Human Movement Science 31 (2012) 1459–1472

Contents lists available at SciVerse ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

# Self-controlled knowledge of results: Age-related differences in motor learning, strategies, and error detection

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A R T I C L E   I N F O

*Article history:*
Available online 17 November 2012

*PsycINFO Classification:*
2330
2340
2343

*Keywords:*
Practice
Feedback
Error detection
Older adults
Performance estimation

A B S T R A C T

Research has demonstrated that a self-controlled KR schedule is advantageous for motor learning; however, the usefulness of a self-controlled KR context in older adults remains unknown. To address this gap in knowledge, we examined whether (1) the learning benefits of a self-controlled KR schedule are modulated by the age of the learner; (2) practicing in a self-controlled KR context concurrently strengthens the learner's error detection mechanism, and (3) the KR strategy during acquisition changes as a function of practice trials completed and age. As a function of age, participants were quasirandomly assigned to either the self-control or yoked group resulting in four experimental groups (Self-Young, Yoked-Young, Self-Old, and Yoked-Old). The results revealed the Self-Young group: (1) demonstrated superior retention performance than all other groups ($p < .05$); (2) was more accurate in estimating motor performance than all other groups during retention ($p < .05$), and (3) self-reported a switch in their strategy for requesting KR during acquisition based on the number of practice trials completed. Collectively, our findings suggest that older adults do not demonstrate the same learning benefits of a self-controlled KR context as younger adults which may be attributed to differences in KR strategies.



## 1. Introduction

Research has unequivocally revealed self-controlled practice to be a learning variable when performers controlled the frequency of observing a modeled demonstration, the use of physical assistive

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http://dx.doi.org/10.1016/j.humov.2012.07.008

devices, and the organization of practice repetitions (see Wulf, 2007 for a review). Similarly, a self-controlled knowledge of results (KR) schedule has proven more effective for motor learning compared to those not provided control (i.e., yoked group) for single task (Chen, Hendrick, & Lidor, 2002; Chiviacowsky & Wulf, 2002, 2005; Patterson, Carter, & Sanli, 2011) and multiple task learning (Patterson & Carter, 2010).

The learning advantages of self-controlled practice are speculated to be the result of an increased *motivation* to learn (Boekaerts, 1996; Chiviacowsky & Wulf, 2002, 2005; Winne, 1995; Wulf, 2007), that practice conditions are *individualized* to the performers information processing capabilities (Chen et al., 2002; Chiviacowsky & Wulf, 2002; Keetch & Lee, 2007), and *task information* is requested only when necessary (Boekaerts & Corno, 2005; Chiviacowsky & Wulf, 2002; Winne, 2005; Wulf, 2007; Zimmerman, 1989). Learners also utilize *deliberate strategies* when provided the opportunity to control task-related information (e.g., KR after *good* trials: Chiviacowsky & Wulf, 2002; Patterson & Carter, 2010).

The preference for KR after perceived good trials challenges theoretical accounts regarding the role of KR in resolving error; that is, minimizing the differences between the actual and the desired performance (Adams, 1971; Schmidt, 1975). The preference for feedback after good trials has been interpreted as a motivational factor during skill acquisition (Chiviacowsky & Wulf, 2002) and the perception that less cognitive effort is required to reproduce a successful response compared to the cognitive effort required to update a motor plan for an unsuccessful response (Chiviacowsky & Wulf, 2002, 2005; Koehen, Dickinson, & Goodman, 2008). The benefits of self-control have been primarily demonstrated in younger adults (see Wulf, 2007 for a review) and more recently in 10 year old children (Chiviacowsky, Wulf, Laroque de Medeiros, Kaefer, & Tani, 2008). In contrast, the usefulness of self-controlled practice in older adults has received minimal attention in the motor learning literature and consequently remains inconclusive (Patterson, Sanli, & Adkin, 2008).

Findings from the cognitive learning literature offer insight into the relationship between self-controlled practice and older adults. Compared to younger adults, older adults self-select practice strategies requiring minimal cognitive effort (e.g., recognition) for word association tasks and novel arithmetic problems compared to the cognitively effortful strategies (e.g., retrieval) considered advantageous for learning (D'Eredita & Hoyer, 2010; Hertzog, Touron, & Hines, 2007; Rogers & Gilbert, 1997; Rogers, Hertzog, & Fisk, 2000; Touron & Hertzog, 2004a, 2004b; Touron, Hoyer, & Cerella, 2004). Older adults' propensity to individualize a learning context that places low demands on their cognitive processes not only results in a less than favorable learning context but also suggests an explicit awareness of their age-related changes to information processing abilities and working memory capacity (Bäckman, Lindenberger, Li, & Nyberg, 2010; Bäckman et al., 2000; Fjell & Walhovd, 2010; Luo & Craik, 2008; Salthouse, 1996). In the motor skill learning literature, older adults have demonstrated similar learning advantages to their younger adult counterparts in learning contexts believed to place heightened demands on their information processing (i.e., cognitively effortful) (e.g., random practice: Jamieson & Rogers, 2000; Lin, Wu, Udompholkul, & Knowlton, 2010; reduced relative frequency of KR: Carnahan, Vandervoort, & Swanson, 1996; Guadagnoli, Leis, van Gemmert, & Stelmach, 2002). However, these practice contexts were externally determined by the researcher. For younger adults, a learner-controlled practice context has proven to positively impact motor skill acquisition. Yet for older adults, it currently remains unknown. The opportunity for the older adult to individualize their learning to match their changing information processing could in fact prove favorable for motor learning. However, based on the cognitive learning literature, the *effort* required by the older adult learner to individualize their learning context is perhaps a less than desirable method of facilitating their skill learning. For the present experiment, we were interested in determining if older adults would individualize a practice context that would place low demands on their information processing (i.e., frequent KR request) to the detriment of learning, *or*, individualize a learning context that optimally challenged their information processing abilities to the advantage of learning.

To address this gap in knowledge, the primary purpose of this experiment was to examine whether the learning advantages of a self-controlled KR schedule are modulated by the age of the learner. Based on the cognitive learning literature and age-related changes to information processing and working memory, we expected frequent KR requests during practice for older adults, at the expense of learning. We were also interested in examining the strategies for requesting KR as a function of age and number of practice trials completed. Previous research asked participants to self-report a singular response regarding their KR strategy at the end of the acquisition phase (Chiviacowsky & Wulf, 2002; Patterson & Carter, 2010; Patterson et al., 2011); however, a limitation of this methodology is that learning is a dynamic process and participants may adjust their KR strategy as a function of practice trials completed. To address this limitation, participants were asked to self-report their KR strategy for trials 1–30 (hereafter termed 1st half) separate from trials 31–60 (hereafter termed 2nd half). Lastly, we were interested in determining if engaging in a deliberate KR strategy also developed the error detection and correction mechanism. According to the guidance hypothesis (Salmoni, Schmidt, & Walter, 1984), an effective KR schedule prevents a dependence on KR by facilitating the ability to interpret and utilize intrinsic feedback sources. However, determining if a self-controlled KR schedule concurrently strengthens error detection abilities is unknown. Previous research has revealed that as practice progresses, participants typically decrease their number of KR requests (Chiviacowsky & Wulf, 2002; Patterson & Carter, 2010). As a result, we predicted an initial increased reliance on KR early in practice to be replaced by a greater reliance on task-related intrinsic feedback later in practice, consequently developing the error detection and correction mechanism of the self-control groups.

## 2. Methodology

### 2.1. Participants

Twenty younger adults (Self-Young, $n = 10$, $M$ age = 22, $SD = 1.15$; Yoked-Young, $n = 10$, $M$ age = 22.7, $SD = 0.95$) and 20 older adults (Self-Old, $n = 10$, $M$ age = 69.9, $SD = 6.05$; Yoked-Old, $n = 10$, $M$ age = 69.2, $SD = 6.11$) participated in the experiment. There were an equal number of males ($n = 5$) and females ($n = 5$) in each experimental group. All participants scoring $\geqslant 25$ on the Mini Mental State Exam (MMSE) (Folstein, Folstein, & McHugh, 1975) and 100 on the Modified Barthel Index (BI) (Shah, Vanclay, & Cooper, 1989)) were included in the present experiment. The MMSE and Modified BI were used as cognitive functioning and functional independence inclusion criteria, respectively. All participants signed an informed consent and were naïve to the purposes of the experiment.

### 2.2. Apparatus and task

All participants were required to push and release a low-friction slider along a horizontal rail to a goal distance of 133 cm (see Fig. 1). The total length of the horizontal rail was 261.6 cm. In a seated position, participants grasped the handle of the slider with a transverse palmar grip using their non-dominant hand. Hand dominance was determined by participants' verbal response to the following question, ''What hand do you write with?'' The first 50 cm of the rail was defined as the pre-response area where participants were required to push and release the slider. A wooden barrier (78.7 cm × 45.7 cm) was located at the 50 cm mark of the rail and occluded the participant's vision of the goal distance and subsequent result of each motor response. The wooden barrier contained an opening slightly larger than the slider, to allow unobstructed travel along the rail. For all acquisition and retention trials, participants wore industrial earmuffs to prevent the receipt of auditory feedback regarding the movement of the slider along the rail.

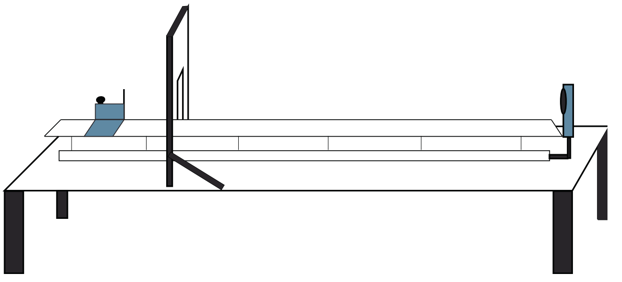

**Fig. 1.** Diagram of the apparatus.

A Vernier Motion Detector (ultrasound frequency of 50 kHz with an accuracy of ±2 mm within a range of 0.5 to 6 m) was mounted to the end of the horizontal rail and detected the end location of the each motor response. The Vernier Motion Detector was connected to a Vernier LabPro® that collected and relayed the end location of each trial to the custom software program. Calibration of the Vernier Motion Detector occurred each day before testing. All experimental stimuli (i.e., instructions, KR) were presented on a 19-inch LCD monitor located 50 cm to the right of the participant.

### 2.3. Procedure

Participants were quasirandomly assigned to their respective self-control and yoked groups as a function of age (Self-Young, Yoked-Young, Self-Old, and Yoked-Old), with the restriction that each self-control and yoked pairing was sex-matched. The task, its associated goal, and how KR would be displayed were presented to participants via PowerPoint. Participants in the self-control groups were informed they would be provided the opportunity to determine whether or not they wanted KR after each trial. Consistent with previous experiments (Chiviacowsky & Wulf, 2002; Patterson & Carter, 2010; Patterson et al., 2011), the self-control groups were instructed to only request KR when necessary and that they would eventually be required to perform the task without KR. Participants in the yoked groups received the identical KR schedule created by a self-control counterpart but were informed they would sometimes receive KR and sometimes they would not and that they would eventually perform that task without KR. All participants completed 60 trials during acquisition and 6 trials for both retention tests.

All trials began with a red circle and a 5 s countdown displayed on the LCD monitor. When the countdown reached zero, the circle turned green prompting the participants to complete their motor response within 5 s. On trials followed by KR, participants viewed the KR display for 5 s which contained the goal distance (e.g., 133 cm), their motor response (e.g., 128 cm), and the difference between the goal and their response (e.g., −5 cm). To maintain a consistent inter-trial interval, participants viewed a blank white screen for 5 s on no-KR trials. To request KR, participants in the self-control groups verbally informed the researcher whereas the provision of KR for the yoked groups was controlled by the custom software program according to the schedule created by an age and sex-matched self-control counterpart.

Upon completion of the acquisition period, all participants completed a multiple choice questionnaire querying their strategy for requesting KR (Chiviacowsky & Wulf, 2002; Patterson & Carter, 2010; Patterson et al., 2011) (see Table 1). The self-control groups were asked to report their KR strategy for the 1st half and 2nd half of the acquisition period separately. Importantly, the timing of the KR strategy questionnaire was chosen to avoid violating internal validity. If participants were asked to self-report their strategy for the 1st half of practice after completing trial 30, this could have cued participants' attention to different KR strategies to adopt during the 2nd half of practice. Yoked participants were asked whether they received KR after the right trials (i.e., when they would have wanted KR), and if not when would they have preferred to receive KR. During acquisition, all participants were verbally informed when the 1st half of practice ended and the 2nd half began.

To assess learning as a function of age and KR group, participants completed two retention tests both consisting of 10 no-KR trials (15-min and 24-hr); however, only the first six trials of the 10 trials were analyzed and reported. To determine whether an enhanced ability to detect and correct errors was a product of practicing with a self-controlled KR schedule relative to a yoked KR schedule, all participants were asked to estimate their perceived outcome of each motor response during both retention tests. Upon completion of the 24-hr retention test, all participants were asked to self-report whether or not they interpreted intrinsic feedback from a list of possible sources (see Table 2) in the presence or absence of KR during the acquisition phase.

### 2.4. Data analysis

To examine whether the frequency of requesting KR was influenced by age, the proportion of KR trials was subjected to a 2 (Age: young, old) × 10 (Blocks) ANOVA with repeated measures on the last factor. To assess performance and learning as a function of age and KR group, variable error (VE),

**Table 1**
Self-reported KR strategies during acquisition as a function of KR condition and age.

| KR condition | Younger adults | Older adults |
|---|---|---|
| | Number of responses | |
| Self-control condition | | |
| *1. When/why did you ask for KR during the first half of practice?* | | |
| a) Mostly after a perceived good trial | 4 | 3 |
| b) Mostly after a perceived bad trial | 0 | 0 |
| c) After perceived good and bad trials equally | 6 | 5 |
| d) Randomly | 0 | 0 |
| e) Other | 0 | 2 |
| *2. When/why did you ask for KR during the second half of practice?* | | |
| a) Mostly after a perceived good trial | 8 | 2 |
| b) Mostly after a perceived bad trial | 0 | 0 |
| c) After perceived good and bad trials equally | 2 | 5 |
| d) Randomly | 0 | 1 |
| e) Other | 0 | 2 |
| Yoked condition | | |
| *1. Do you think your received KR after the right trials?* | | |
| a) Yes | 5 | 7 |
| b) No | 5 | 3 |
| *2. If the answer to the above question was NO, when would you have preferred to receive KR?* | | |
| a) Mostly after a perceived good trial | 5 | 0 |
| b) Mostly after a perceived bad trial | 0 | 0 |
| c) After perceived good and bad trials equally | 0 | 3 |
| d) Randomly | 0 | 0 |
| e) Other | 0 | 0 |

**Table 2**
Self-reported use of intrinsic feedback sources as a function of KR condition and age.

| KR condition | Younger adults | Older adults |
|---|---|---|
| | Number of responses | |
| Self-control condition | | |
| 1. *During practice, did you use/interpret any other sources of information in addition to KR or when KR was not available?* | | |
| a) Yes | 10 | 10 |
| b) No | 0 | 0 |
| 2. *If the answer to the above question was YES, please indicate all the sources you used/interpreted during practice.* | | |
| a) Hand position | 3 | 6 |
| b) Wrist position | 2 | 3 |
| c) Arm position | 1 | 7 |
| d) Elbow position | 0 | 0 |
| e) Shoulder position | 0 | 6 |
| f) Produced force | 10 | 10 |
| g) Other | 0 | 1 |
| Yoked condition | | |
| 1. *During practice, did you use/interpret any other sources of information in addition to KR or when KR was not available?* | | |
| a) Yes | 10 | 7 |
| b) No | 0 | 3 |
| 2. *If the answer to the above question was YES, please indicate all the sources you used/interpreted during practice.* | | |
| a) Hand position | 9 | 7 |
| b) Wrist position | 1 | 7 |
| c) Arm position | 10 | 5 |
| d) Elbow position | 0 | 0 |
| e) Shoulder position | 0 | 4 |
| f) Produced force | 8 | 7 |
| g) Other | 0 | 0 |

absolute error (AE), and constant error (CE) were calculated for all experimental phases. For acquisition, mean VE, AE, and CE were grouped into 10 blocks of six trials and analyzed in separate 2 (Age: young, old) × 2 (KR group: self-control, yoked) × 10 (Block) ANOVAs with repeated measures on the final factor. To examine the development of the error detection and correction mechanism as a function of age and KR group, absolute difference (AD) was calculated by subtracting the participant's perceived outcome from their actual outcome. For retention, VE, AE, CE, and AD were collapsed into one block consisting of the first six trials and analyzed in separate 2 (Age: young, old) × 2 (KR group: self-control, yoked) × 2 (Retention Test: 15-mins, 24-hrs) ANOVAs with repeated measures on retention test. Tukey's HSD with an alpha level set at $p < .05$ was used for all statistically significant main effects and interactions and effect sizes are reported as partial eta squared ($\eta_p^2$).

## 3. Results

### 3.1. KR requests during acquisition

The proportion of KR requests for blocks 1-10 of acquisition for the Self-Young and Self-Old groups were 70%, 73%, 55%, 68%, 60%, 61%, 60%, 68%, 73%, & 58% and 77%, 80%, 70%, 68%, 72%, 68%, 72%, 68%, 83%, & 78%, respectively. The relative frequency that KR was requested throughout acquisition by the Self-Young and the Self-Old groups were 65% ($SD$ = 32 %) and 74% ($SD$ = 39 %), respectively. The differences between groups over the course of the acquisition period for proportion of KR trials did not reach statistical significance ($p$'s > .05).

### 3.2. Variable error (VE)

#### 3.2.1. Acquisition

The means for VE for all experimental groups are displayed in Fig. 2A. There was a significant main effect for age, $F(1,36) = 5.54$, $p < .05$, $\eta_p^2 = .13$, with the younger adults ($M$ = 10.75, $SD$ = 2.85) demonstrating more consistent performance than the older adults ($M$ = 12.97, $SD$ = 2.33). The main effects for KR group and block were superseded by a KR group × Block interaction, $F(9,324) = 2.60$, $p < .05$, $\eta_p^2 = .10$. The post hoc analysis indicated that within the Self groups, block 1 was more variable than blocks 3 to 10 and block 2 was more variable than blocks 7 and 9. The post hoc analysis also revealed the following between group differences: block 1 for the Self groups was more variable than blocks 4, 6, and 10 of the Yoked groups; block 7 for the Self groups was less variable than blocks 1, 2, 3, 5, and 8 of the Yoked groups; block 9 for the Self groups was less variable than blocks 1, 2, 3, and 8 of the Yoked groups; and block 10 for the Self groups was less variable than block 1 of the Yoked groups.

#### 3.2.2. Retention

The means for VE for all experimental groups are displayed in Fig. 2A. There was a significant main effect for KR group, $F(1,36) = 8.35$, $p < .05$, $\eta_p^2 = .19$, with the Yoked groups ($M$ = 11.55, $SD$ = 2.28) performing more variable than the Self groups ($M$ = 8.47, $SD$ = 1.58). There was also a significant KR group × Age interaction, $F(1,36) = 6.44$, $p < .05$, $\eta_p^2 = .15$. The post hoc analysis indicated that the Self-Young group ($M$ = 7.18, $SD$ = .13) was less variable than the Yoked-Young group ($M$ = 12.97, $SD$ = 2.73) but not the Self-Old ($M$ = 9.75, $SD$ = .94), and the Yoked-Old ($M$ = 10.12, $SD$ = .27) groups.

### 3.3. Absolute error (AE)

#### 3.3.1. Acquisition

The means for AE for all experimental groups are displayed in Fig. 2B. There was a main effect for age, $F(1,36) = 15.61$, $p < .05$, $\eta_p^2 = .31$, with the younger adults ($M$ = 18.69, $SD$ = 5.46) demonstrating less AE than the older adults ($M$ = 26.84, $SD$ = 5.62). There was also a main effect for block, $F(9,324) = 18.28$, $p < .05$, $\eta_p^2 = .37$, where block 1 was performed with more AE than blocks 2 to 10; block 2 was performed with more AE than blocks 6 to 10; and blocks 3 and 4 were performed with more AE than blocks 9 and 10. The KR group × Block interaction was also significant,

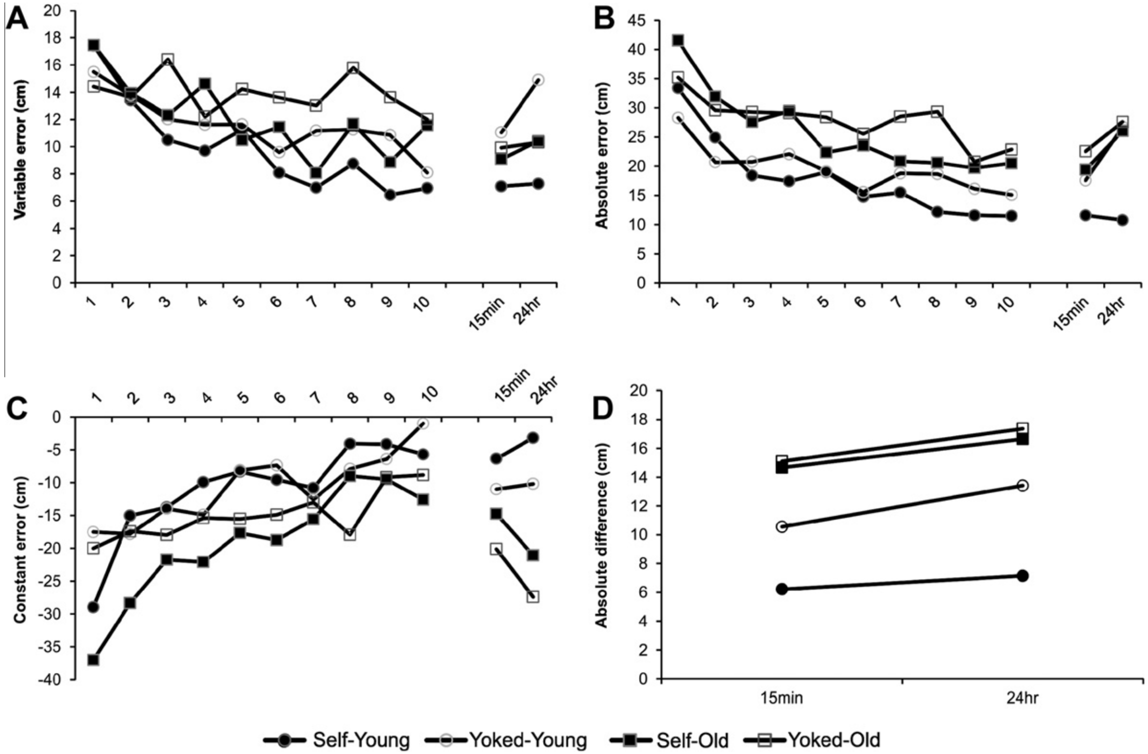


**Fig. 2.** The dependent variables for acquisition (blocks 1 to 10) and retention (15-min and 24-hr) as a function of KR condition and age. (A) Variable error; (B) Absolute error; (C) Constant error; and (D) Absolute difference.

$F(9, 324) = 2.56$, $p < .05$, $\eta_p^2 = .10$. The post hoc test indicated the following within group differences: block 1 had more AE than blocks 2 to 10 in the Self groups and block 1 had more AE than blocks 6, 9, and 10 in the Yoked groups. The post hoc analysis also revealed the following between group differences: block 1 for the Self groups was less accurate than blocks 2 to 10 of the Yoked groups, block 1 for the Yoked groups was less accurate than blocks 5 to 10 of the Self groups.

#### *3.3.2. Retention*

The means for AE for all experimental groups are displayed in Fig. 2B. There was a main effect for retention test, $F(1, 36) = 11.74$, $p < .05$, $\eta_p^2 = .11$, where the 15-min retention test ($M = 17.79$, $SD = 4.61$) was performed with less AE than the 24-hr retention test ($M = 22.78$, $SD = 8.03$). The main effects for KR group and age were superseded by a KR group × Age interaction, $F(1, 36) = 4.34$, $p < .05$, $\eta_p^2 = .11$. The post hoc analysis revealed the Self-Young group ($M = 11.19$, $SD = .58$) performed with less AE than the Yoked-Young ($M = 22.16$, $SD = 6.48$), Self-Old ($M = 22.72$, $SD = 4.69$), and the Yoked-Old ($M = 25.07$, $SD = 3.56$) groups.

### *3.4. Constant error (CE)*

#### *3.4.1. Acquisition*

The means for CE for all experimental groups are displayed in Fig. 2C. There was a main effect for block, $F(9, 324) = 11.07$, $p < .05$, $\eta_p^2 = .24$, where the participants significantly undershot the target in block 1 compared to blocks 3–10; block 2 compared to blocks 8–10; and blocks 3 and 4 compared to blocks 9 and 10. The KR group × Block interaction was also significant, $F(9, 324) = 2.24$, $p < .05$, $\eta_p^2 = .06$. The target was significantly undershot by the Self groups in blocks 1 and 2 compared to blocks 3–10 and 8–10, respectively. The Yoked groups significantly undershot the target in blocks 1 and 2 compared to block 10. Lastly, the Self groups significantly undershot the target in block 1 compared to blocks 3–10 of the Yoked groups.

#### *3.4.2. Retention*

The means for CE for all experimental groups are displayed in Fig. 2C. The main effect for age was significant, $F(1, 36) = 13.04$, $p < .05$, $\eta_p^2 = .27$, with the older adults ($M = -20.84$, $SD = 5.19$) undershooting the target to a greater extent than the younger adults ($M = -7.68$, $SD = 3.61$).

### *3.5. Absolute difference (AD)*

#### *3.5.1. Retention*

The means for AD for all experimental groups are displayed in Fig. 2D. The main effects for age and KR group were superseded by an Age × KR group interaction, $F(1, 36) = 4.17$, $p < .05$, $\eta_p^2 = .15$. The post hoc results indicated the Self-Young ($M = 6.68$, $SD = .66$) group was more accurate in estimating their motor performance during the retention tests compared to the Yoked-Young ($M = 11.98$, $SD = 2.02$), Self-Old ($M = 15.66$, $SD = 1.40$), and Yoked-Old ($M = 16.23$, $SD = 1.60$) groups. The main effect for retention test was also significant, $F(1, 36) = 5.27$, $p < .05$, $\eta_p^2 = .13$, with participants' estimations being more accurate on the 15-min retention test ($M = 11.63$, $SD = 4.15$) compared to the 24-hr retention test ($M = 13.64$, $SD = 4.66$).

### *3.6. Self-reported KR scheduling strategies as a function of age and practice trials completed*

The results of the KR questionnaire are displayed in Table 1. The most interesting finding in the Self-Young group was a self-reported switch in their KR scheduling strategy from *perceived good and bad trials equally* (6 of 10) in the 1$^{st}$ half practice to *perceived good trials only* (8 of 10) during the 2$^{nd}$ half of practice. For the 1$^{st}$ half of practice, the remaining Self-Young participants (4 of 10) reported requesting KR after *perceived good trials only.* The remaining two Self-Young participants reported asking for KR after *perceived bad trials only* during the second half of practice. Unlike the Self-Young group, the majority of Self-Old participants self-reported using the same KR strategy, *perceived good and bad trials equally* for both the 1$^{st}$ (5 of 10) and 2$^{nd}$ (5 of 10) halves of practice. For the 1$^{st}$

half of practice, the remaining Self-Old participants reported a preference for KR after *perceived good trials* (3 of 10) or a strategy not listed on the questionnaire (2 of 10) (e.g., "I wanted feedback all the time" and "always"). For the $2^{nd}$ half of practice, the remaining Self-Old participants reported requesting KR either after *perceived good trials only* (2 of 10), *randomly* (1 of 10), or a strategy not listed on the questionnaire (2 of 10) (e.g., "I always wanted feedback" and "always").

In the Yoked-Young group, five participants reported they received KR after the right trials while the other five reported they did not receive KR after the right trials. Of the five participants not satisfied with their KR schedule, all of them reported they would have preferred to receive KR after *good trials only*. In the Yoked-Old group, seven participants stated they received KR after the right trials while the remaining three participants reported they did not receive KR after the right trials. Of these three participants not satisfied with their KR schedule, all of them reported they would have preferred to receive KR after *perceived good and bad trials equally*. In summary, the results from the KR strategy questionnaire revealed that the self-reported KR scheduling strategies were differentially impacted as a function of age and the number of practice trials completed.

### *3.7. Self-reported use of intrinsic feedback sources*

The results of the intrinsic feedback questionnaire are displayed in Table 2. All participants in the Self-Young, Self-Old, and Yoked-Young groups reported they utilized intrinsic sources of information during the acquisition period, whereas seven of the 10 participants in the Yoked-Old group reported using intrinsic information. All participants in the Self-Young group reported utilizing only one source of intrinsic information (e.g., produced force) during acquisition. In contrast, a reliance on multiple sources of intrinsic information was reported by the Yoked-Young (e.g., hand position, arm position, and produced force), Self-Old (e.g., hand position, arm position, shoulder position, and produced force), and the Yoked-Old (e.g., hand position, wrist position, and produced forced) groups. The results of this questionnaire suggest that age and KR group differentially influenced the self-reported use of intrinsic feedback sources during acquisition.

## 4. Discussion

The purpose of this experiment was three-fold. First, we were interested in determining whether the learning advantages of a self-controlled KR context would be modulated by the age of the learner with the expectation that in an attempt to alleviate the cognitive demands associated with no-KR trials (see Wulf & Shea, 2004 for review), older adults would request KR more frequently than younger adults at the expense of learning. Second, we were interested in determining if participants would adjust their KR scheduling strategy during practice as a function of practice trials completed and age. Lastly, we investigated whether practicing with a self-controlled KR schedule would ameliorate error detection abilities relative to practicing with a yoked KR schedule. The results of the experiment showed: (1) the Self-Old group did not experience similar learning advantages from controlling their KR schedule as the Self-Young group relative to their respective yoked counterparts; (2) the relative frequency of KR requests between the Self group were not statistically different despite age-related differences in KR scheduling strategies throughout the acquisition period; and (3) the ability to accurately estimate motor performance in retention was a function of KR group and age. A discussion of these findings follows.

### *4.1. Motor learning and self-controlled KR schedules as a function of age*

Our primary interest for the present experiment was to determine if the age of the participant would differentially impact the previously found learning advantages of self-controlled KR schedules in younger adults (Chen et al., 2002; Chiviacowsky & Wulf, 2002, 2005; Patterson & Carter, 2010). Therefore, it was important to replicate the findings of these studies in younger adults because unlike previous experiments that used a serial key pressing task, a discrete target task was used in the present experiment. The Self-Young group demonstrated more accurate and less variable performance in retention compared to their yoked counterparts, substantiating the findings of previous self-controlled KR experiments. Compared to the Self-Young participants, we expected the Self-Old participants to request KR more frequently throughout the acquisition period as a method of alleviating the heightened cognitive demands of no-KR trials. Research has revealed when older adults are provided the choice to self-select a strategy during cognitive skill learning they consistently select the less effective, low effortful strategy (e.g., recognition) whereas younger adults utilize the more effective, more cognitively effortful strategy (e.g., retrieval) (Hertzog et al., 2007; Rogers & Gilbert, 1997; Rogers et al., 2000; Touron & Hertzog, 2004a, 2004b; Touron et al., 2004). These findings offer insight into potential differences between older and younger adults in a self-controlled motor learning context. Similar to the cognitive learning literature, the learning advantages of self-control were modulated by the age of the learner in the present study. Specifically, the Self-Old and Yoked-Old groups demonstrated equated motor performance (indexed by VE, AE, and CE) in retention, suggesting that unlike younger adults, providing control over their KR schedule was not advantageous for learning. We suggest the difference in motor learning between the Self-Young and Self-Old participants is not attributed to a disparity in the relative frequency of KR requests throughout acquisition (i.e., Self-Young: $M = 64.6\%$, $SD = 27\%$; Self-Old: $M = 74.1\%$, $SD = 35\%$); thus, our first prediction was not supported. To account for the differences in motor learning as a function of age and self-control, we offer two alternative explanations.

First, practicing in a self-controlled context is considered cognitively effortful since participants must make decisions regarding the practice variable they are controlling while concomitantly engaging in the mental processes requisite for learning (Kanfer & Ackerman, 1989). Therefore, our results suggest a self-controlled KR schedule interacted negatively with age-related changes in cognition, especially those areas involved in executive functions (see Drag & Bielauskas, 2010 for a review). Furthermore, older adults' aversion to using cognitively effortful strategies during practice is suggested to be related to the older adult failing to accurately monitor their performance in order to guide strategy selection as practice progresses, resulting in the continued self-selection of less effective strategies (Rogers et al., 2000; Touron & Hertzog, 2004a). In previous research, older adults' reluctance to use the cognitively effortful retrieval strategy was correlated to low confidence in their ability to successfully use this strategy (Touron & Hertzog, 2004a, 2004b). If controlling their KR schedule did in fact exceeded the cognitive abilities of the Self-Old participants, it would be expected that the Yoked-Old participants would demonstrate superior learning compared to the Self-Old participants since a yoked group does not experience the additional cognitive demands inherent in self-controlled practice. However, our retention results do not support this notion and consequently a different factor must have contributed to the equivalent learning between the Self-Old and Yoked-Old groups.

Importantly, our inability to replicate the learning benefits of self-controlled KR schedules in older adults was not due to a failure in learning the task, but instead resulted from the Self-Old group not learning the task to a greater degree than their yoked counterparts. This was determined by comparing AE between Block 1, Block 10, and retention (collapsed across days). The analysis revealed a main effect for block where motor performance was less accurate in block 1 than in block 10 and retention, $F(2,36) = 36.61$, $p < .05$, $\eta_p^2 = .67$. Therefore, irrespective of KR group, older adults successfully learned the motor task relative to Block 1 of acquisition.

Therefore, an alternative and more likely explanation for the equivalent learning between the Self-Old and Yoked-Old groups relates to the relative *frequency* of KR during acquisition rather than the *decision* to receive or not receive KR. In fact, experimenter-defined KR schedules have revealed enhanced learning when older adults practiced with high frequency KR schedules when increased task demands were placed on sensorimotor integration (e.g., 90 offset bimanual coordination pattern: Wishart, Lee, Cunningham, & Murdoch, 2002; isometric force production: van Dijk, Mulder, & Hermens, 2007). The motor task in the present experiment also placed increased demands on sensorimotor integration with a greater proportion of KR presentations having a positive impact on motor learning since the majority of older adults practiced with a high frequency KR schedule (range: 88% to 100%). Interestingly, these findings oppose the Guidance hypothesis which states a high frequency KR schedule will hinder motor learning because a dependence on KR develops in lieu of learning to interpret intrinsic feedback sources (Salmoni et al., 1984). However, in accordance with Challenge Point Framework and optimally challenging the information processing capabilities of the performer

(Guadagnoli & Lee, 2004), it is possible that a high frequency KR schedule coupled with the heightened requirements for sensorimotor integration situated the Self-Old and Yoked-Old participants in their *optimal challenge point*, thus resulting in equivalent learning.

### 4.2. Self-reported KR strategies during acquisition

Previous research has shown a strong preference for KR after perceived good trials by participants when provided the opportunity to decide when to receive and not receive KR throughout acquisition (Chiviacowsky & Wulf, 2002; Patterson & Carter, 2010; Patterson et al., 2011). However, it remains unknown whether the strategies for requesting KR change as a function of practice trials completed because these studies queried participants to provide a single strategy for the entire acquisition period. However, recent theoretical accounts on KR highlight the dynamic nature of learning whereby the informational role of KR changes as a function of scheduling and motor performance (Guadagnoli & Lee, 2004). Therefore, we expected the number of practice trials completed would influence the KR scheduling strategies of the Self-Young and Self-Old participants.

For the first half of practice, the Self-Young and Self-Old groups reported a preference for KR after perceived good and bad trials equally. This strategy early in practice intuitively makes sense since it would involve a greater proportion of KR trials. This increased proportion of KR trials early in practice may relate to the informational properties of KR (Salmoni et al., 1984); that is, directing the participants' attention to the relationship between intrinsic feedback and the task goal (Anderson, Magill, & Sekiya, 2001; Lee, Swinnen, & Serrien, 1994; Salmoni et al., 1984); thereby, allowing participants to verify the difference between a good and poor trial based on intrinsic feedback. An analysis of the proportion of KR trials revealed no significant difference between the Self-Young ($M = 65\%$; $SD = 33\%$) and Self-Old ($M = 73\%$; $SD = 37\%$) groups in the first half of acquisition.

During the second half of practice, the Self-Young group self-reported a KR strategy shift from perceived good and poor trials equally in the first half of practice to perceived good trials only. This preference for KR is consistent with the findings from research utilizing younger adults self-controlling their receipt of KR (e.g., Chiviacowsky & Wulf, 2002). In contrast, the Self-Old group persisted with their 1$^{st}$ half strategy (perceived good and poor trials equally) in the 2$^{nd}$ half of practice. This finding is consonant with the cognitive learning literature where older adults are reluctant to change their learning strategy over the course of a practice period (Hertzog et al., 2007; Rogers & Gilbert, 1997; Rogers et al., 2000; Touron & Hertzog, 2004a, 2004b; Touron et al., 2004). Yet, despite the self-reported differences in KR request strategies for the second half of practice between age groups, the analysis of the proportion of KR trials in the second half of acquisition revealed no significant differences between proportion of KR trials for the Self-Young ($M = 64\%$, $SD = 31\%$) and Self-Old ($M = 74\%$, $SD = 40\%$) groups. Our finding that self-control participants, independent of age did not create a faded KR schedule during acquisition is not commensurate with Chiviacowsky and Wulf (2002), but is consistent with findings from other self-controlled KR schedules (e.g., Chen et al., 2002; Hansen, Pfeiffer, & Patterson, 2011; Huet, Jacobs, Camachon, Goulon, & Montagne, 2009; Patterson & Carter, 2010; Patterson et al., 2011). Interestingly, the self-reported preference for KR by those participants in the Yoked-Young (5 out of 10) and Yoked-Old (3 out of 10) who were not satisfied with their KR schedule mirrored the KR strategy used in the 2$^{nd}$ half of practice by their age-matched self-control counterparts (i.e., perceived good trials for younger adults; good and poor trials equally for the older adults).

To verify whether the preferences for KR on a *perceived good trial* were commensurate with those participants' actual motor performance on KR trials, we conducted a 2 (Group: Self, Yoked) $\times$ 2 (Age: Young, Old) $\times$ 2 (Trial type: KR, no-KR) $\times$ 2 (Practice half) ANOVA to examine AE on the KR and no-KR trials for the Self-Young and Self-Old participants reporting this strategy throughout practice. Previous research has revealed that participant's preference for KR on perceived good trials was in fact commensurate with their actual movement error (indexed by AE) on KR trials compared to trials when KR was not requested (Chiviacowsky & Wulf, 2002, 2005). Although there was a trend for less AE on KR trials (perceived as *good* trials by participants) than no-KR trials in both age groups, this difference was not statistically significant at the $p < .05$ level. Although this finding is inconsistent with Chiviacowsky and Wulf (2002, 2005), it is consistent with other self-controlled KR experiments (Patterson & Carter, 2010; Patterson et al., 2011) which also did not find a statistical difference between the KR and no-KR trials, despite the participants' self-reported preference for KR on perceived good trials.

Our purpose for examining participants' self-reported KR strategy for the 1st and 2nd halves of the acquisition period, as a function of age, was to determine whether preference for KR changed as a function of the number of acquisition trials completed. In fact, younger and older adult participants' requests for KR for the first and second half of the acquisition period may have been modulated by their current stage of learning (i.e., Fitts & Posner, 1967) interacting with their age. Previous research has shown that younger adults frequently request KR early in acquisition (Chiviacowsky & Wulf, 2002), suggesting the cognitive stage of learning (Fitts & Posner, 1967) where KR is required by the performer to successfully achieve the motor task goal. As practice continues, KR is requested less frequently by the performer (Chiviacowsky & Wulf, 2002), as they have achieved the ability to consistently achieve the task goal independent of KR, suggesting they have progressed to the later stages of motor learning (associative and autonomic stage of learning: Fitts & Posner, 1967). To our knowledge, the present study was the first to examine: (1) the utility of a self-controlled KR context for older adults and, (2) their subsequent preference for KR as a function of practice trials completed. Thus, it was possible that participants' preference for KR was modulated by the participant's age and their achieved stage of learning upon completion of the acquisition period. Therefore, if the Self-Young and Self-Old participants were progressing through the early stages of learning at different rates, it is possible this could have differentially influenced their motor performance and requests for KR (i.e., proportion of KR trials) during the first and second half of the acquisition period. However, inspection of the AE and VE for the first and second half of practice showed no statistical motor performance differences between the Self-Young and Self-Old conditions, suggesting the older and younger adults were learning the motor task at a similar rate. Furthermore, inspection of the proportion of KR trials for the first and second halves of the acquisition period were also not significantly different between the Self-Young and Self-Old conditions. Collectively, these findings suggest the self-reported preferences for KR from the Self-Young and Self-Old participants upon completion of the acquisition period were based on a similar stage of motor learning achieved upon completion of the acquisition period. However, we suggest that future research is required to further understand whether participant's strategical preference for the practice variable they are controlling is a function of their stage of skill acquisition and age or characteristics of their central nervous system (e.g., stroke, multiple sclerosis).

### 4.3. Error detection and correction as a function of KR group and age

To our knowledge, this was the first attempt to determine if a self-controlled KR schedule would concurrently strengthen the ability to detect and correct errors during retention compared to a yoked KR schedule. This interest was based on past research reporting a systematic decrease in KR requests during practice by self-control participants. Chiviacowsky and Wulf (2002) reported a decrease from 45% in Block 1% to 28% in the final block whereas a more modest decrease was reported by Patterson and Carter (2010) of 62% in Block 1% to 59% in the final block. However, these authors did not investigate whether the decreased KR requests were replaced by an increased reliance on intrinsic feedback, subsequently strengthening error detection abilities. To address this gap, we asked all participants to estimate their perceived outcome of each motor response during retention. Based on the findings of Chiviacowsky and Wulf (2002) and Patterson and Carter (2010), we predicted a self-controlled KR schedule would enhance the ability to detect errors in the absence of KR during retention irrespective of age compared to a yoked KR schedule. This prediction was partially supported as the Self-Young group was significantly more accurate at estimating their retention performance than the Yoked-Young group whereas no significant differences were found between the Self-Old and Yoked-Old groups. Therefore, we suggest that one of the mechanisms subserving motor learning during self-controlled practice is a strengthened error detection and correction mechanism. To account for this age-dependent finding, we offer the following hypothesis.

We suggest the combined effect of previously noted age-related decreases in proprioceptive acuity in older adults (Adamo, Martin, & Brown, 2007; Meeuwsen, Sawicki, & Stelmach, 1993) and the high frequency KR schedule (88% to 100%) experienced by the majority of older adult participants contributed to their inability to accurately estimate their motor performance in retention. Although the high frequency KR schedule facilitated motor learning in the Self-Old and Yoked-Old groups, the lack of no-KR trials during acquisition was detrimental to the development of a reference of correctness for the motor task, which had a negative impact on retention performance. When the provision of KR is high during practice, it is believed participants ignore intrinsic feedback sources considered instrumental in developing a reference of correctness (i.e., the Guidance hypothesis); however, the ability to successfully use intrinsic feedback sources to detect and correct errors is essential to motor learning since unlike KR, it is always available to the learner (Lee et al., 1994; Wulf & Shea, 2004).

## 5. Conclusion

In summary, the results of the present experiment suggest the learning benefits of a self-controlled KR schedule are modulated by the age of the learner. Although recent research found a self-controlled KR schedule enhanced motor learning in children (Chiviacowsky et al., 2008), our results suggest these advantages do not extend to older adults. Data from the Self-Young group not only provides further support to the utility of self-controlled practice in younger adults but also adds to our theoretical understanding of self-controlled KR in two important ways. First, a self-controlled KR schedule concurrently strengthened the error detection mechanism relative to a yoked KR schedule. Second, a shift in KR scheduling strategies occurs between the first and second halves of practice. Overall, these findings provide new insight regarding the potential mechanisms responsible for the robust learning advantages of self-controlled KR schedules in younger adults. To date, the relationship between self-controlled practice and older adults has received minimal attention in the motor learning research. As a result, it is not well understood and remains a fruitful area for further inquiry.

## Acknowledgments

This experiment was supported by a Frederick Banting and Charles Best Canada Graduate Scholarship from the Canadian Institutes of Health Research awarded to the first author. The authors thank Alex Kartalianakis for her help in participant recruitment and testing, and Dr. Diane Ste-Marie and two anonymous reviewers for their helpful comments on an earlier version of this manuscript.

## References

Adamo, D. E., Martin, B. J., & Brown, S. H. (2007). Age-related differences in upper limb proprioceptive acuity. *Perceptual and Motor Skills, 104*, 1297–1309.

Adams, J. A. (1971). A closed-loop theory of motor learning. *Journal of Motor Behavior, 3*, 11–150.

Anderson, D. I., Magill, R. A., & Sekiya, H. (2001). Motor learning as a function of KR schedule and characteristics of task-intrinsic feedback. *Journal of Motor Behavior, 33*, 59–66.

Bäckman, L., Ginovart, N., Dixon, R. A., Wahlin, T. B. R., Wahlin, A., Halldin, C., et al (2000). Age-related cognitive deficits mediated by changes in the striatal dopamine system. *American Journal of Psychiartry, 157*, 635–637.

Bäckman, L., Lindenberger, U., Li, S. C., & Nyberg, L. (2010). Linking cognitive aging to alterations in dopamine neurotransmitter functioning: Recent data and future avenues. *Neuroscience and Behavioral Reviews, 34*, 670–677.

Boekaerts, M. (1996). Self-regulated learning at the junction of cognition and motivation. *European Psychologist, 1*, 100–112.

Boekaerts, M., & Corno, L. (2005). Self-regulation in the classroom: A perspective on assessment and intervention. *Applied Psychology: An International Review, 54*, 199–231.

Carnahan, H., Vandervoort, A. A., & Swanson, L. R. (1996). The influence of summary knowledge of results and aging on motor learning. *Research Quarterly for Exercise and Sport, 67*, 280–287.

Chen, D. D., Hendrick, J. L., & Lidor, R. (2002). Enhancing self-controlled learning environments: The use of self-regulated feedback information. *Journal of Human Movement Studies, 43*, 69–86.

Chiviacowsky, S., & Wulf, G. (2002). Self-controlled feedback. Does it enhance learning because performers get feedback when they need it? *Research Quarterly for Exercise and Sport, 73*, 408–415.

Chiviacowsky, S., & Wulf, G. (2005). Self-controlled feedback is effective if it is based on the learner's performance. *Research Quarterly for Exercise and Sport, 76*, 42–48.

Chiviacowsky, S., Wulf, G., Laroque de Medeiros, F., Kaefer, A., & Tani, G. (2008). Learning benefits of self-controlled knowledge of results in 10-year-old children. *Research Quarterly for Exercise and Sport, 79*, 405–410.

D'Eredita, M. A., & Hoyer, W. J. (2010). Transfer of instances in cognitive skill learning: Adult age differences. *Experimental Aging Research, 36*, 23–39.

Drag, L. L., & Bielauskas, L. A. (2010). Contemporary Review 2009: Cognitive aging. *Journal of Geriatric Psychiatry and Neurology, 23*, 75–93.

Fitts, P. M., & Posner, M. I. (1967). *Human Performance*. Belmont, CA: Brooks/Cole.
Fjell, A. M., & Walhovd, K. B. (2010). Structural brain changes in aging: Courses, causes and cognitive consequences. *Reviews in the Neurosciences, 21*, 187–221.
Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). Mini-Mental State: A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*, 189–198.
Guadagnoli, M. A., & Lee, T. D. (2004). Challenge point: A framework for conceptualizing the effects of various practice conditions in motor learning. *Journal of Motor Behavior, 33*, 217–224.
Guadagnoli, M. A., Leis, B., van Gemmert, A. W. A., & Stelmach, G. E. (2002). The relationship between knowledge of results and motor learning in Parkinsonian patients. *Parkinsonian & Related Disorders, 9*, 89–95.
Hansen, S., Pfeiffer, J., & Patterson, J. T. (2011). Self-control of feedback during motor learning: Accounting for the absolute amount of feedback using a yoked group with self-control over feedback. *Journal of Motor Behavior, 42*, 113–199.
Hertzog, C., Touron, D. R., & Hines, J. C. (2007). Does a time-monitoring deficit influence older adults' delayed retrieval shift during skill acquisition? *Psychology and Aging, 22*, 607–624.
Huet, M., Jacobs, D. M., Camachon, C., Goulon, C., & Montagne, G. (2009). Self-controlled concurrent feedback facilitates the learning of the final approach phase in a fixed-base flight simulator. *Human Factors, 51*, 858–871.
Jamieson, B. A., & Rogers, W. A. (2000). Age-related effects of blocked and random practice schedules on learning a new technology. *Journal of Gerontology: Psychological Sciences, 55*, 343–353.
Kanfer, R., & Ackerman, P. L. (1989). Motivation and cognitive abilities: An integrative/aptitude-treatment approach to skill acquisition. *Journal of Applied Psychology, 74*, 657–690.
Keetch, K. M., & Lee, T. D. (2007). The effect of self-regulated and experimenter-imposed practice schedules on motor learning for tasks of varying difficulty. *Research Quarterly for Exercise and Sport, 78*, 476–486.
Koehen, J. D., Dickinson, J., & Goodman, D. (2008). Cognitive demands of error processing. *Psychological Reports, 102*, 532–538.
Lee, T. D., Swinnen, S. P., & Serrien, D. J. (1994). Cognitive effort and motor learning. *Quest, 46*, 328–344.
Lin, C.-H. J., Wu, A. D., Udompholkul, P., & Knowlton, B. J. (2010). Contextual interference effects in sequence learning for younger and older adults. *Psychology and Aging, 4*, 929–939.
Luo, L., & Craik, F. I. M. (2008). Aging and memory: A cognitive approach. *The Canadian Journal of Psychiatry, 53*, 346–353.
Meeuwsen, H. J., Sawicki, T. M., & Stelmach, G. E. (1993). Improved foot position sense as a result of repetitions in older adults. *Journal of Gerontology, 48*, P137–P141.
Patterson, J. T., & Carter, M. (2010). Learner regulated knowledge of results during the acquisition of multiple timing goals. *Human Movement Science, 29*, 214–227.
Patterson, J. T., Carter, M., & Sanli, E. (2011). Decreasing the proportion of self-control trials during the acquisition period does not compromise the learning advantages in a self-controlled context. *Research Quarterly for Exercise and Sport, 82*, 624–633.
Patterson, J. T., Sanli, E., & Adkin, A. (2008). Effects of age on performer controlled augmented feedback schedules while practicing a two-part timing task. Unpublished manuscript.
Rogers, W. A., & Gilbert, D. K. (1997). Do performance strategies mediate age-related differences in associative learning? *Psychology and Aging, 12*, 620–633.
Rogers, W. A., Hertzog, C., & Fisk, A. D. (2000). An individual differences analysis of ability and strategy influences: Age-related differences in associative learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*, 359–394.
Salmoni, A. W., Schmidt, R. A., & Walter, C. B. (1984). Knowledge of results and motor learning: A review and critical reappraisal. *Psychological Bulletin, 95*, 355–386.
Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103*, 403–428.
Schmidt, R. A. (1975). A schema theory of discrete motor skill learning. *Psychological Review, 82*, 225–260.
Shah, S., Vanclay, F., & Cooper, B. (1989). Improving the sensitivity of the Barthel Index for stroke rehabilitation. *Occupational Therapy, 42*, 703–709.
Touron, D. R., & Hertzog, C. (2004a). Distinguishing age differences in knowledge, strategy use, and confidence during strategic skill acquisition. *Psychology and Aging, 19*, 452–466.
Touron, D. R., & Hertzog, C. (2004b). Strategy shift affordance and strategy choice in young and older adults. *Memory & Cognition, 32*, 298–310.
Touron, D. R., Hoyer, W. J., & Cerella, J. (2004). Age-related differences in the component processes of cognitive skill learning. *Psychology and Aging, 19*, 565–580.
van Dijk, H., Mulder, T., & Hermens, H. J. (2007). Effects of age and content of augmented feedback on learning an isometric force-production task. *Experimental Aging Research, 33*, 341–353.
Winne, P. H. (1995). Inherent details in self-regulated learning. *Educational Psychologist, 30*, 173–187.
Winne, P. H. (2005). Key issues in modeling and applying research on self-regulated learning. *Applied Psychology: An International Review, 54*, 232–238.
Wishart, L. R., Lee, T. D., Cunningham, S. J., & Murdoch, J. E. (2002). Age-related differences and the role of augmented visual feedback in learning a bimanual coordination pattern. *Acta Psychologica, 110*, 247–263.
Wulf, G. (2007). Self-controlled practice enhances motor learning: Implication for physiotherapy. *Physiotherapy, 93*, 96–101.
Wulf, G., & Shea, C. H. (2004). Understanding the role of augmented feedback: The good, the bad and the ugly. In A. M. Williams & N. J. Hodges (Eds.), *Skill acquisition in sport: Research theory and practice* (pp. 121–144). New York, NY: Routledge.
Zimmerman, B. J. (1989). A social cognitive view of self-regulated learning. *Journal of Educational Psychology, 81*, 329–339.