7 Self-controlled learning

Current findings, theoretical perspectives, and future directions

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Introduction

Organizing an effective practice session incorporates many levels of decision making given the numerous variables that practitioners can modify within a session. In this chapter, we consider the idea that the practitioner may not need to plan everything down to the last detail, and that allowing learners to control aspects of their practice could be advantageous. Research on this topic has been referred to as self-guided learning (Brydges, Carnahan, Rose, & Dubrowski, 2010), subject-controlled learning (Janelle, Kim, & Singer, 1995), self-directed learning (e.g., Jowett, LeBlanc, Xeroulis, MacRae, & Dubrowski, 2007; Karlinsky & Hodges, 2014), self-regulated learning (e.g., Hodges, Edwards, Luttin, & Bowcock, 2011; Keetch & Lee, 2007; Patterson & Lee, 2010), and self-controlled learning (e.g., Chiviacowsky, Wulf, & Lewthwaite, 2012a; Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Patterson, Carter, & Sanli, 2011; Post, Aiken, Laughlin, & Fairbrother, 2016). Given that some of these terms are used in other research fields, such as self-control from the perspective of willpower (Baumeister, Bratslavsky, Muraven, & Tice, 1998) or the broader view of metacognitive strategies for self-regulated learning (Zimmerman, 1989), we want to be clear on the research focus here; specifically, our focus is whether motor skill acquisition is enhanced when learners are provided choice over certain features of the practice environment as opposed to having the feature determined by the coach. The term self-controlled learning is used to capture this research area.

As an overview of the chapter, we first review the current findings emanating from research that allows learners choice over: (1) the variability of the practice schedule; (2) the use of action observation; and (3) the use of augmented feedback. It is recognized that other features have been studied in reference to self-controlled learning including, but not limited to, the use of physical assistive devices (e.g., Wulf & Toole, 1999), difficulty level of the task (Andrieux, Danna, & Thon, 2012), type of instructional assistance (Laughlin, et al., 2015), and duration of practice (Post, Fairbrother, & Barros, 2011) (for a broader review, see Sanli, Patterson, Bray, & Lee, 2012; Wulf, 2007). We have chosen to focus on just these three topics because they have been identified as key learning variables by leading motor learning researchers (e.g., Lee, Swinnen, & Serrien, 1994; Schmidt & Bjork, 1992). Second, we present the theoretical perspectives that have been proposed to explain the underlying mechanisms associated with self-controlled learning benefits. The third section serves to present evidence-based recommendations and we finish with ideas for future research.

The typical research protocol of self-controlled learning involves the comparison of learning outcomes for those who are provided choice over the provision of a practice variable (i.e., self-controlled learning group) with those whom are not provided that choice, referred to as the yoked group. Those in the yoked group are paired with a counterpart within the self-controlled group such that they receive the practice variable in the same manner as that of the self-controlled group during an acquisition phase, with the only difference being the lack of choice. A delay interval then occurs between the practice phase and later assessments of learning of the skill. The retention test involves the skill being performed the exact same, whereas, in the transfer test, the skill is modified in some manner. In motor learning research, the emphasis is always on the delayed retention and transfer test results for understanding the impact of a practice variable on learning because those tests provide information about the relative permanence of the motor memory (Kantak & Winstein, 2012).

Figure 7.1 illustrates a typical experimental protocol along with contrived findings in which the self-controlled and yoked groups do not show any differences in the acquisition phase (divided into blocks of trials; B1–B6) or the immediate retention test (R1). The self-controlled group, however, then shows enhanced learning compared to the yoked group on delayed (~24-hrs) retention (R2) and transfer (T1) tests. Next, we provide evidence of self-controlled benefits from three different practice variables.

Self-controlled learning and practice scheduling

Our use of the term practice scheduling here is in regard to the manner in which variability can be introduced into one's practice; specifically, in terms of the amount of contextual interference introduced into practice (i.e., blocked or random schedules), or the introduction of task variations of the same task (i.e., constant or variable practice). In regard to the latter practice schedule, variability is considered in the context of one skill being practiced and whether this is done under the same (constant practice) or varying initial conditions (variable practice). As an example, consider basketball in which the learner may shoot the ball from varied positions on the court within a practice session; thus, engaging in variable practice. Alternatively, the practice schedule may have the learner consistently practice shooting from the foul line of the court, which is a constant practice schedule. When comparing variable practice to constant practice, motor skill retention is typically enhanced following variable practice conditions as opposed to constant practice (Catalano & Kleiner, 1984).

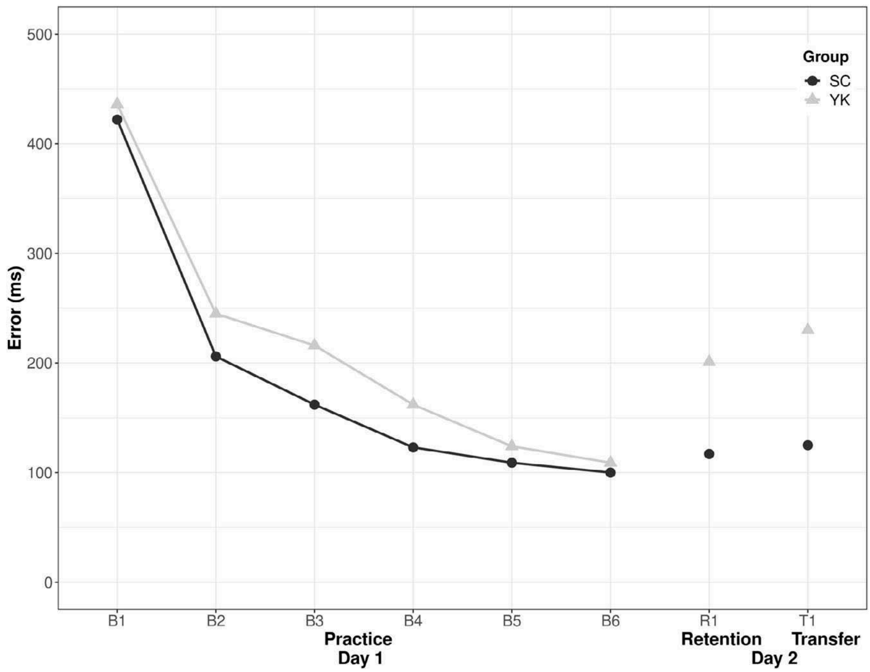

Figure 7.1 Hypothetical data that illustrates the typical pattern of results for participants that practice a motor skill in a self-controlled group (SC; circles) versus participants that practice in a yoked group (YK; triangles). Performance is captured by the amount of (timing) error during a practice phase consisting of six blocks (B1 through B6) on Day 1 and 24-hour retention (R1) and transfer (T1) tests on Day 2. In a typical self-controlled versus yoked experiment, no performance differences between the two groups are shown during the practice phase. In delayed retention and transfer tests of 24-hours or more, however, superior performance (in this case reduced error) is typically noted for the self-controlled group compared to the yoked group.

Investigation into self-controlled practice scheduling conditions of variable versus constant practice has been done with participants learning a table tennis task (Bund & Wiemeyer, 2004). The researchers first questioned all participants on 16 different features in the practice environment which they would be most interested in controlling (e.g., frequency of feedback, number of practice trials, order of practice). The preferred practice feature to have control over was self-observation, whereas choice over direction and distance away of balls delivered each block (i.e., task variability) was the least preferred. Participants were assigned in a factorial combination of self-controlled or yoked conditions combined with choice over observation schedule or task variability. The self-controlled learning conditions, for both choice features, resulted in superior form scores on a delayed retention test. Thus, advantages were seen despite participants having ranked choice over variability of practice as their least preferred option. Also of note is that self-controlled learning benefits were seen regardless of the amount of variability introduced. That is, participants who chose a constant practice schedule gained the same advantages as those who chose a variable practice schedule.

Variability in practice scheduling as a function of contextual interference involves granting control over the scheduling of multiple skills or tasks (typically within the same practice session, but sometimes studied across practice days). Blocked practice is characterized by numerous trials of one skill before the practice of another. Using a golf example, a learner would want to perfect a variety of swings with varied clubs. Under a blocked practice regime, the person may first execute 15 drives, then do 15 chip shots, followed by 15 putts; a practice schedule with low contextual interference. In contrast, random practice rarely has practice of the same skill completed on consecutive trials and instead, practice on any one task is interspersed with the practice of others. Therefore, the learner may do a drive, then a putt, then a chip shot, then a putt, and so on in this random order. This practice schedule creates a high level of contextual interference because of the intermixing of the skills. Researcher have shown that a random practice schedule is superior to a blocked schedule when examining learning effects using a delayed retention or transfer test (Brady, 2004; Lee, 2012).

Researchers examining learners having self-control over the scheduling of multiple tasks, versus assigned random or blocked schedules have found varied results. Self-controlled groups have been shown to have similar learning outcomes as those of an imposed random schedule group, with both showing better learning than an imposed blocked schedule (Titzer, Shea, & Romack, 1993). This experiment used a laboratory-based task that had participants completing three versions of a computer-controlled knockdown barrier task. The results demonstrated that self-controlling the practice schedule generated similar learning advantages as that created by a random schedule. The experimenters, however, failed to include a yoked control group, making it difficult to isolate whether the benefits were rooted in self-controlling the repetition schedule or the schedule itself that was chosen.

Other experimenters have shown no significant differences when self-controlled groups were compared to imposed random and blocked groups, when learning a computer-based, sequencing task, regardless of task difficulty (Keetch & Lee, 2007). The group who self-scheduled, however, was the only group to show a significant decrease in movement time from the last block of acquisition to retention; thus, providing limited evidence for self-control of practice schedule being advantageous compared to the yoked and imposed schedules. These results should be taken with some caution, however, as the self-control group did have the slowest movement time compared to all other groups in the last block of acquisition and significant differences in retention were not found for all dependent variables.

Yet again, different findings were reported in an experiment in which the learners were tasked with learning three relative timing patterns of a computer sequence task (Wu & Magill, 2011). Participants were either assigned to the self-control group or were in the yoked group and followed the practice schedule of a self-controlled counterpart. While significant advantages were found for the self-controlled group in terms of less error and less variability in the movement, the schedules adopted by the self-controlled group showed a number of variations, with some choosing schedules that mimicked more of a blocked practice schedule, while others a random schedule. Thus, the provision of choice in terms of when to switch between tasks was the more important learning variable here than was the actual variability that had been produced by the practice schedule. These results are similar to those noted earlier for self-control over variability of practice (Bund & Wiemeyer, 2004).

Researchers have studied how experts in domains other than sport (i.e., music) scheduled their practice of three novel disc-throwing skills (Hodges et al., 2011). These "practice experts" were compared with novice learners who also self-controlled their practice (novice self-controlled) and a yoked group who were provided the same schedule as that selected by the music experts. It was assumed that the expert musicians would have knowledge of effective practice methods, such as the use of random schedules, and that they would transfer these habits across domains. Although the music experts did not choose a more random schedule compared to the novices, they did adopt a successful practice strategy of introducing higher amounts of interference later in practice. The delayed retention results revealed the music experts to be more accurate (i.e., lower radial error) for the two backhand throws compared to the two novice groups (although the reverse was true for the forehand). Better form scores, however, were found for both the expert musicians and the yoked group over that of novice self-controlled group. Thus, the more effective practice schedule used by the music experts seemed to thwart the negative effects associated with no choice, for the qualitative aspect of the movements. These results provide evidence that self-controlled learning advantages are complex, as a learner's previous practice experiences can influence not only their chosen practice schedule, but also its impact on learning.

Overall, the research findings on self-control over variability in practice (of both single and multiple skills) have shown that self-controlled learning advantages can occur, but they are not necessarily tied to the actual practice schedule adopted. Learners who chose a constant practice or blocked practice schedule, schedules that have been deemed as inferior to variable or random schedules (Schmidt & Lee, 2011), still showed learning advantages as compared to those who were not provided choice (Bund & Wiemeyer, 2004; Wu & Magill, 2011). Furthermore, learners with, assumedly, more knowledge of effective practice scheduling techniques self-selected higher quality practice schedules and showed learning advantages over novices who were provided with the opportunity to control their practice. Such findings suggest that we need to better understand the impact of learner characteristics on the effectiveness of self-controlled practice before clear recommendations can be made about its benefits.

Self-controlled learning and observation

Providing learners with a demonstration, whether by the instructor, another peer in the class, or a video of someone showing the skill, is a common teaching technique and several researchers have shown advantages associated with such observational practice (see Hodges & Ste-Marie, 2013; McCullagh, Law, & Ste-Marie, 2012). Researchers have studied whether there are benefits associated with controlling the frequency of these demonstrations. In one of the first experiments, the acquisition of a badminton serve was tested under three conditions: (1) self-controlled condition; (2) a condition in which a demonstration was provided before every trial (100% frequency); and (3) one in which no demonstrations were given (control) (Wrisberg & Pein, 2002). The self-controlled group, despite a low observation frequency of 10%, showed equivalent movement form learning as that of the 100% group, both of which were superior to the control group. The authors, however, acknowledged the lack of a yoked group, such that it may just be that a lower frequency of modeling explained the benefits. This limitation was addressed in a subsequent experiment in which a yoked group was compared to a self-controlled observation schedule group for the learning of a basketball jump shot (Wulf, Raupach, & Pfeiffer, 2005). Self-controlled learners again showed superior movement form on a delayed retention test and those participants also requested a low frequency of demonstrations (on average 5.8% of trials).

An experimental design in which learners were provided choice over the frequency of observation (6 trials versus 2 trials) showed that learners who self-selected the higher frequency were better able to recall the essential elements of the dance skill than those who chose only two observations (Fagundes, Chen, & Laguna, 2013). These findings were used to suggest that the higher frequency group developed a better cognitive representation of the dance skill. The relevance of assessing the learner's cognitive representation is rooted in Bandura's (1977) social learning theory. Bandura proposed that the observation process included the development of a cognitive representation of the observed skill which later served to guide motor reproduction. He argued that one could be learning and improving the cognitive representation, but that such learning may not translate to immediate motor changes for varied reasons. Consequently, changes to a learners' cognitive representation is of relevance. Despite this better cognitive representation, no differences were reported for physical execution of the skill, which may have been related to the low number of combined physical (15) and observation trials (2 or 6). Moreover, there were no yoked groups in which no choice was given, and the frequency of demonstrations was confounded with the scheduling of those demonstrations, thus cautious interpretation of these findings is warranted.

A recently completed experiment had learners control the schedule of modeled demonstrations under different guiding constraints (St. Germain, Lelievre, & Ste-Marie, 2019). The rationale was that learning benefits obtained from the low observation frequencies typically chosen by participants (e.g., Wrisberg & Pein, 2002; Wulf et al., 2005) might be better optimized when constraints are in place which encourage a higher frequency of observation (although still self-controlled). During a practice session comprised of interspersed observational and physical practice, all groups were instructed that they could self-select when to observe a video model demonstrating the pirouette-en-dehors, (see Figure 7.2). For four of the groups, they were constrained to choose a demonstration on either 10%, 25%, 50% or 75% of learning trials (see Sidaway & Hand, 1993, whose research showed that a higher frequency of observation trials was better for learning novel motor skills, as compared to lower frequencies). A fifth group was able to self-select as many observational trials as they desired (no-constraint group). To illustrate, the 25% group were told that within the next 60 trials, they were to watch a video demonstration 15 times and perform the skill 45 times, but that they could choose how to schedule the two types of practice.

All groups improved in their capability at determining correct performances of the skill (cognitive representation test scores), as well as in movement form (physical performance test scores). No group differences, however, were observed. Therefore, in this study, the frequency of self-selected observation was not a moderating factor on performance and learning. To note, while the no-constraint group was expected to select a low frequency of observation, a relatively high frequency (M = 50%) was selected compared to that seen in previous research (e.g., Wrisberg & Pein, 2002; Wulf et al., 2005). This suggests that the difficulty of the skill and emphasis on movement quality might have necessitated a high number of demonstrations than that needed for tasks with clear outcome goals (i.e., badminton serving or basketball shooting). Consequently, task characteristics likely influence how participants use self-control over observation frequency in motor learning situations.

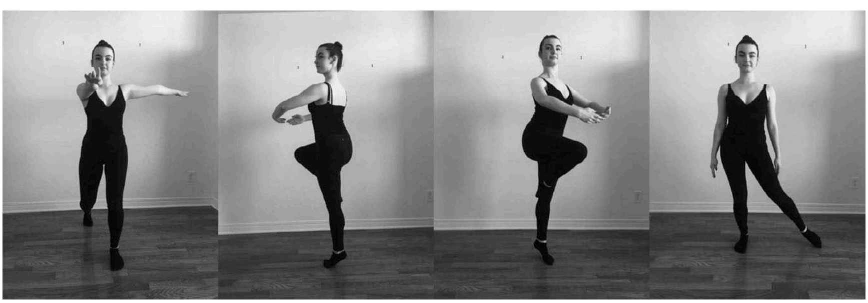

Figure 7.2 A visual illustration of the pirouette-en-dehors; the motor task used by St. Germain et al. (2019).

Moving to a different field in which movement execution is of importance, that of medical education, students were tested under conditions in which they self-controlled the scheduling of an instructional video concerning suturing skills. Two self-controlled groups were included; one which formed process goals associated with the performance of the skill and another group which formed performance outcome goals (Brydges, Carnahan, Safir, & Dubrowski, 2009). Following Zimmerman's (1989) model of self-regulated learning, process goals were defined as those related to the mechanics of the suturing skill, whereas outcome goals were those associated with the final product of the skill. Only the self-controlled group that set process goals outperformed a third, yoked group, suggesting that we must consider factors beyond just self-control when considering efficacy of self-controlled learning conditions. Similarly, Brydges et al. (2010) showed that nursing students who were able to select the frequency in which they accessed an instructional video regarding intravenous catheterization during simulator training, as well as controlling when the fidelity of the simulator increased, performed better than a yoked group.

Overall, providing choice over the frequency of demonstrations has resulted in learning advantages, which occur even when learners select very low frequencies of observation (Wrisberg & Pein, 2002; Wulf et al., 2005). While Fagundes et al. (2013) showed better cognitive representation scores for learners who chose to watch 6 demonstrations over 2 demonstrations, there is no clear evidence that higher self-selected frequencies, at least within the range of 10–75%, confer differential benefits (St. Germain et al., 2019). Finally, there may also be benefits to studying other variables that can affect the efficacy of the self-controlled observation. In addition to process goals, for example, one might consider other self-regulation variables such as planning and monitoring processes that are known to affect learning (Zimmerman, 1989).

Self-controlled learning and augmented feedback

Augmented feedback is information that is provided by an external source, which can come from a variety of sources, such as a coach, video, or even biofeedback. It is referred to as augmented as it heightens the task intrinsic feedback that is available to learners through their own sensory sources. It is classified into one of two types: knowledge of performance (KP) or knowledge of results (KR) (Schmidt & Lee, 2011). KP concerns information provided about the movement mechanics, such as that which can be provided by viewing a video or being told by a coach about the positioning of certain body parts (Schmidt & Lee, 2011). KR is information concerning the learners' success in attaining the desired outcome of the movement (Salmoni, Schmidt, & Walter, 1984); for example, being informed about the position of one's golf ball relative to the hole. Augmented feedback has been considered one of the most critical variables for enhancing motor learning, and thus it is not surprising that this practice variable has received the most focus in the self-controlled learning research. First, we review research related to choice over KP, and then turn to that related to KR.

Self-controlled learning and knowledge of performance (KP)

The self-control of the provision of KP was examined for the learning of an underhand throwing task (Janelle et al., 1995). Of particular interest are three of the five experimental groups: (1) choice given over when to receive KP following execution; (2) KP provided on a yoked schedule; or (3) KP provided following an evidence-based, best practice method. Verbal KP about the mechanics of the throwing arm, force, or trajectory of the toss was provided. The self-controlled participants executed the underhand throw more accurately, as measured by less absolute error on a 10-min retention test, than those in the remaining groups. In a subsequent study from the same research group, guided video feedback (i.e., coach provided cueing and transitional information) was used as KP, this time for the learning of an overhand throw, in which throwing form, accuracy, and speed were measured as learning outcomes (Janelle et al., 1997). The self-controlled KP group had superior throwing form scores compared to a yoked KP group and an evidence-based best practice schedule on retention tests. Thus, learning advantages associated with choice over KP scheduling were not limited to throwing accuracy, but extended to movement form. Using a similar experimental protocol, researchers have shown that children benefit from self-controlled video feedback while learning double mini-trampoline skills (Ste-Marie, Carter, Law, Vertes, & Smith, 2016; Ste-Marie, Vertes, Law, & Rymal, 2013).

While the research mentioned to date has had the KP supplemented by a knowledgeable coach, others have queried whether self-controlled video feedback advantages would be seen without additional cueing provided by a coach (Aiken, Fairbrother, & Post, 2012; Post et al., 2016). In these situations, self-controlled KP and yoked groups were compared for form and accuracy on both retention and transfer tests. Self-controlled KP advantages were found for basketball shooting form (Aiken et al., 2012) and golf chip shot accuracy and form (Post et al., 2016), but only during the transfer tests (no retention test differences). Additionally, participants in the self-controlled group accessed instructional cues more than the yoked group during acquisition (Aiken et al., 2012), suggesting that learners in self-controlled conditions may independently seek out relevant information for learning more than under experimenter (or coach) defined learning environments. Self-controlled learners were also able to recall a greater number of critical task features of a successful golf chip than the yoked group (Post et al., 2016). Such findings provide continued support for the use of self-controlled learning conditions in the absence of a coach and suggest that receiving feedback when needed aids memory for important task features.

In sum, researchers have shown that self-controlled learning advantages extend to the scheduling of KP in both verbal and video feedback form. In terms of video feedback, the learning gains can occur both in the presence and absence of a knowledgeable instructor. Advantages have been evidenced for both movement form and accuracy on a variety of sport skills.

Self-controlled learning and knowledge of results

In one of the first studies investigating the effectiveness of self-controlled KR schedules for motor skill learning, Chen, Hendrick, and Lidor (2002) had participants learn a five-digit key press sequence in either a self-controlled KR group, an experimenter-induced self-controlled KR group, or one of the two corresponding yoked groups. The difference between the two self-controlled groups was that one self-controlled group was simply told that they had choice over when to receive KR, whereas the experimenter-induced group received a decision prompt after each practice trial with regard to whether KR was desired. While no performance differences between the two self-controlled groups were shown on an immediate retention test, the experimenter-induced KR group performed more accurately than all groups on the delayed 48-hour retention test. Both self-controlled groups did, however, demonstrate enhanced learning relative to their yoked counterparts, and both were shown to ask for similarly high levels of KR frequency (>95%). This experiment highlighted the importance of decision prompts for enhancing the learning effectiveness of self-controlled KR schedules and this procedure has become dominant in subsequent studies.

Using a similar key pressing task to that of Chen and colleagues (2002), Chiviacowsky and Wulf (2002) showed that participants in a self-controlled KR group performed with significantly greater timing accuracy on a 24-hour transfer test compared to a yoked KR group (although they did not differ on the retention task). This transfer effect suggested an enhanced ability to generalize, which is highly relevant for the training of sports skills where the conditions of practice are often considerably different to those experienced in a game situation (e.g., less dynamic, slower speed, increased predictability). Thus, knowing which practice manipulations facilitate skill transfer, such as self-controlled learning, is important information for coaches. Others have shown that the effectiveness of self-controlled KR schedules for single task learning extends to learning multiple motor tasks within the same practice session (Patterson & Carter, 2010) and that these self-controlled learning effects were enhanced when the multiple skills were practiced in a random/interleaved order, rather than a blocked/fixed order (Patterson, Carter, & Hansen, 2013). Also noteworthy is that children have also been shown to have the same self-controlled KR benefits as that of adults (Chiviacowsky, Wulf, de Medeiros, Kaefer, & Tani, 2008; Chiviacowsky, Wulf, de Medeiros, Kaefer, & Wally, 2008).

Although there is a reliable learning benefit when individuals are permitted to make decisions about when to receive KR during practice, there is the question of *why* individuals choose to receive (or not receive) feedback on a particular trial. Early efforts to gain insight into this question queried participants about their KR preferences at the end of practice using multiple-choice questionnaires (e.g., Chiviacowsky & Wulf, 2002; Patterson & Carter, 2010). These questionnaires revealed that most participants in self-controlled groups asked for KR after trials that they thought were successful relative to the task goal, highlighting that individuals engage in deliberate strategies for requesting KR when given opportunity to self-schedule feedback during practice. Participants' preferences for requesting KR, however, are more dynamic than that identified using these single time point, end of practice, questionnaires. For instance, participants in self-controlled KR groups reported requesting KR for different purposes in the early and late stages of practice (Carter & Patterson, 2012; Carter, Rathwell, & Ste-Marie, 2016). Table 7.1 provides information concerning the wide range and dynamic nature of strategies used by learners who self-controlled their KR schedule. Thus, allowing learners to self-select their KR schedule appears to be a useful technique that allows learners to receive KR only when it would serve the purpose of providing a meaningful learning experience based on some individualized criterion (for an example, see Hansen, Pfeiffer, & Patterson, 2011).

Overall, there is considerable support for allowing learners to self-select when to receive KR to enhance learning compared to being denied this choice opportunity. Despite these consistent findings, a potential limitation of the self-controlled KR

Table 7.1 Strategies identified using an inductive thematic analysis, for requesting knowledge of results feedback during practice of a force production task

	Percentage of Responses	
KR Request Strategies	*1st Half of Practice*	*2nd Half of Practice*
Establish a baseline understanding	33*	25
Example response: *"I asked for feedback early on to get a sense for how far I was pushing the object. Once I found out it wasn't that far, it allowed me to adjust"*		
Confirm a perceived "good" trial	19	29*
Example response: *"Asked for feedback when I felt my throws were accurate to see if I was applying the right amount of force"*		
Evaluate a change in (motor) strategy	19	17
Example response: *"When I changed the amount of force I placed on the object [or] when I changed my arm movement"*		
Schedule feedback based on trial	22	25
Example response: *"Asked for the first 3 tries of every block"*		
Evaluate a perceived "poor" attempt	7	4
Example response: *"If I felt I was getting bad/lazy with my movement"*		

Note. Asterisk (*) identifies the dominant strategy in each half of practice. Data adapted from Carter et al. (2016) with permission.

research when making recommendations to real-world sport settings is that researchers have primarily used simple, laboratory-based tasks (e.g., movement about a single joint) or sport tasks devoid of its ecological validity (e.g., golf putting to a target with concentric rings on artificial mats rather than on grass to a hole). Moreover, when manipulations have been made to augmented feedback, these have not been with respect to the chosen content, such as whether KP or KR feedback is desired. Further research is warranted on these possible choice manipulations under sport conditions with greater ecological validity.

Explanations for self-controlled learning benefits

The learning advantages of allowing learners to control a feature of their practice environment relative to yoked schedules is well documented, yet the driving mechanism(s) of this learning effect is still being questioned. Initial explanations for self-controlled learning advantages in the motor skill learning domain were heavily influenced by ideas from the verbal learning and educational psychology literature (e.g., Butler & Winne, 1995; Zimmerman, 1989). For instance, it was suggested that self-controlled practice contexts increased participants' motivation to learn (Boekaerts, 1996; Winne, 1995), that individualizing one's practice context increased cognitive effort (Kanfer & Ackerman, 1989), and that task information was processed in deeper and more meaningful ways (Boekaerts & Corno, 2005; Winne, 1995; Zimmerman, 1989).

Researchers now generally adopt one of two explanations for self-controlled practice effects, in which the essence of earlier explanations remain evident. Some researchers have argued that exercising choice is intrinsically rewarding (Lewthwaite, Chiviacowsky, Drews, & Wulf, 2015), satisfies a basic psychological need for autonomy (Chiviacowsky, 2014), and enhances performance expectations (i.e., perceived competence, self-efficacy) (Chiviacowsky et al., 2012a). These in turn increase motivation, presumably through changes in dopaminergic processing (Wulf & Lewthwaite, 2016), which exerts a positive influence on learning. This has been referred to as the *motivational influences* perspective, which has been further captured in the recently proposed "OPTIMAL" (optimizing performance through intrinsic motivation and attention for learning) theory of motor learning (Wulf & Lewthwaite, 2016).

Support for the *motivational influences* explanation is mixed, with some researchers reporting increased motivation (e.g., Chiviacowsky, Wulf, Lewthwaite, & Campos, 2012b) and greater self-efficacy for self-controlled versus yoked (i.e., control) groups (e.g., Chiviacowsky, 2014; Post et al., 2016), whereas others have not demonstrated increased motivation (e.g., Grand et al., 2015) or self-efficacy (e.g., Ste-Marie et al., 2013) despite self-controlled learning advantages. Using a causal modeling analysis, self-efficacy and intrinsic motivation did not explain the enhanced learning of double-mini trampoline skills in a self-controlled group relative to their yoked counterparts (Ste-Marie et al., 2016). Similarly, Leiker et al. (2016) noted that greater reported motivation was coincident to increased learning at a group level, but individual differences in learning were not explained by individual differences in motivation.

Some researchers contend that exercising choice facilitates greater or more varied information-processing activities than those experienced by participants in yoked groups. This includes the adoption of new or better learning strategies (e.g., Carter et al., 2016; Hartman, 2007) that may more effectively reduce any uncertainties regarding task performance (e.g., Carter, Carlsen, & Ste-Marie, 2014; Huang, Shadmehr, & Diedrichsen, 2008), engaging in error estimation or performance appraisals (e.g., Chiviacowsky & Wulf, 2005), and increased meta-cognitive processing (e.g., Patterson et al., 2011). This view is often termed the *information-processing* perspective and resonates with the notion of increased cognitive effort—an important motor learning concept in which it has been argued that practice conditions that induce greater cognitive effort are more effective for skill learning than less cognitively demanding contexts (for reviews, see Guadagnoli & Lee, 2004; Lee et al., 1994). Some evidence consistent with greater information-processing was recently provided by Grand and colleagues (2015). Participants learned a throwing task and received KR about their throwing outcome in either a self-controlled KR group or a yoked KR group. Not only did the self-controlled group demonstrate superior performance on a delayed transfer test compared to the yoked group, they also had increased information-processing of their KR as measured with the electroencephalography-derived, feedback-related negativity potential (Grand et al., 2015).

Additional support for the *information-processing* perspective has come from experiments that have manipulated the timing of when the learner is asked to make their decision about receiving (or not receiving) KR. When learners in a self-controlled KR group completed their feedback decision *before* executing their movement, this failed to produce the typical self-controlled learning advantage over a yoked group and resulted in retention and transfer performance that was significantly less accurate than a self-controlled KR group that made their feedback decision *after* executing their movement (Carter et al., 2014; Chiviacowsky & Wulf, 2005). It was argued that completing the feedback decision after a movement was effective for learning because the learner was able to base this decision on a subjective evaluation of performance based on intrinsic feedback (e.g., proprioception). In line with this, Carter et al. (2014) showed that participants in a self-controlled KR group that made the feedback decision after a trial developed more accurate error estimation abilities than a self-controlled KR group that made the feedback decision before a trial (see Figure 7.3). Similarly, researchers have shown that interfering with the processing of intrinsic feedback immediately upon movement completion eliminates the typical self-controlled learning advantages (Carter & Ste-Marie, 2017a). Thus, self-controlled learning benefits seem to be strongly tied to the information-processing activities of the learner and, in particular, those related to the processing of intrinsic feedback (e.g., Carter & Ste-Marie, 2017a; Chiviacowsky & Wulf, 2005) and the provided KR (e.g., Grand et al., 2015).

Support for the information-processing explanation, like that for the motivational influences perspective, is mixed. For instance, some researchers have noted learning benefits can occur independent of choice relevancy such that

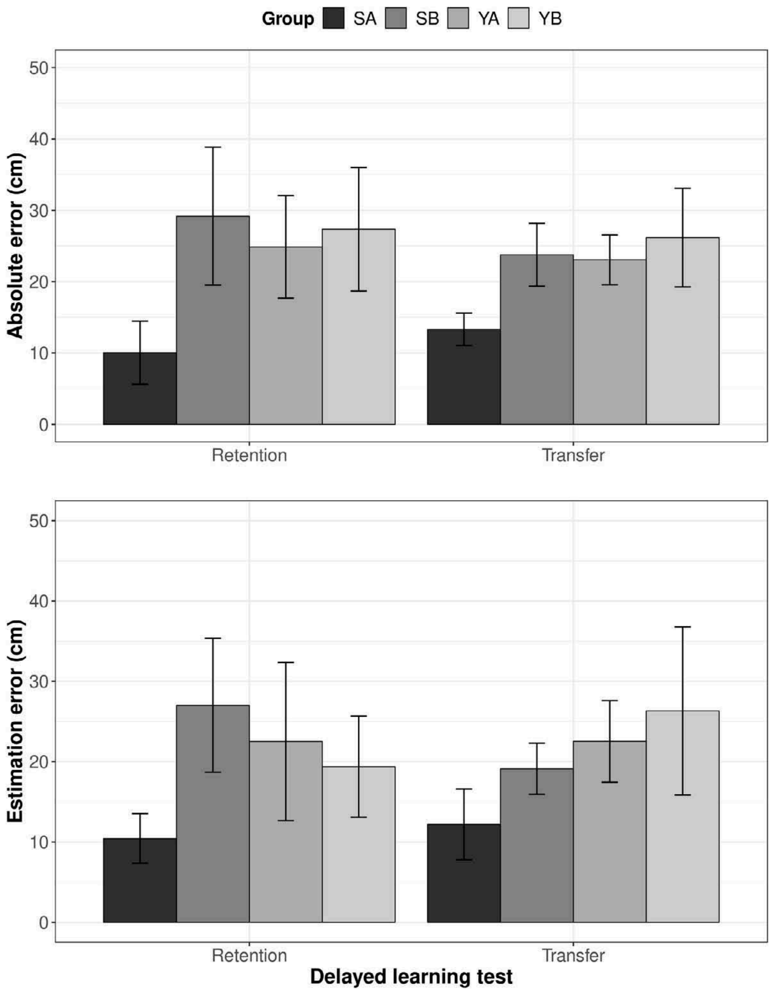

Figure 7.3 Data from an experiment that investigated how the timing of the feedback decision, either before (SB) or after (SA) a motor response influenced the effectiveness of self-controlled feedback schedules. Corresponding yoked groups were matched to each of these self-controlled groups (YA and YB). (Top) Error scores for the four groups on the delayed (~24-hour) retention and transfer tests. Note that the Self-After (SA) group performed with the least error on both tests compared to the Self-Before (SB), the Yoked-After (YA), and the Yoked-Before (YB) groups. There was no performance advantage of exercising choice over feedback if this decision was made before a trial; there was comparable error in the Self-Before and Yoked-Before groups on both tests. (Bottom) After each trial on the retention and transfer tests, participants were asked to make an estimation of their error for that trial relative to the task goal. Similar to the physical performance data, the Self-After group had more accurate error estimations on both learning tests. Error bars depict 95% confidence intervals.

both task-relevant and task-irrelevant choices enhance motor learning (Wulf, Chiviacowsky, & Cardozo, 2014; Wulf et al., 2017). These task-irrelevant choices influencing learning challenges the idea that choice benefits task related information-processing activities. Others, however, have not replicated the benefits seen for task-irrelevant choices (Carter & Ste-Marie, 2017b; Grand, Daou, Lohse, & Miller, 2017); thus, more research on these varied choice types is warranted.

Although we have two varied perspectives on the mechanisms that may drive self-controlled learning benefits, it is not to say that only one of these mechanisms necessarily captures all of the findings. It is possible that both motivational and informational factors contribute to the observed self-controlled learning benefits, but that they vary in the extent of their contributions. Regardless of the perspective adopted, the extant literature strongly supports the idea that relinquishing some control to the learner during practice has beneficial effects on the retention of motor skills, as well as the learners' ability to generalize or adapt the motor skill to varied contexts and situations. To the best of our knowledge, negative effects associated with self-controlling practice have not been demonstrated.

From theory into practice: some evidence-based recommendations

There are a number of practice variables for which the learner can be provided choice and show advantages in learning motor skills relative to a group that has not been afforded that choice. Some examples of this include allowing learners to determine: (1) the level of variability to introduce via practice scheduling; (2) when to watch a model to gain instructional information about the skill; (3) when to seek verbal KP/KR from a coach/instructor; and (4) when to seek KP via video feedback. As such, it is recommended that practices be structured to provide athletes with an environment in which choice over one or more of these variables is provided. There is evidence, that has not been expanded upon in this chapter, showing that choice over other practice variables, such as practice duration, task difficulty and the use of physical assistive aides is also beneficial for learning, so considering these practice features is pertinent. Our recommendations presented in Table 7.2 are focused only on those variables we have covered in this chapter. Although we can make these listed recommendations with confidence, there are certainly other avenues for further research on this topic which would impact or elaborate upon these recommendations. In our concluding section, we make some suggestions in terms of possible research directions.

Conclusions and future directions

We would like to reinforce some of those ideas suggested throughout the chapter, as well as bring forward new ideas and challenges. To begin with a new

Table 7.2 Recommendations for applying self-controlled learning

1.	Provide choice over practice features even if it seems the learner is disinterested in making such choices over those practice features.
2.	Provide choice over the scheduling of multiple tasks, or of variations of the same task, within a practice session.
3.	When providing choice over the use of a demonstration on video, also make available instructional information about the skill for learners to access when needed.
4.	When providing choice over video feedback, direct the learner's attention to important cues and/or provide transitional statements. When this is not possible, learners can still profit from choosing to watch video feedback alone or coupled with an expert performance of the skill (split screen technique).
5.	When providing choice over KR, have learners make the choice after the motor skill has been executed.
6.	When providing choice for KR/KP, encourage the learner to first estimate how well they performed/their errors etc., before giving the augmented feedback.
7.	When setting up practice with choice, be patient for the learning outcomes. That is, it might not seem like there is an advantage during the practice session itself, but advantages are more likely in later practice sessions or in transfer to new situations.

Note: KR = knowledge of results; KP = knowledge of performance

idea, no researchers to date have tested effects related to the number of choices provided to learners. Most researchers have provided choice over one practice feature, and, for experimental control reasons, have kept fixed other practice variables. It is possible, however, that learners can be involved in more choices within a practice session. What would the impact be of sessions with a number of choice opportunities? Would this situation produce additive effects, or is there a limit to how much advantage can be drawn from choice situations? A recent meta-analysis of 41 studies in which the effect of choice on intrinsic motivation, and other related features, was examined provides some indication that there may be an optimal bandwidth for the number of choices (Patall, Cooper, & Robinson, 2008). In that analysis, the number of successive choices was a moderating variable and greater effects of choice were observed when 2–4 successive choices were provided. Findings suggests that perhaps there is an optimal range for choice in motor learning as well.

With respect to the number of choices, one would also need to consider factors related to task complexity, skill level of the learner, and other possible features (e.g., number of options to choose from, whether choices are task relevant or irrelevant). Self-controlled research in which learners have been able to make a variety of choices has shown that the skill level of a learner will influence the choices made and subsequent learning outcomes (Coughlan, Williams, McRobert, & Ford, 2014; Hodges et al., 2011). Coughlan et al., for example, had both expert and intermediate level Gaelic football players practice two kicks (one defined as a weaker kick relative to a stronger kick, as measured by performance accuracy) within four, 15-min practice sessions (3x5 min blocks within the session) that occurred over successive weeks. During these practice sessions, the players were free to choose the frequency of attempts for each kick and the schedule in which they practiced the kicks. The expert players chose to practice the relatively weaker kick more frequently and adopted a more interfering (random) practice schedule compared to the intermediate players. These variations in the practice adopted by the experts likely contributed to the improved accuracy of the relatively weaker kick that was seen during the retention test, whereas the intermediate players did not show such learning benefits from their practice. Thus, continued research on the influences of the learners' characteristics, along with the number of choices provided is recommended.

To return to an earlier recommendation made, we argue that further research is needed to determine the effects of choice over irrelevant features of a task. While some researchers have shown learning gains from such choices; such as choosing the colour of a golf ball before practice (e.g., Lewthwaite et al., 2015; Wulf et al., 2017), others have not shown any advantages (e.g., Carter & Ste-Marie, 2017b; Grand et al., 2017). It is important to get a better understanding of these effects as they have implications concerning the theoretical underpinnings of self-controlled learning benefits. From an informational perspective, it is hard to understand how choices which do not provide information relevant to the task could lead to learning advantages, yet a motivational advantage would speak to the changes that could occur through meeting the learner's basic psychological needs of autonomy-support when choice is provided.

On another note, in much of the research to date, participants choose their practice schedules or the frequency of feedback/demonstrations, without guidance as to what might be effective for the learner. There is the possibility that information concerning evidence-based guidelines in conjunction with choice may be helpful. Alternatively, structuring the choice situation such that there are constraints which effectively channel the learner to adopt motor learning principles, which have been shown to be effective, could also be a viable option. This idea that learners may benefit from guiding principles when provided choice leads us to question the common experimental paradigm used in self-controlled research in which the self-controlled learning group is compared to yoked participants who are naïve to the task and, assumedly, basic motor learning principles. Would different findings emerge, if self-controlled learners were compared against an informed instructor/coach who could use their expertise to determine when augmented feedback (or any other practice variable) should be provided? Would this enhanced understanding of the task and, assumedly, of when and how to best provide augmented feedback (or any other practice variable) outweigh the advantage associated with the choice provided to the learner? One can look to the limited research on self-controlled learning where experts have been compared to other groups to help understand the importance of these factors for self-controlled learning decisions. For example, both elite Gaelic football players (Coughlan et al., 2014) and expert musicians (Hodges et al., 2011) self-selected what would be considered more effective practice schedules than their comparison groups, and both the football players and the musicians showed better learning outcomes on the motor skills being practised. Such findings hint at the idea that the comparison groups used in most self-controlled literature may not paint a true picture concerning the benefits of allowing novice learners to choose relevant practice parameters. This leads to the recommendation that research is needed which compares self-controlled learning to that of coach-controlled learning, or peer-controlled learning (e.g., see Karlinsky & Hodges, 2014), is needed.

In conclusion, self-controlled learning appears to be advantageous under a variety of learning conditions. There is sufficient evidence, both with laboratory-based tasks and more applied sport-based tasks, to provide informed recommendations for those involved in motor skill acquisition. Currently, it is reasonable to suggest that coaches do not need to prescribe all details of a practice and that learners can be provided varied choices, with relevant instructional resources available to them, in their practice contexts. There still remains, however, a number of unanswered questions and further research on the topic will only move us toward a better theoretical and practical understanding of self-controlled learning.

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