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Effects of Self-Controlled Knowledge of Results on Learning a Taekwondo Serial Skill

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Abstract

Allowing learners to control feedback has been an effective strategy in motor skills learning. However, most studies of self-controlled (SC) feedback have used simple tasks that may be dissimilar to sports skills that generally demand more degrees of freedom and cognition. Thus, this study investigated the effects of SC knowledge of results (KR) on learning a complex Taekwondo skill. Twenty-four undergraduate volunteers of both sexes, aged 18-35 years, practiced a specific serial Taekwondo skill that was novel to them. We divided participants randomly into SC and yoked groups and compared their performance after they learned a specific displacement sequence, finishing with a lateral kick (bandal-tchagui) at a punching bag within a target time span. During acquisition, all participants performed 48 trials divided into six blocks and, on a retention test 24 hours later, they performed 10 more trials. We found that both groups reduced their errors from the first to the last block of the acquisition phase and that the SC group showed a better performance on the retention test, relative to the yoked control group. SC KR participants requested KR mainly after good trials, though they showed no statistically significant differences between trials with and without KR. Their inefficiency in estimating their own errors may have been due to task complexity, since many aspects of the task beyond its temporal requirement demanded the learners' attention. Our results, using a novel

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Taekwondo serial skill, confirm and extend the benefits of SC KR from just simple motor learning in past studies to learning complex motor skills.

Keywords
motor learning, feedback, self-control, Taekwondo, serial skill

Introduction

In traditional motor learning studies, researchers have manipulated variables that affect motor skills learning such as practice schedule, demonstration, feedback, and physical assistance in attempts to adjust the practice context to enhance motor learning (Ishikura & Inomata, 1995; Shea & Morgan, 1979; Winstein & Schmidt, 1990). Past investigators have reported that when learners have more autonomy, they are more motivated and more actively engaged in learning, leading to better skill retention (Wulf, 2007). This was shown in several studies in which learners who self-controlled (SC) some of the practice variables bested learners that had no such self-control (Janelle, Kim, & Singer, 1995; Tsai & Juo, 2015; Wulf, Raupach, & Pfeiffer, 2005; Wulf & Toole, 1999). The variable that has received the most attention in self-control research is knowledge of results (KR; Chiviacowsky & Wulf, 2002, 2005; Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Janelle et al., 1995). KR is a type of extrinsic feedback that can be provided to learners; it contains information about the outcome of performing a skill (Magill & Anderson, 2007). When KR is SC, learners can determine when to receive KR during practice by requesting this information in accordance with their own needs instead of receiving it on some extrinsically defined schedule. Although there have been specific conditions when SC versus externally controlled KR did not result in superior learning (e.g., see Bokums, Meira, Neiva, Oliveira, & Maia, 2012; Ferreira et al., 2019), most studies have shown that personal control over KR scheduling positively affected motor skill learning, retention, and transfer (e.g., Carter, Rathwell & Ste-Marie, 2016; Chiviacowsky & Wulf, 2002; Figueiredo, Ugrinowitsch, Freire, Shea, & Benda, 2018; Grand et al., 2015; Hansen, Pfeiffer, & Patterson, 2011).

It has been proposed that, learners with control over KR achieve greater information processing (Chiviacowsky & Wulf, 2005; Figueiredo et al., 2018; Grand et al., 2015). This is probably due to learners' constant need to evaluate their own performance in order to determine when to request KR. This constant evaluation process, stimulated by SC KR, seems to strengthen both the mental representation of the skill in the learner's memory and the learner's use of intrinsic feedback (Carter, Carlsen & Ste-Marie, 2014; Chiviacowsky & Wulf, 2005). The ability to adapt the KR schedule to the learners' personal needs can also lead to the adoption of different strategies throughout the skill acquisition process (Carter et al., 2016). Among these strategies, those that increase learners' motivations by protecting their perceptions of personal competence during the learning process stand out; thus, requesting KR after perceived good trials and not requesting KR after perceived bad trials has been beneficial to learning effectiveness (Carter et al., 2014; Chiviacowsky & Wulf, 2002; Chiviacowsky, Wulf, & Lewthwaite, 2012). Since this strategy is based on the previously obtained performance, it demands constant and efficient self-evaluations of the motor response. This is a cognitively effortful process, making SC KR and increased information processing interdependent complimentary.

Many motor learning investigations of SC KR used laboratory or simple tasks with few degrees of freedom. These tasks involved mainly manual actions such as key pressing (Chiviacowsky & Wulf, 2002, 2005; Ferreira et al., 2019; Hansen et al., 2011; Patterson & Carter, 2010; Patterson, & Carter, & Hansen, 2013), linear positioning (Carter & Patterson, 2012), beanbag or ball throwing to a target (Chiviacowsky, de Medeiros, Kaefer, Wally, & Wulf, 2008; Fairbrother, Laughlin, & Nguyen, 2012; Grand et al., 2015; Hemayattalab, Arabameri, Pourazar, Ardakani, & Kashefi, 2013; Janelle et al., 1995, 1997), force control (Chiviacowsky, Medeiros, & Kaefer, 2007), golf putting (Ko, Kim, & Kim, 2007), anticipatory timing (Chiviacowsky, 2014; Chiviacowsky et al., 2012), ball transport (Figueiredo et al., 2018), and extension-flexion reversal of the forearm (Carter & Ste-Marie, 2017). Although these studies have provided relevant insights regarding motor skill learning and particularly regarding the effects of SC KR, some aspects of these tasks (i.e., the use of few simultaneous articulations of the body) may limit their applicability to applied complex motor skills like those in sports training for which there are requirements of more cognition and degrees of freedom (Schaefer & Hengge, 2016; Wulf & Shea, 2002).

To define whether tasks used in SC studies are complex or simple, it is necessary to establish criteria by which task complexity might be evaluated. This can be a problem, since an exact definition of task complexity is not possible. However, Wulf and Shea (2002) proposed that task complexity is related to its information-processing demands, the cognitive effort it requires, the degrees of freedom within it, and the practice required to reach performance asymptotes. Thus, among other factors, task complexity is related to the number of muscle actions and coordinated actions performed and the task's required speed and accuracy (Wulf & Shea, 2002). Considering these factors in our review of past research, we identified a small number of studies that investigated SC feedback using skills that could be considered complex (Lim et al., 2015; Sigrist, Rauter, Riener, & Wolf, 2011). Lim et al. (2015) found SC feedback superior to externally controlled feedback in learning a Taekwondo Pomse. Although this skill is a sequence of motor movements with little relation to the Taekwondo fight itself, it is still highly complex, considering the number of movements to be performed by multiple body segments in a specific order. It is important to note that the feedback controlled by learners in this study was knowledge of performance (KP); KP contains different information than KR and is used differently by self-control learners (Zetou, Vernadakis, Mountaki, & Karypidou, 2018), limiting the ability to generalize Lim et al.'s KP findings to the KR literature. Sigrist et al. (2011) also investigated feedback self-control in a complex task. In their study, participants learned a rowing skill in a virtual environment, within specific spatial and temporal goals, over several days. Their results showed improvements in only the spatial features of the task, indicating that participants may have focused on certain movement features rather than the overall movement pattern, perhaps due to task complexity. Moreover, learners in this study were not able to estimate their performance effectively, preventing them from using the strategy of protecting their perception of competence. No control condition was used in this study, further limiting the meaningfulness of some results regarding self-control effects.

Considering that SC KR studies have predominantly used simple tasks, the question arises as to whether presumed SC KR benefits would extend to learning the more complex motor tasks with several degrees of freedom that occur naturally in many real-life contexts. Prior research informs us that motor learning principles derived from studying simple skills do not always generalize to learning complex skills (for a review, see Wulf & Shea, 2002). Developing a mental representation of more complex (vs. simpler) skills takes more time and requires more effort and information processing. Considering that SC effects also demand increased informational processing (Carter & Ste-Marie, 2017; Chiviacowsky & Wulf, 2005; Grand et al., 2015), the informational processing demands of a highly complex task could lead to informational overload for the learner (Hebert, Landin, & Solmon, 1996; Lai & Shea, 1998), jeopardizing the benefits of SC KR in motor learning (Carter & Ste-Marie, 2017). On the other hand, learners with self-control might adjust a part of their practice context by self-selecting how much and when to receive KR, allowing them to control KR efficiently and still benefit from KR self-control during learning (Carter et al., 2014; Grand et al., 2015).

With these unsettled questions in mind, we sought to investigate whether self-control KR would enhance learning a serial Taekwondo task, with several degrees of freedom. We suspected that, in addition to skill retention benefits, KR request strategies and KR distribution throughout practice might contribute to a better understanding of the relationship between SC KR and task complexity. We hypothesized that SC KR (vs. externally scheduled or yoked [YK] KR) would still lead to better skill retention, even when learning a complex serial skill. We also hypothesized that SC KR learners would employ a strategy of protecting their perceptions of competence and distribute KR requests equally through practice trials.

Method

Participants

Participants were 24 undergraduate volunteers of both sexes (16 men and 8 women; $M_{age} = 22.9$, $SD = 3.9$ years), all unfamiliar with the Taekwondo task and all self-declared right-handed individuals. The Institutional Review Board of the University (Protocol no. 14742213.7.00005149) approved the study, and all participants provided informed consent prior to participation.

Equipment and Task

The study apparatus consisted of a specific set of equipment built for the purposes of the present investigation (see Figure 1). The set up consisted of four pressure sensors embedded in hard plastic mats (contact mats) 33 cm wide and 60 cm long, 10 cm^2 pressure sensors embedded in the dorsal surface of a Taekwondo foot protector (right foot), a kick bag with a 98 cm circumference and 80 cm in length. This kick bag contained a metal-shaped sensor around its surface, 40 cm wide and long and located in the middle part of the bag. We also used a laptop and an auxiliary PC screen. A software program developed in the LABVIEW environment, with Windows 7 operating system was used to control the task, measure and store the data. A 12 cm diameter green light stimulus was randomly displayed (1–3 seconds following a warning signal provided by an experimenter) on the auxiliary screen in front of the participant, near and above the kick bag in order to start the task. When the light stimulus was presented, it triggered a timer and the time variables began to be recorded, within 1 milliseconds accuracy. The mats were arranged on the floor within 15 cm of each other, as shown in Figure 1(a), and the distance from the third mat to the kick bag was 1 m. This arrangement of the mats allowed participants of different sizes to perform the task comfortably.

The task consisted of performing a serial Taekwondo skill composed of sequential specific displacements of the Taekwondo fight, stepping on the four contact plates, followed by a specific kick (bandal tchagui) to a target (kick bag) within a time constraint (Figure 1). The participant was asked to stand with the left leg (anterior leg) on Mat 1 and the right leg on Mat 2. The displacement sequence was comprised of the following movements: (a) body spin while changing the position of the feet: left leg placed on Mat 2 and right leg on Mat 1 (base change) (Figure 1(a) to (b)); (b) move forward in same position for Mats 2 (left leg) and 3 (right leg) (Figure 1(b) to (c)); and (c) another body spin, passing the left leg forward (Mat 3) and turning the right leg 45° back, reaching Mat 4 (Figure 1(c) to (d)). From this final position, the participant performed a bandal tchagui with the right leg (back) on the target located in the kick bag (Figure 1(d) to (e)).

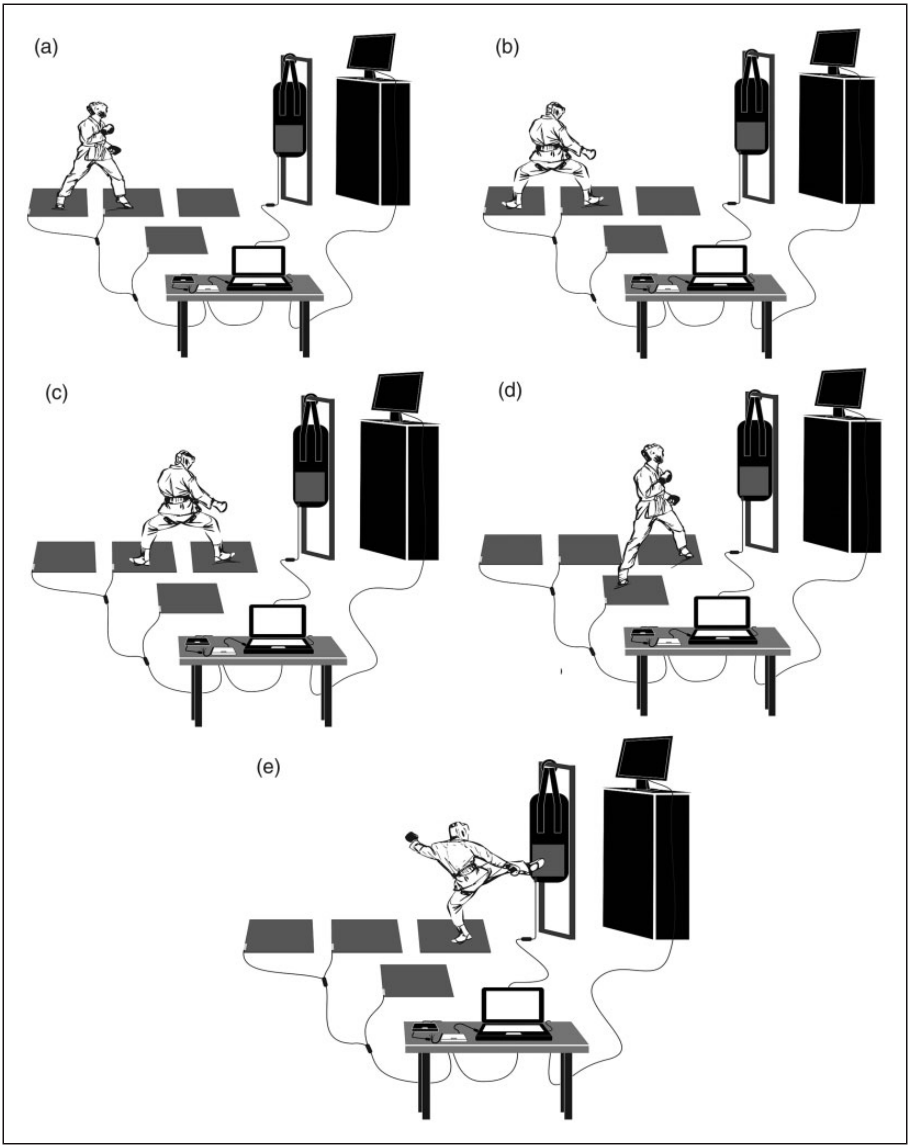

Figure 1. Apparatus and task diagram.

We adopted questionnaires similar to those used by Chiviacowsky and Wulf (2002) to access the learner's KR request strategies (for self-control participants) and the learner's preferences and perceptions over the course of KR (for yoked participants).

Research Design

Participants were randomly assigned to one of two groups ($n = 12$ in each): SC, for which KR was provided whenever requested by participants following a trial; and YK, for which KR was provided on the same trials as participants in the SC group. After preparing to start the task, each participant received three verbal instructions and three demonstrations performed by an expert in Taekwondo. They were informed that they should be as accurate as possible in relation to the task execution time goal (1,600 milliseconds). After clarifying any doubts, the participant started the practice. The study was composed of an acquisition phase and a retention test. The acquisition phase consisted of 48 trials in which participants would or would not have control over KR requests (according to their experimental condition). When requested, KR was provided immediately on the auxiliary screen directly in front of the participant as quantitative information regarding the direction and magnitude of the error ("you were X ms slower than the target time" or "you were X ms faster than the target time"). One of the experimenters also provided this information verbally, as soon as it was available on screen. For SC participants, KR could be requested after any trial and the next trial would only start three seconds after the KR provision. For YK participants, there were 3-second intervals before and after trials with KR provision. During the acquisition phase, there were 2-minute intervals after every eight trials, to prevent fatigue. After completing the acquisition phase, participants were asked to answer the questionnaire adapted from Chiviacowsky and Wulf (2002).Twenty-four hours after the acquisition phase, participants performed a retention test that consisted of 10 trials in which no KR was provided. The task target time was held constant (1,600 milliseconds) during the acquisition phase and retention test.

Data Analysis

Performance time data were converted to average absolute error (AE), constant error (CE), and variable error (VE) for six blocks of eight trials for the acquisition phase and one block of 10 trials for the retention test. Data did not meet the normality assumptions in Shapiro–Wilk test nor homoscedasticity assumptions in Levene's test; therefore, nonparametric tests were adopted in the following analyses (Erceg-Hurn & Mirosevich, 2008).

Data analysis of the acquisition phase was performed using the Friedman test for repeated measures within groups. To identify differences between blocks in the acquisition phase, the Wilcoxon test was used to compare all blocks of trials in this phase, and Bonferroni corrections for multiple comparisons were applied. In this case α level was set to .003. In the retention test, the comparison between the groups was performed using the Mann–Whitney test. The same test was used to compare the performance between trials in which KR was requested and trials in which KR was not requested for individuals that declared to request KR when

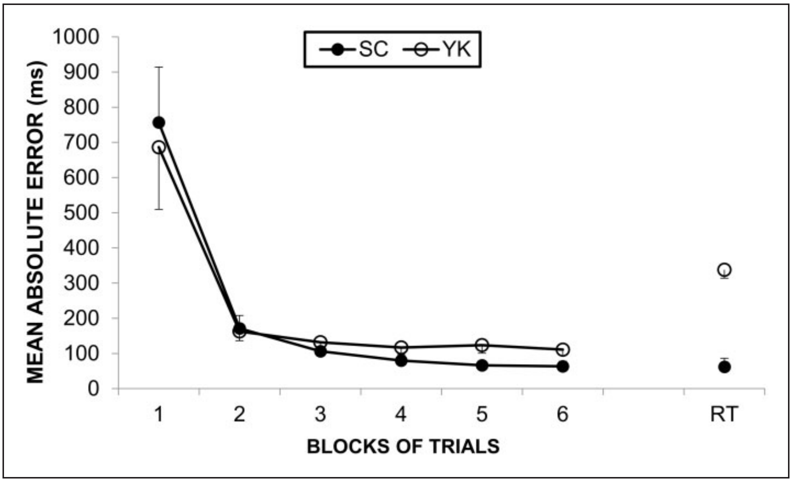

Figure 2. Group (SC and YK) mean AE in acquisition phase (BL1-BL6) and retention test (RT) in blocks of 8 and 10 trials, respectively. The error bar denotes standard error (*SE*) across participants. SC: self-controlled; YK: yoked.

they had good performances. The comparison of the mean relative frequencies of KR request throughout the acquisition phase was performed using the Friedman test. Effect sizes were reported using Pearson's r, and α level was set to .05.

Results

Absolute Error

Figure 2 shows AE measures computed across trial blocks for the acquisition phase and retention test. Friedman test revealed a significant main effect for blocks in SC (χ^2 [$N = 12$, $df = 5$] = 39.09, $p = .001$) and YK (χ^2 [$N = 12$, $df = 5$] = 22.9, $p = .001$) during acquisition phase. Wilcoxon test revealed that accuracy in the last block was greater than in the first block of trials in SC (Z [$N = 12$] = 3.06, $p = .002$, $r = .624$) and YK (Z [$N = 12$] = 3.06, $p = .002$, $r = .624$) during acquisition phase. In the retention test, the Mann–Whitney test indicated that SC group was more accurate than the YK group (Z [$N = 12$] = −3.58, $p = .001$, $r = .731$).

Constant Error

Figure 3 shows CE measures computed across trial blocks for the acquisition phase and retention test. Friedman test revealed a significant main effect for blocks in SC (χ^2 [$N = 12$, $df = 5$] = 36.61, $p = .001$) and YK (χ^2 [$N = 12$,

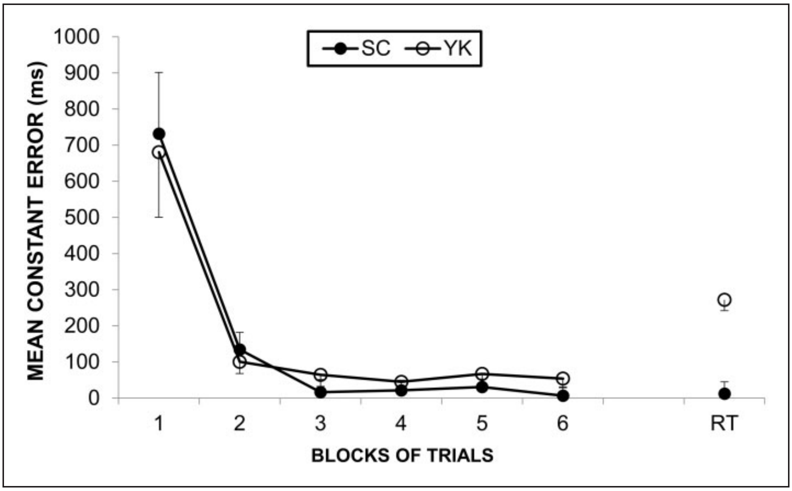

Figure 3. Group (SC and YK) mean CE in acquisition phase (BL1-BL6) and retention test (RT) in blocks of 8 and 10 trials, respectively. The error bar denotes standard error (*SE*) across participants. SC: self-controlled; YK: yoked.

$df = 5] = 28$, $p = .001$) during acquisition phase. Wilcoxon test revealed that accuracy in the last block was greater than in the first block of trials in SC (Z [$N = 12$] $= 3.05$, $p = .002$, $r = .624$) and YK (Z [$N = 12$] $= 3.06$, $p = .002$, $r = .624$) during acquisition phase. In the retention test, the Mann–Whitney test indicated that SC group was more accurate than the YK group (Z [$N = 12$] $= -2.63$, $p = .008$, $r = .542$).

Variable Error

Figure 4 shows VE measures computed across trial blocks for the acquisition phase and retention test. Friedman test revealed a significant main effect for blocks in SC (χ^2 [$N = 12$, $df = 5$] $= 34.19$, $p = .001$) and YK (χ^2 [$N = 12$, $df = 5$] $= 27.38$, $p = .001$) during acquisition phase. Wilcoxon test revealed that accuracy in the last block was greater than in the first block of trials in SC (Z [$N = 12$] $= 3.06$, $p = .002$, $r = .624$) and YK (Z [$N = 12$] $= 3.06$, $p = .002$, $r = .624$) during acquisition phase. In the retention test, the Mann–Whitney test indicated no significant group differences (Z [$N = 12$] $= -1.41$, $p = .15$, $r = .295$).

Questionnaires

Most SC participants reported requesting KR after what they thought to be a good trial (66.66%), and the next most prevalent reported requests were equally distributed after perceived good and bad trials (16.66% each). As for trials in

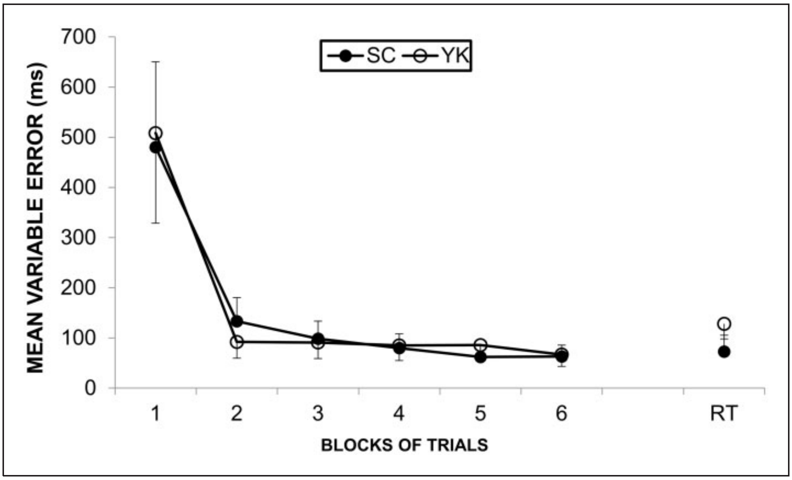

Figure 4. Group (SC and YK) mean VE in acquisition phase (BL1-BL6) and retention test (RT) in blocks of 8 and 10 trials, respectively. The error bar denotes standard error (*SE*) across participants. SC: self-controlled; YK: yoked.

which no KR was requested, most SC participants declared that KR was not necessary when they thought they had a bad performance (75%), followed in prevalence by an unspecified strategy that had not been an available choice for them to select on the posttraining questionnaire (16.66%). The questionnaire administered to the YK group showed that most YK participants reported that they did not receive KR after the trials on which they needed this information (91.66%). The majority of YK participants also reported that they would have preferred to receive KR after trials they perceived to be good trials (83.33%).

Performance Estimation

We compared the performance of SC participants on trials with KR ($M = 204.03$ milliseconds, $SD = 71.41$ milliseconds) and without KR ($M = 308.46$ milliseconds, $SD = 336.56$ milliseconds) to determine whether these individuals were able to discriminate good and bad trials effectively, only including in this analysis those individuals who reported requesting KR after perceived good trials. The Mann–Whitney test showed no significant difference between these participants' performance on trials with or without KR ($Z\ [N = 8] = -1.31$, $p = .19$, $r = .32$).

KR distribution

SC participants requested KR on 42.2% of acquisition phase trials. To determine if this request presented a homogenous KR distribution, a Friedman test was carried out. No differences were found in KR requests between the blocks of trials, confirming a homogeneous KR distribution throughout the phase (χ^2 [$N = 12$, $df = 5$] $= 4.68$, $p = .46$).

Discussion

This study investigated the effectiveness of SC KR scheduling on learning a Taekwondo serial skill. Considering previous evidence of benefits to SC KR, and the fact that self-control allows learners to individualize KR requests according to their own needs throughout the learning process (Carter & Ste-Marie, 2017; Chiviacowsky & Wulf, 2002, 2005), we hypothesized that the SC KR condition would lead to better task retention even for learning this complex skill. Our findings confirmed this hypothesis, as the self-control group presented superior performance on the retention test, compared with YK control participants. This finding is consistent with previous studies that also demonstrated the superiority of the SC condition over the YK condition on retention tests (Carter & Patterson, 2012; Grand et al., 2015; Lim et al., 2015; Patterson & Carter, 2010). We also proposed that KR would be used to protect learners' perception of competence and KR requests would be equally distributed during practice. This hypothesis was partially confirmed, as participants did use KR strategically to protect their perceptions of competence in a homogeneous distribution across practice. However, participants were not able to use this strategy effectively, as their performance estimates were not accurate. We hypothesize that this difficulty accurately estimating performance was related to the high task complexity and to the amount of information produced by its many degrees of freedom, leading to some informational overload that interfered with performance estimations.

Participants who had control over KR requests in this study showed better skill retention relative to YK participants, as hypothesized. This probably occurred because the opportunity to request KR freely through acquisition allowed SC participants to seek KR when they thought this information was most helpful to their learning (Chiviacowsky & Wulf, 2005; Janelle et al., 1995). To receive this benefit, learners had to perform constant evaluations of their own performance to decide when to request KR, possibly increasing cognitive effort and enhancing motor learning (Sherwood & Lee, 2003). Through these constant evaluations, learners developed more efficient error detection, favoring strengthened mental representation of the motor skill through the use of intrinsic self-evaluation feedback (Carter & Ste-Marie, 2017; Marteniuk, 1986). These propositions are in line with the hypothesis that SC KR benefits for motor learning derive principally from increased information processing (Carter et al., 2014; Carter & Ste-Marie, 2017; Chiviacowsky & Wulf, 2005; Grand et al., 2015; Hansen et al., 2011).

Another possible explanation for KR self-control benefits relates to motivational benefits associated with specific KR control strategies (Carter et al., 2014; Chiviacowsky & Wulf, 2005). Several studies reported that when learners have control over KR requests they ask for KR mainly after perceived good trials, in order to confirm their good performance (Carter et al., 2014; Chiviacowsky & Wulf, 2005; Chiviacowsky et al., 2012). This strategy protects learners' perceptions of competence, thus increasing motivation during the learning process (Chiviacowsky et al., 2012). In our study, we observed this strategy to protect the perception of competence, since the most frequently reported KR strategy on our participant questionnaire was to request KR after perceived successful trials. Participants also reported that KR was not requested after participants thought they had a bad performance. This finding is consistent with findings from other SC KR studies (Carter et al., 2014; Chiviacowsky & Wulf, 2002). However, although participants indicated their preference for requesting KR after good trials, the difference between their errors on trials with and without KR requests was not statistically significant, indicating that they may not have accurately discriminated between good and bad trial performances. This self-evaluative difficulty may have been due to task complexity that made it harder to self-estimate errors because of many task features (beyond its temporal feature) that competed for the learners' attention. Unlike simpler tasks, the task in this study may have requested learners to process more information than just intrinsic feedback, due to the amount of muscle actions and coordinated actions to be performed within a specific temporal goal (Wulf & Shea, 2002), justifying learners' inability to estimate performance efficiently (Sigrist et al., 2011). Although our results seemed not to support the expected motivational benefits to SC KR, we cannot rule out these effects either because we had no direct measure of motivation such as tools to measure fundamental psychological need satisfactions such as autonomy or self-determination (Sanli, Patterson, Bray, & Lee, 2013; Wulf et al., 2018).

We also sought to investigate how our SC participants controlled KR distribution during practice when learning our complex motor task. In studies with simpler tasks, such as key-pressing tasks, participants with control over KR tended to maintain similar KR request frequencies throughout the whole acquisition phase (Chiviacowsky & Wulf, 2002; Patterson & Carter, 2010). Similarly, despite our use of a more complex task, our SC participants requested similar KR frequencies (average of 42.2%) across the acquisition phase. It is possible that maintaining similar KR request frequencies throughout the acquisition phase is an economic strategy for learners, as it liberates resources for other relevant aspects of self-control and learning, including constant self-monitoring to decide when to request KR (Patterson & Carter, 2010). This strategy seems to be even more important when learning a complex task such as the bandal tchagui Taekwondo skill, with its greater number of degrees of freedom and increased information processing demands.

On the other hand, Lim et al. (2015) also investigated the learning of a Taekwondo serial task, but their participants, with control over KP, showed a decreasing proportion of KP requests over the acquisition phase. We believe that differences between our results and Lim et al.'s (2015) are due to the different types of feedback provided and the different demands of the skill tasks to be learned. Regarding the type of feedback provided, there is evidence that learners use KP differently than KR in self-control conditions (Aiken, Fairbrother, & Post, 2012; Laughlin et al., 2015). Gentile (1972) proposed that KP involves a comparison between the planned movement and movement performed, while KR involves a comparison between the task goal and the task result achieved by the movement performed. Such informational differences may explain differences in how participants used available feedback in our study compared with Lim et al. (2015). Regarding the task itself, while both experiments used serial Taekwondo tasks, the number of components and the duration of the performances were very distinct across the two studies, altering the main demands of the task. While Lim et al. (2015) assessed performance through the movement pattern, we assessed performance temporally. Despite these differences in task demands, informational content and even on how information was handled through the acquisition phase, both studies reported advantages for the SC conditions over externally controlled KR, reinforcing SC KR benefits even when learning complex skills with high ecological validity to the sport context. Learners were not overwhelmed by the amount of information being processed in this complex SC motor learning. It is likely that these benefits come from a more meaningful stimulation of working memory throughout the learning process. The opportunity to control feedback allows learners to use more personally relevant information, since information is requested when the learner feels the need for it. This use of more meaningful information may have contributed to a better consolidation of the skill in the learner's long-term memory (Craik & Tulving, 1975).

The results of this study add to existing evidence that providing learners with control over KR efficiently enhances motor learning by showing that the benefits of SC KR might be extended to complex tasks with greater similarity to actual sports, as was the case with this serial Taekwondo skill. Even though this is such a complex task, and participants showed a low capacity to discriminate between their good and bad trials, self-control proved to be more efficient for skill retention than the externally controlled learning condition. Cognitively economic strategies such as maintaining a similar KR distribution through acquisition phase and requesting KR mainly after perceived good trials (in order to confirm an adequate response instead of correcting an inadequate response) may have favored such results. These findings suggest that coaches and trainers should give learners the opportunity to control aspects of their practice, even when learning complex skills with an increased number of degrees of freedom, as this is an effective strategy to enhance motor learning. Future studies should verify whether these findings could be generalized to other complex tasks with different demands or through the control over different variables other than KR. Moreover, using motivational measures and instruments that allows accessing information processing on SC protocols could provide important further information about self-control advantages on complex skills learning.

Declaration of Conflicting Interests

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