a perceived *good trial and poor trial equally*. Further, 20% of participants in the Faded-Self condition and 10% of participants in the All-Self condition requested KR *randomly*. Finally, 20% of participants in the Self-Self and Faded-Self conditions used strategies not identified on the questionnaire. They reported these individualized strategies as "always" and "every four trials to see if still on the right track." Thus, the questionnaire data suggested that Self participants' preferences for KR varied as a function of the KR schedule experienced during the first half (e.g., Blocks 1–5) of the acquisition period.

For the yoked conditions, 90% of participants in the Yoked-Yoked condition, and 30% of participants in the All-Yoked and Faded-Yoked conditions reported receiving KR after the appropriate trials. For those yoked participants who reported that they did not receive KR after the appropriate trials, 30% of participants in the All-Yoked condition and 10% of participants in the Faded-Yoked condition reported that they would have requested KR after a *perceived good trial*, whereas 20% of participants in the Faded-Yoked condition would have preferred KR on a *perceived poor trial*. Finally, 10% of participants in the Yoked-Yoked condition, 30% in the All-Yoked condition, and 40% in the Faded-Yoked condition reported they would have preferred KR on perceived *good and poor trials equally*. Finally, only 10% of participants from the All-Yoked condition indicated they would have requested KR randomly throughout the acquisition period.

Table 2. Number of responses of self and yoked participants to questions regarding feedback scheduling

	Self-Self	All-Self	Faded-Self
When/why did you ask for feedback?			
Mostly after a perceived good trial	3	5	6
Mostly after you perceived a poor trial	1	1	0
After perceived good trials and poor trials equally	6	1	0
Randomly	0	1	2
Other	0	2	2
When did you not ask for feedback?			
After perceived good trials	0	3	0
After perceived bad trials	2	2	6
After perceived good trials and poor trials equally	1	2	1
Randomly	5	3	2
Other	2	0	1
	Yoke-Yoke	**All-Yoke**	**Faded-Yoke**
Do you think you received feedback after the right trials?			
Yes	9	3	3
No	1	7	7
If you answered NO, when would you have preferred to receive feedback?			
After perceived good trials	0	3	1
After perceived bad trials	0	0	2
After good trials and poor trials equally	1	3	4
Randomly	0	1	0
Other	0	0	0

To verify whether the preferences for KR on a *perceived good trial* were commensurate with those participants' actual motor performance on those trials, we examined |CE| on the no-KR and KR trials for the Self condition participants using this strategy during Blocks 6–10. The Self-Self condition performed with less |CE| on the KR (M = 151.12 ms, SE = 64.62) compared to the no-KR trials (M = 203.69, SE = 81), as did the All-Self condition, who also performed with slightly less |CE| on the KR (M = 159.92, SE = 50.05) compared to the no-KR trials (M = 174.06, SE = 62.74). Further, the Faded-Self condition also performed with less |CE| on the KR (M = 167.89 ms, SE = 62.74) compared to the no-KR trials (M = 216.10, SE = 57.28). We conducted a Feedback Type (self/yoked) x Feedback Frequency (Self, ALL, Faded) x Trial Type (KR/no-KR) ANOVA with repeated measures on trial type. The results of the ANOVA indicated a main effect for trial type, $F(1, 22) = 6.108$, $p > .05$, $MSE = 34{,}802$, $\eta_p^2 = .217$, with less |CE| on KR trials (M = 208.11, SE = 22.07) compared to the no-KR trials (M = 260.14, SE = 27.67). However, neither the Feedback Type (self/yoked) x Trial Type (KR/no-KR), $F(1, 22) = .426$, $p > 05$, nor the Feedback Type x KR Schedule x Trial Type, $F(2, 22) = 2.650$, $p > .05$, interactions reached statistical significance.

Retention

Absolute Constant Error. The |CE| measures for the retention period are presented on the right side of each panel in Figure 1 for the self-control and yoked groups, respectively. Regardless of the KR schedule experienced during Blocks 1–5 in the acquisition period, the ANOVA indicated no differences among the three Self conditions during the retention portion of the experiment.

Consistent with the extant literature (e.g., Chiviacowsky & Wulf, 2002; Patterson & Carter, 2010), the Self conditions demonstrated less |CE| compared to their yoked counterparts. Specifically, the Self-Self condition (M = 106.7, SE = 31.4) demonstrated less |CE| compared to their Yoked-Yoked counterparts (M = 273.2, SE = 44.1). This main effect was significant, $F(1, 18) = 8.06$, $p < .05$, $MSE = 15{,}705$, $\eta_p^2 = 0.31$. The All-Self condition (M = 169.6, SE = 28.3) demonstrated less |CE| compared to the All-

Yoked condition (M = 288.3, SE = 65.1). This main effect was also statistically significant, $F(1, 18) = 4.67$, $p < .05$, $MSE = 30{,}301$, $\eta_p^2 = 0.21$. The Faded-Self condition (M = 185.8, SE = 43.9) demonstrated less |CE| compared to the Faded-Yoked condition (M = 289.4, SE = 41.9), supported by a main effect for group, $F(1, 18) = 5.78$, $p < .05$, MSE = 18,568, $\eta_p^2 = .24$.

Variable Error. The VE measures for the retention period are presented on the right side of each panel in Figure 2 for the self-control and yoked groups, respectively. The ANOVA indicated a Self Group x Retention Test interaction The post hoc test revealed that the All-Self condition demonstrated a significant decrease in VE from the immediate (M = 151.35) to the delayed retention test (M = 66.54). However, differences among the three Self conditions were not statistically significant.

Similar to retention |CE|, the Self conditions demonstrated less VE compared to their respective yoked counterparts. Specifically, the Self-Self condition (M = 118.1, SE = 20.1) demonstrated less VE compared to their Yoked-Yoked counterparts (M = 181.97, SE = 28.5). This difference was supported by a group main effect, $F(1, 18) = 4.69$, $p < .05$, MSE = 8,507, $\eta_p^2 = 0.21$. The All-Self condition (M = 108.9, SE = 15.4) demonstrated less VE compared to the All-Yoked condition (M = 155.7, SE = 26.4). However, this difference was not statistically significant as indicated by the absence of a group main effect and a Group x Retention Test interaction. The Faded-Self condition (M = 91.9, SE = 14.4) demonstrated less VE compared to the Faded-Yoked condition (M = 166.2, SE = 12.3). This difference was supported by a group main effect, $F(1, 18) = 18.20$, $p < .05$, MSE = 3,027, $\eta_p^2 = 0.50$.

Transfer

Absolute Constant Error. The |CE| measures for the transfer period are presented on the far right side of each panel in Figure 1 for the self-control and yoked groups, respectively. Similar to the retention period, the ANOVA examining the transfer performance of the three Self conditions did not reveal a statistically significant difference among these conditions.

Further, the Self conditions demonstrated less |CE| compared to their respective yoked counterparts. Specifically, the Self-Self condition (M = 187.9, SE = 47.6) demonstrated less |CE| compared to their Yoked-Yoked counterparts (M = 345.6, SE = 47.6), as supported by a group main effect, $F(1, 18) = 5.47$, $p < .05$, MSE = 22,729, $\eta_p^2 = 0.23$. The All-Self condition (M = 167.9, SE = 28.1) demonstrated less |CE| compared to the All-Yoked condition (M = 311.8, SE = 28.1), also supported by a group main effect, $F(1, 18) = 13.07$, $p < .05$, MSE = 7,917, $\eta_p^2 = 0.42$. The Faded-Self condition (M = 250, SE = 48.5) demonstrated similar |CE| compared to the Faded-Yoked condition (M = 293.6, SE = 48.4).

Variable Error. The VE measures for the transfer period are presented on the far right side of each panel in Figure 2 for the self-control and yoked groups, respectively. Overall, measures of VE during the transfer portion of the experiment, revealed no statistically significant main effects or interactions.

Discussion

The purpose of the present experiment was two-fold. First, we were interested in determining whether the learning advantages of a self-controlled practice context would be similar for participants given control over their receipt of KR for a portion (50%) of the acquisition trials compared to a group of participants controlling their receipt of KR on all acquisition trials, similar to the existing research (Chiviacowsky & Wulf, 2002, 2005; Patterson & Carter, 2010). We expected that if learning was a function of the *proportion* of control trials, then those in the Self condition with 100% control would demonstrate superior learning compared to those in the Self conditions with 50% control. However, if learning was independent of the amount of control afforded, the *cognitive* effort required to individualize a practice context could be considered the important mechanism facilitating learning (e.g., Butler & Winne, 1995; Chiviacowsky & Wulf, 2002, 2005; Kanfer & Ackerman, 1989; Patterson & Lee, 2010). Our second purpose was to determine whether the structure of the KR schedule preceding the control trials would differentially impact Self participants' requests for KR and subsequent learning. To examine this query, participants in the first half of practice controlled their receipt of KR on all trials (Self-Self), received KR on all trials (All-Self), or experienced a fading schedule of KR (Faded-Self), similar to Winstein & Schmidt (1990). Based on the guidance hypothesis (Salmoni et al., 1984), we expected the structure of the KR schedule experienced during the first half of the acquisition period to differentially affect participants' proportion of self-control KR trials during the second half of the acquisition period and subsequent learning.

Our first main finding was that independent of the proportion of trials that participants were afforded control over (50 or 100%), practicing in a Self condition demonstrated superior learning to those in the respective yoked conditions. These results add further support to the learning advantages of individuals afforded the opportunity to self-control their receipt of KR (Chiviacowsky & Wulf, 2002, 2005; Chiviacowsky et al. 2008; Janelle et al., 1997; Janelle et al., 1995; Patterson & Carter, 2010; Patterson & Lee, 2010). It is important that our results extend previous research by suggesting that the advantages of a self- controlled practice context remain despite control being afforded to participants for only half of the acquisition trials. We suggest that the learning similarities among the three

Self conditions is a function of these individuals sharing a heightened demand on their information processing during the self-control trials, a processing demand not expected to be experienced by the yoked conditions. In fact, the role of KR when self-controlled by an individual is believed to resolve a perceived metacognitive discrepancy between the perceived success of a just-completed response and actual response success (see Butler & Winne, 1995 for a review). Thus, the information gained during this introspective process is believed to inform the individual's decision to either receive or not receive KR (Chiviacowsky & Wulf, 2002, 2005).

It is interesting that an individual's decision to receive KR was consistent with, and also inconsistent with the existing literature (e.g., Chiviacowsky & Wulf, 2002). For example, a majority of the participants in the Faded-Self and All-Self conditions reported a preference for KR after a *perceived good trial*, consistent with the findings of Chiviacowsky and Wulf (2002). However, the majority of participants in the Self- Self condition reported a preference for KR after a perceived *good trial and poor trial* equally. This finding is inconsistent with Chiviacowsky & Wulf (2002), who reported a preference for KR after a perceived *good trial* by participants provided control on all acquisition trials. Independent of a Self participant's preference to receive KR, the cognitive effort required to determine whether or not KR is required is believed to be the end product of a process requiring individuals to make a judgment about the success of their response based on the interpretation of their intrinsic feedback. The information gained from this process is predicted to inform the individual's decision whether or not KR is required. Because these metacognitive processes are theoretically assumed, further research is required to understand the role of individual error detection during the individualization of a KR schedule. It is important that the results of the present experiment add further credence to practice contexts that facilitate the cognitive processes requisite for motor skill learning (e.g., Lee et al., 1994; Schmidt & Bjork, 1992).

As expected, the KR schedule experienced by individuals in the Self conditions during the first half of trials in acquisition *did* differentially affect the frequency of KR requests during the second half of practice. Unexpectedly however, participants in the All-Self and Faded- Self conditions requested KR less often during the second half of practice (Blocks 6–10) compared to participants in the Self-Self condition. The Self-Self condition requested KR on 71.3% of the second-half acquisition trials compared to the All-Self (44%) and the Faded-Self (39%) conditions. The relatively similar proportion of KR trials requested by a majority of individuals in the All-Self and Faded-Self conditions is, we suggest, a function of these individuals reporting a similar preference for KR, that is after a *perceived good trial*. However, a majority of individuals in the Self-Self condition reported a preference for KR on perceived *good trials and poor trials equally*. In fact, the higher proportion of KR trials for the Self-Self condition, relative to the other Self conditions, is consistent with their reported preference for KR on *perceived good trials and poor trials equally* that would intuitively include a greater proportion of KR trials. However, the less frequent KR requests by the All-Self and Faded-Self conditions is commensurate with these individuals' preference for KR according to a stricter criterion (e.g., after a perceived good trial), which intuitively would indicate fewer KR trials, exactly as demonstrated by these individuals.

The results of the present study suggest that providing the individual with self-control for the second half of the acquisition period circumvented the expected negative consequences of receiving KR on all trials during the first half of acquisition (e.g., Salmoni et al., 1984). Interestingly, evidence from the cognitive science literature recommends providing the learner control later in skill acquisition. Specifically, the cognitive effort required to individualize a practice context is expected to interact less than optimally with the cognitive demands required to perform the task early in skill acquisition (Kanfer & Ackerman, 1989). Based on this notion, and the results of the present experiment, one could question whether the learning advantages of a self-controlled practice context would remain if control were provided for only the first half of the acquisition period, or perhaps after every other trial? Findings from these investigations would provide further insight into the theoretical understanding of self-control trials on learning when provided at different points during motor skill acquisition. As well, the learning advantages associated with manipulating the placement of control is expected to interact with the complexity of the motor task. Specifically, the information-processing demands required to perform the motor task are expected to interact, perhaps less than optimally, with the processing demands required to individualize a practice context (e.g., Guadagnoli & Lee, 2004; Kanfer & Ackerman, 1989). Recent evidence from research examining the acquisition of surgical skills showed that the utility of a self-controlled practice was a function of individuals attempting to achieve process goals (e.g., technical skill information) compared to those individuals in a self-regulated condition attempting to achieve outcome goals (Brydges, Carnahan, Safir, & Dubrowski, 2009). These results suggested that the skill level of the learner, the structure of the practice context, and the complexity of the task result in an important interaction in determining the utility of a self-controlled practice context (e.g., Guadagnoli & Lee, 2004). Further research is required to examine this interaction.

In summary, the results of the present experiment suggest that decreasing the proportion of control trials during the acquisition period does not compromise the learning advantages in a self-controlled context. More research is required to examine whether the placement of the control trials, such as at the beginning of practice or perhaps after every other trial, differentially affects the utility of a self-controlled practice context. Also of importance, the structure of the KR schedule preceding the self-control trials did not compromise learning in a self-controlled practice context. This finding is an extension of previous motor learning investigations that demonstrated learning advantages for practice contexts modulated over the course of the acquisition based on a researcher-defined criterion. In conclusion, the learning advantages demonstrated from a self-controlled practice context have facilitated a renewed interest in theoretically understanding the practice factors facilitating the processes requisite for motor skill learning.

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Note

1. Direct correspondence with Psychology Software Tools, Inc., resulted in a recommendation to perform a series of critical timing tests (i.e., RefreshClock Test), as outlined in Chapter 3 and Appendix A in the *E-Prime User's Guide*, Version 1 (Schneider, Eschman, & Zuccolotto, 2002), to confirm millisecond precision timing of our experiment. The results of the critical timing tests confirmed millisecond timing precision was preserved in the present experiment using the reported LCD monitor.

Authors' Notes

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