

**Increased perceptions of autonomy through choice fail to enhance motor skill
retention**

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Abstract

There has been growing research interest in the effects that motivation plays in motor learning, and specifically how autonomy, competence, and social relatedness may directly benefit the learning process. Here, we present a preregistered manipulation of autonomy-support by providing learners with choice during the practice of a speed cup-stacking skill. One group was given control over when a video demonstration was provided and the viewing speed. A yoked control group received an identical demonstration schedule, but without choice (as their schedule was matched to a participant with choice). Critically, we addressed a gap in the literature by adding a yoked group who was explicitly told that they were being denied choice and that their schedule was chosen by another participant. We found no statistically significant learning differences between groups, despite finding evidence that providing choice increased perceived autonomy. Equivalence tests further showed that although the groups were not statistically equivalent, the effect size is likely too small to practically study the effects of autonomy-support through choice in most motor learning labs. These findings add to a growing body of research that questions a causal role of autonomy-support on motor learning, and the robustness of the so-called self-controlled learning advantage.

Keywords: Motor learning; Pre-registered; Self-controlled; Observation; Equivalence testing

Increased perceptions of autonomy through choice fail to enhance motor skill retention

A popular recommendation in recent years for creating an effective environment for motor skill learning has been to allow the learner to take control over an element of their practice that is traditionally controlled by a coach, therapist, or teacher (Sanli et al., 2013; Ste-Marie et al., 2019). This recommendation is based on the consistent finding that participants in a self-controlled (i.e., choice) group perform with higher proficiency compared to participants in a yoked (i.e., control) group on delayed retention and/or transfer tests. Participants in the yoked group do not experience the same choice opportunity provided to those in the self-controlled group. Instead, they are linked to a self-controlled participant and experience this participant's self-selected practice schedule. This so-called self-controlled learning advantage has been shown when participants are given the opportunity to schedule task difficulty (e.g., Andrieux et al., 2012; Leiker et al., 2016), the order that multiple tasks are practiced (e.g., Wu & Magill, 2011), the frequency of watching a modeled demonstration (e.g. Wulf et al., 2005), and when to receive augmented feedback (e.g., Janelle et al., 1997; Patterson & Carter, 2010).

Over the years, this manipulation has been described using a variety of names (e.g., self- and/or learner-controlled; -regulated; -directed; -selected), but more recently it has been subsumed by autonomy-support. In fact, autonomy-support is considered such a robust learning variable that it is one of three key pillars in the recently proposed "OPTIMAL" theory of motor learning (Wulf & Lewthwaite, 2016). Wulf and Lewthwaite (2016) argued that providing learners with opportunities for choice—considered an autonomy-supportive practice manipulation—can facilitate motor performance and learning by enhancing learner's expectancies for success, and by allowing the learner to maintain their attentional focus on the task by reducing the need for self-regulatory activity (Abdollahipour et al., 2017; Chua et al., 2018; Wulf et al., 2018). In other words, these psychological and attentional benefits,

1 and concomitant increases in performance and learning are a by-product of exercising choice
2 during practice. Overall, autonomy-support is seen as a means to efficient goal-action
3 coupling (Wulf & Lewthwaite, 2016) and also links the “OPTIMAL” theory with
4 Self-Determination theory (Deci & Ryan, 2000).

5 Despite its prominent role within the “OPTIMAL” theory of motor learning, there
6 are numerous reasons to doubt the importance of autonomy-support through the provision of
7 choice during practice. First, if the benefits are the result of having opportunities for choice
8 then learning differences should not emerge between different self-controlled groups.
9 However, in experiments where different groups of participants have choice over their
10 feedback schedule, such learning differences have been found, but not limited to, when this
11 choice is made *after* rather than before a performance attempt (Carter et al., 2014;
12 Chiviacowsky & Wulf, 2005), when different criteria for success are provided to participants
13 (Chiviacowsky et al., 2012), and when the absolute number of feedback choice opportunities
14 are limited compared to unlimited at the outset of practice (Hansen et al., 2011; Patterson et
15 al., 2011). Second, there has been little-to-no support for the notion that practicing in a
16 self-controlled group is perceived as more autonomy-supportive than being in a yoked group.
17 Ste-Marie et al. (2013), for example, had participants in the self-controlled and yoked groups
18 complete the perceived choice subscale of the Intrinsic Motivation Inventory and failed to
19 find the expected effect of higher self-reported scores during practice in the self-controlled
20 group. Similar findings have been reported by others (Barros et al., 2019; Carter &
21 Ste-Marie, 2017b; McKay & Ste-Marie, 2020b). However, McKay and Ste-Marie (2020a)
22 recently found that practicing in a self-controlled group was perceived as more
23 autonomy-supportive than practicing the same task in a yoked group. This increased
24 perceived autonomy-support did not, however, translate into enhanced learning compared to
25 the yoked group. Although the available literature does not provide substantial evidence
26 that self-controlled practice is autonomy-supportive, this does not necessarily mean such a
27 manipulation is not autonomy-supportive (Altman & Bland, 1995). For instance, this effect

1 may in fact be quite small and require much larger sample sizes to detect than those
2 commonly used in motor learning experiments (Lohse et al., 2016).

3 There are at least two other methodological issues that warrant consideration. The
4 first of these is that in self-controlled motor learning experiments participants in the
5 self-controlled group are usually given choice over a single component (e.g., feedback or when
6 to watch a modeled demonstration) of their practice and participants in the yoked group are
7 not given choice over this component. However, within the context of practice itself there are
8 many other opportunities for choice that participants may explore, independent of their
9 assigned group. Target-based tasks such as basketball free throws (e.g., Aiken et al., 2012) or
10 bean-bag tossing (Grand et al., 2015) are a popular choice in motor learning experiments
11 and have been used in self-controlled learning experiments. While a participant in the yoked
12 group may not be permitted choice over their feedback schedule (or some other practice
13 variable) in these experiments, this does not preclude them from opportunities for
14 choice—and thus autonomy-support—when deciding to try different throwing techniques,
15 speeds, and/or release points. Thus, labeling yoked groups as being devoid of choice
16 opportunities may be a misnomer. The other consideration relates to the instructions that
17 are provided to participants in the yoked group. In the context of feedback¹, these
18 participants are typically informed that during practice they may or may not receive
19 feedback after a given trial (e.g., Chiviacowsky & Wulf, 2002; Patterson & Carter, 2010).
20 This means that participants in yoked groups are not even aware that they have been denied
21 an opportunity for choice, nor that their feedback schedule was created by another
22 participant who was given choice over when feedback was or was not provided. Either of
23 these in isolation, or both simultaneously could contribute to the consistent finding that
24 participants in self-controlled and yoked groups report similar perceived autonomy scores

¹ While feedback is used in this example, this issue surrounding instructions is also relevant to other practice variables commonly used in self-controlled learning experiments.

Table 1

Group specific instructions detailing the observation schedule that would be experienced during Acquisition.

Acquisition instructions	
Self-Controlled	Before each trial, you will be asked whether you wish to watch a modeled demonstration of the task. If you choose YES, you will then be asked whether you want to watch the video in real-time or in slow-motion.
Traditional Yoked	Before each trial, you may or may not watch a modeled demonstration of the task based on a pre-determined schedule. If you observe a model, it might be presented in real-time or in slow-motion based on the pre-determined schedule.
Explicit Yoked	Before each trial, you may or may not watch a modeled demonstration of the task based on the schedule another participant selected. If you observe a model, it might be presented in real-time or in slow-motion based on what that participant selected.

when asked about their opportunities for choices with respect to the motor task (Ste-Marie et al., 2013) or about their practice environment in general (Barros et al., 2019; Carter & Ste-Marie, 2017b; McKay & Ste-Marie, 2020b).

Here we investigated the effects of making participants in a yoked group explicitly aware of not only being denied opportunities for choice over their frequency of watching and the playback speed of video demonstrations, but also that the schedule they would experience during practice was created by another participant in the experiment. The addition of this novel yoked group allowed us to address one of the previously identified methodological limitations regarding experimental group instructions in past self-controlled research. We compared the performance of this explicit yoked group with traditional self-controlled and yoked groups on a speed cup-stacking task in practice and in a delayed retention test.

Methods

We report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study (Simmons et al., 2012). The experimental

design and analyses were preregistered using AsPredicted.org and can be viewed here:
<https://aspredicted.org/ze8cj.pdf>.

Participants

One-hundred and fifty participants completed the experiment. Sample size was determined by an a priori power calculation based on our smallest comparison of interest. An early estimate for the effect of self-controlled over yoked practice was a Hedges' $g = 0.63$ (McKay et al., 2014) and while planning this experiment this effect was estimated to be $g = 0.52$ (Z. Yantha, personal communication, October 2019). Based on this effect, a positive correlation of $r = 0.6$ between retention and pre-test as the covariate, and 80% power to detect a difference between the self-controlled and traditional yoked groups, the required number of participants was 31 per group. Considering the novelty of our Explicit Yoked group, we assumed a smaller effect, $g = 0.4$, between it and the Traditional Yoked group. With the same parameters as above, this resulted in our final sample of 50 participants per group.

Participants completed the experiment in either the Self-Controlled group ($M_{age} = 18.0$, $SD = 0.34$), the Traditional Yoked group ($M_{age} = 19.5$, $SD = 1.89$), or the Explicit Yoked group ($M_{age} = 19.2$, $SD = 1.55$). We collected the Self-Controlled group first as their self-selected observation schedule was required for the yoking procedure for the two other groups. Once the Self-Controlled group had been collected, participants were randomly assigned to one of the two Yoked groups. All participants provided written informed consent approved by and conducted in accordance with the University's Research Ethics Board. Participants received either \$15 or a course bonus for their participation.

Material

Participants were tasked with learning the 3-6-3 speed cup stacking sequence based on the rules of the World Sport Stacking Association (<https://www.thewssa.com/>). The

sequence consisted of an upstack phase and a downstack phase using official Speed Stacks cups (<https://www.speedstacks.com/>). Participants performed the task using both their hands and had to complete an upstacking and a downstacking phase. The upstacking phase began by completing the first 3 cup pyramid, followed by the 6 cup pyramid, and then the other 3 cup pyramid. The downstacking phase began by returning to and collapsing the 3 cup pyramid that was upstacked first, then the 6 cup pyramid, and finally the last 3 cup pyramid.

Procedure

Participants completed two data collection sessions separated by approximately 24 hours. Session 1 consisted of a pre-test and an acquisition phase. Session 2 consisted of a delayed retention test. At the start of each phase of the experiment, all participants received phase-specific instructions (see Data and code availability section). Group specific instructions were provided prior to the acquisition phase (see Table 1). The instructions appeared on a 22-inch computer monitor (1920x1080 resolution) positioned to the right of the participant. Participants followed along as the instructions were read aloud by the researcher.

Each trial began with participants standing at a standard height table with their hands on marked positions on the table in front of them. The 12 cups were located in upside down stacks of 3-6-3 in front of the participant. Following a “Get Ready!” prompt displayed for 1 s on the monitor and a constant foreperiod of 1 s, an audiovisual “Go-signal” (green square and a beep tone) was presented. Participants were instructed to start stacking as quickly as possible following the “Go-signal” as its presentation initiated the timer. Once the upstack and downstack phases were completed, participants were instructed to press the spacebar on a keyboard located in front of them to stop the timer. If an error occurred (e.g., only completed the upstack phase then stopped the timer, forgot to hit the timer, etc), the experimenter recorded the trial number for later removal.

1 The pre-test and delayed retention test both consisted of five no-feedback trials. The
2 acquisition phase had 25 trials and was the only phase where the video demonstration could
3 be watched based on group assignment. Participants in the Self-Controlled group could
4 decide at the start of each trial if they wanted to watch the video demonstration. If they
5 chose to watch the video, they were then asked whether they wanted to watch it in real-time
6 or slow motion (35% of real-time). The real-time video was 6 s in duration and the slow
7 motion version was 18 s. To ensure a constant viewing period of 18 s, a blank screen was
8 shown for 12 s following the end of the real-time video. If they chose not to watch the video,
9 a blank screen was shown for 18 s. Participants in the Traditional Yoked and Explicit Yoked
10 groups received the demonstration schedule created by a participant in the Self-Controlled
11 group with the exception that participants in the Explicit Yoked group were made aware
12 that this schedule was created by another participant. Feedback about stacking time (s) was
13 displayed for 2 s after every acquisition trial.

14 To test predictions based on the “OPTIMAL” theory regarding the role of motivation,
15 enhanced expectancies, and autonomy-support, participants completed the
16 interest/enjoyment and perceived competence subscales from the Intrinsic Motivation
17 Inventory (McAuley et al., 1989) and a custom scale regarding choice used in previous
18 self-controlled motor learning experiments (Barros et al., 2019; Carter & Ste-Marie, 2017b).
19 The order of questions from each scale were randomized and each question was rated using a
20 7-point Likert scale. Participants answered these questions after the pre-test, after trials five
21 and 25 of acquisition, and before the delayed retention test.

22 A custom LabVIEW (National Instruments Inc.) program was created that
23 controlled the presentation of all instructions, the video demonstrations, the timing of the
24 experimental protocol, and recorded and stored the data for later analysis.

1 Data analysis

2 Our primary outcome measure was stacking time (i.e., response time) in seconds.
 3 Trials recorded as errors ($76/5250 = 1.45\%$) during data collection were manually removed
 4 prior to data analysis. For each participant, pre-test and delayed retention trials were
 5 aggregated into one block of five trials and acquisition was aggregated into five blocks of five
 6 trials. Significance level was set to 0.05 for all statistical tests. Effect sizes for omnibus tests
 7 are reported using generalized eta squared (η_G^2) or eta squared (η^2). Post hoc comparisons
 8 were conducted using Holm’s correction. A Cook’s distance of ≥ 1 was used to identify any
 9 influential cases.

10 Results

11 Pre-registered analysis

12 To test whether delayed retention (Figure 1C) was differentially impacted by the
 13 experimental group (i.e., Self-Controlled, Traditional Yoked, Explicit Yoked) experienced
 14 during acquisition, we performed a one-way ANCOVA controlling for pre-test. As can be
 15 seen, the Self-Controlled group ($M = 9.99$, $95\%CI = [9.68, 10.31]$), the Traditional Yoked
 16 group ($M = 10.18$, $95\%CI = [9.86, 10.50]$), and the Explicit Yoked group ($M = 10.12$,
 17 $95\%CI = [9.81, 10.44]$) all had similar stacking times in retention (means are shown as the
 18 adjusted means controlling for pre-test). The effect of Group was not significant,
 19 $F(2, 146) = .335$, $p = .716$, $\eta^2 = .002$.

20 Non pre-registered analyses

21 *Traditional self-controlled learning advantage*

22 To investigate whether a traditional self-controlled learning advantage existed—that
 23 is a comparison between the Self-Controlled and Traditional Yoked groups—we analyzed the
 24 non-adjusted retention scores using a Welch’s t -test. The analysis revealed that the
 25 Self-Controlled group ($M = 9.77$, $95\%CI = [9.55, 9.99]$) and the Traditional Yoked group

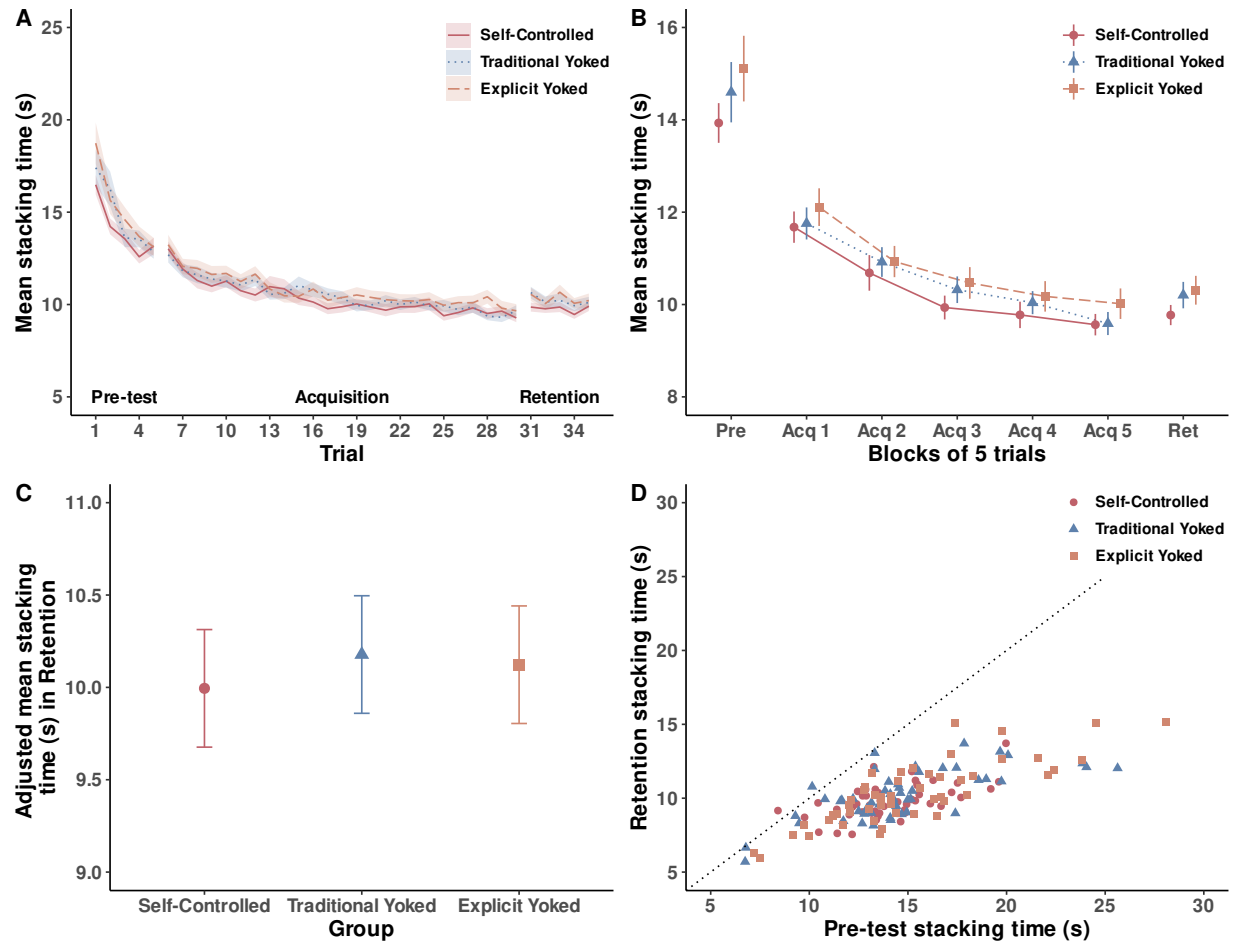


Figure 1

Physical performance data of the experiment. The Self-Controlled group is shown in red with solid lines and/or circles, the Traditional Yoked group is shown in blue with dotted and/or triangles, and the Explicit Yoked group is shown in orange with dashed and/or squares. **A.** Trial-by-trial stacking time (s) data averaged across participants within each group (shaded area represents standard error). Splits between line segments denote the end of one phase and the start of the next. Pre-test (Trials 1 to 5) and Acquisition (Trials 6 to 30) occurred on Day 1 and Retention (Trials 31 to 35) occurred on Day 2, approximately 24-hours later. **B.** Mean stacking time (s) for each group was computed by averaging the data from **A** into 7 blocks of trials. Error bars represent 95% confidence intervals. Splits between line segments denote the end of one phase and the start of the next. **C.** Mean stacking time (s) adjusted for pre-test for each group. Error bars represent 95% confidence intervals. **D.** Scatterplot showing the relationship between each participant's mean stacking time (s) in pre-test and retention.

1 ($M = 10.20$, $95\%CI = [9.92, 10.49]$) were not statistically different, $t(88.10) = 1.45$, $p = .15$,
 2 $g = .29$.

3 *Acquisition phase*

4 Model frequency and the video speed request data are reported in Table 2. The mean
 5 frequency of viewing the video demonstration during acquisition was 16.7%. When a video
 6 demonstration was selected, the mean frequency that the regular speed was selected was
 7 37.3%. Stacking time for each Group decreased across acquisition trials (Figure 1A) and
 8 blocks (Figure 1B). A 3 Group x 5 Block mixed ANOVA with repeated measures on Block
 9 revealed a significant Block effect, $F(3.63, 533.79) = 116.73$, $p < .001$, $\eta_G^2 = .133$. Post hoc
 10 comparisons revealed all acquisition blocks were significantly different from each other. Both
 11 the Group effect, $F(2, 147) = .738$, $p = .48$, $\eta_G^2 = .008$, and Group x Block interaction,
 12 $F(7.26, 533.79) = .543$, $p = .802$, $\eta_G^2 = .001$, were not statistically significant.

13 *Perceived autonomy*

14 Self-reported perceived autonomy scores are displayed in Figure 2A where it can be
 15 seen that the Self-Controlled group reported slightly higher scores compared to the two
 16 Yoked groups at all time points following the pre-test. A 3 Group x 3 Time ANCOVA
 17 controlling for pre-test revealed a significant Group effect, $F(2, 146) = 8.04$, $p < .001$,
 18 $\eta_G^2 = .083$. Post hoc comparisons on the adjusted means revealed that the Self-Controlled
 19 group ($M = 5.61$, $95\%CI = [5.42, 5.80]$) had significantly higher perceptions of autonomy
 20 compared to both the Traditional Yoked group ($M = 5.13$, $95\%CI = [4.94, 5.32]$) and the
 21 Explicit Yoked group ($M = 5.13$, $95\%CI = [4.94, 5.32]$), which did not differ from each other
 22 (and were, in fact, identical to two decimal places). Both the Time effect,
 23 $F(1.61, 234.98) = .867$, $p = .400$, $\eta_G^2 = .001$, and Group x Time interaction,
 24 $F(3.22, 234.98) = 2.10$, $p = .096$, $\eta_G^2 = .005$, were not significant.

Table 2

The mean frequencies for each acquisition block of requesting to watch the video demonstration and choosing the regular viewing speed.

	Block 1	Block 2	Block 3	Block 4	Block 5
Model viewing frequency	32.6%	16.9%	12.0%	12.9%	9.3%
Regular speed frequency	33.8%	38.1%	50.0%	34.4%	30.4%

Intrinsic motivation

Self-reported intrinsic motivation scores can be found in Figure 2B. At each time point, all groups reported similar scores on the interest/enjoyment subscale. A 3 Group x 3 Time ANCOVA controlling for pre-test revealed non-significant effects for Group, $F(2, 146) = 2.08$, $p = .129$, $\eta_G^2 = .024$, Time, $F(1.68, 245.73) = .563$, $p = .541$, $\eta_G^2 = .001$, and the Group x Time interaction, $F(3.37, 245.73) = .333$, $p = .824$, $\eta_G^2 = .001$.

Perceived competence

The scores from the perceived competence subscale at each time point are displayed in Figure 2C. As can be seen, perceived competence scores showed a modest increase over time followed by a slight decrease before the delayed retention test. A 3 Group x 3 Time ANCOVA controlling for pre-test showed an effect of Time, $F(1.75, 255.22) = 10.60$, $p < .001$, $\eta_G^2 = .015$. Post hoc tests on adjusted means revealed that scores were rated as significantly higher at the end of acquisition ($M = 3.98$, $95\%CI = [3.67, 3.89]$) and before retention ($M = 3.78$, $95\%CI = [3.67, 3.89]$) compared to after trial 5 ($M = 3.60$, $95\%CI = [3.49, 3.71]$). However, perceived competence was significantly lower before retention compared to the end of acquisition. No significant effect of Group, $F(2, 146) = 2.65$, $p = .074$, $\eta_G^2 = .028$, or Group x Time interaction, $F(3.50, 255.22) = .549$, $p = .677$, $\eta_G^2 = .002$, was found.

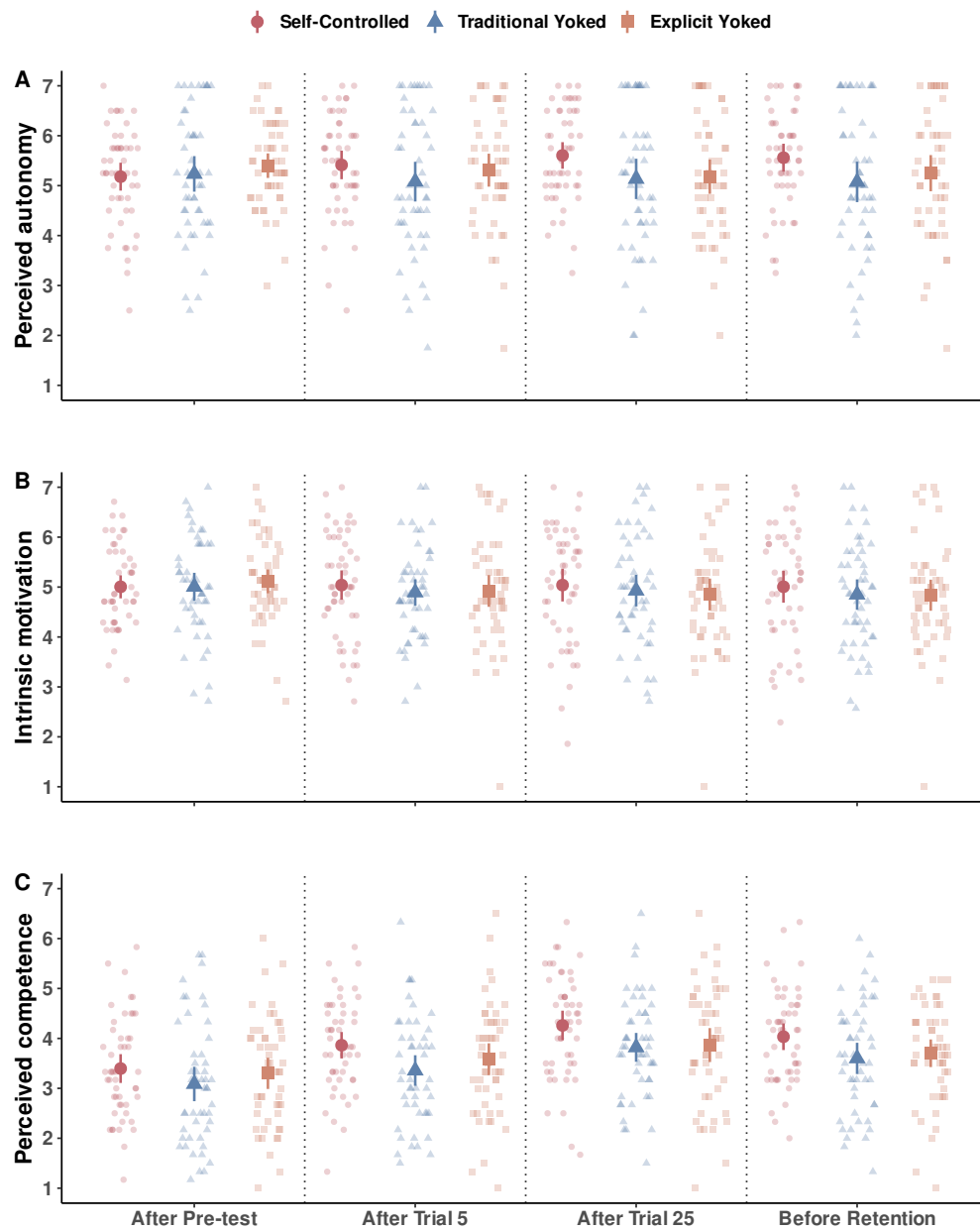


Figure 2

*Questionnaire data. Groups means for **A** perceived autonomy, **B** intrinsic motivation, and **C** perceived competence after pre-test, trial 5, and trial 25 on Day 1, and before retention on Day 2. The Self-Controlled group is shown in red circles, the Traditional Yoked group is shown in blue triangles, and the Explicit Yoked group is shown in orange squares. Dots represent individual participants in each group. Scores could range from 1 (Strongly disagree) to 7 (Strongly agree). Error bars represent 95% confidence intervals.*

Equivalence tests

To further probe our null effects (Harms & Lakens, 2018) related to our main predictions, two equivalence tests (Self-Controlled versus Traditional Yoked and Traditional Yoked versus Explicit Yoked) on pre-test adjusted retention stacking times were carried out using the two one-sided test procedure (Lakens et al., 2018; Schuirmann, 1987). To establish our smallest effect size of interest (Lakens, 2021) we calculated the effect size our design had 33% power to detect (Simonsohn, 2015), which was $d_s = .31$. The Self-Controlled and Traditional Yoked groups were not statistically different, $t(97.99) = -0.830$, $p = 0.409$, and not statistically equivalent, $t(97.99) = 0.720$, $p = 0.237$, given equivalence bounds of $-.355$ and $.355$ (on a raw scale). Similarly, the Traditional Yoked and Explicit Yoked groups were not statistically different, $t(97.99) = 0.262$, $p = 0.794$, and not statistically equivalent, $t(97.99) = -1.288$, $p = 0.100$, given equivalence bounds of $-.355$ and $.355$ (on a raw scale).

Discussion

It has been argued that self-controlled practice conditions are effective for motor learning because they are autonomy-supportive in nature (Wulf & Lewthwaite, 2016). Yet, this claim has received, at best, modest support in the motor learning literature (e.g., McKay & Ste-Marie, 2020a; but see Barros et al., 2019; Carter & Ste-Marie, 2017b; Ste-Marie et al., 2013 for non-support). Here, we addressed a possible methodological limitation for this lack of support. That is, in previous self-controlled motor learning research, participants in the yoked group are not made aware that they have been denied opportunities to exercise choice over a practice variable such as feedback or watching a modeled demonstration. In the present experiment we introduced a novel yoked group that was explicitly told that the observation schedule—frequency and speed of video—they would receive during practice was actually one created by another participant in the experiment. Contrary to our prediction, the Explicit Yoked group did not report significantly lower perceived autonomy scores than the Traditional Yoked group, which was only informed their

1 observation schedule was predetermined. In line with the “OPTIMAL” theory (Wulf &
2 Lewthwaite, 2016), the Self-Controlled group reported significantly higher perceived
3 autonomy-support than both the Traditional and Explicit Yoked groups. However, this
4 boost in perceived autonomy did not lead to enhanced motor performance or learning. These
5 findings from a well-powered experiment are difficult to reconcile with a core pillar of the
6 “OPTIMAL” theory of motor learning.

7 **Self-controlled practice conditions as autonomy-supportive**

8 A common problem with many of the self-controlled or choice motor learning
9 literature claiming autonomy-support as an underlying mechanism for self-controlled
10 learning advantages is a failure to include measures that actually test this claim (e.g.,
11 Chiviacowsky, 2014; Chiviacowsky et al., 2012; Lewthwaite et al., 2015). Instead, this link to
12 autonomy-support is merely assumed based on the provision of choice to one group of
13 participants versus not giving the same choice to another group of participants. As noted
14 earlier, an issue with this assumption is that within the practice environment itself, there are
15 myriad opportunities for participants, independent of group, to exercise choice. In throwing
16 tasks common to motor learning, participants can explore the task workspace by attempting
17 different throwing techniques. In more lab-based tasks that consist of multiple spatial and
18 timing goals (e.g., waveform matching), participants can choose a single goal to focus on and
19 master before shifting their attention to another goal. Commensurate with this idea,
20 Ste-Marie et al. (2013) found no differences in perceived choice regarding the motor task
21 being learned between their self-controlled and yoked groups, despite the self-controlled
22 group showing enhanced retention. This may explain why research has consistently reported
23 perceived autonomy scores that do not differ significantly between self-controlled and yoked
24 groups (Barros et al., 2019; Carter & Ste-Marie, 2017b; McKay & Ste-Marie, 2020b).

25 Another possible explanation for the finding that being in a self-controlled group has
26 not been perceived as more autonomy-supportive than being in a yoked group is that choice

1 is typically provided over a single element of the practice variable, such as the frequency of
2 receiving feedback (e.g., Aiken et al., 2012; Carter & Ste-Marie, 2017a) or the level of task
3 difficulty (Andrieux et al., 2012; Leiker et al., 2016). Control or choice over a single
4 dimension may not be strong enough to elicit a large enough boost in perceived autonomy
5 above and beyond that of being able to explore one’s task workspace as mentioned above.
6 Thus, to increase the saliency of the self-controlled manipulation in the present experiment,
7 we gave the self-controlled participants control over two elements of their observation
8 schedule: viewing frequency and video playback speed. Having control of these two
9 dimensions resulted in higher perceptions of autonomy in our Self-Controlled group
10 compared to the Traditional and Explicit Yoked groups. This may explain the inconsistency
11 with past research failing to find this effect (Barros et al., 2019; Carter & Ste-Marie, 2017b;
12 McKay & Ste-Marie, 2020b; Ste-Marie et al., 2013). However, McKay and Ste-Marie (2020a)
13 recently found that choice over a single element increased perceived autonomy, but similar to
14 our data they also did not find this led to increased learning. Thus, it is unclear whether the
15 higher autonomy scores in the present experiment can in fact be attributed to having control
16 over multiple elements of one’s observation schedule.

17 In a similar vein, past research has also suggested that self-controlled learning benefits
18 are not dependent on the amount of choice opportunities over a single element (Patterson et
19 al., 2011). Given these findings, we argue that the most likely explanation for the
20 inconsistency surrounding the effect of self-controlled practice being autonomy-supportive is
21 that this effect is quite small, and the designs of previous experiments have lacked the
22 statistical power to reliably detect this effect. These experiments have had sample sizes of
23 20 participants or less per group, whereas there were 50 participants in each group in the
24 present experiment and 64 per group (when collapsed across constant and variable practice
25 schedules) in McKay and Ste-Marie (2020a). Collapsing across our two yoked groups, we
26 estimate an effect of autonomy-support of $g = .197$ whereas the estimate from McKay and
27 Ste-Marie (2020a) was $g = .57$. Regardless of the estimated size of the effect for

1 autonomy-support through a self-controlled practice condition, a larger issue and challenge to
2 the “OPTIMAL” theory is that significantly higher perceptions of autonomy did not result in
3 superior performance in either acquisition or delayed retention (Wulf & Lewthwaite, 2016).

4 **No learning advantage from a self-controlled observation schedule**

5 The delayed retention results in the present experiment not only are inconsistent with
6 numerous past experiments reporting a self-controlled motor learning benefit (for a review
7 see Ste-Marie et al., 2019), but also the general consensus that the self-controlled learning
8 advantage is a robust effect (Wulf & Lewthwaite, 2016). Of late, however, there has been an
9 increase in the number of papers reporting a failure to detect the so-called self-controlled
10 learning advantage (e.g., Barros et al., 2019; Grand et al., 2017; McKay & Ste-Marie, 2020a,
11 2020b). This recent lack of support may arise from the self-controlled learning advantage
12 being a much smaller effect than originally estimated ($g = 0.63$ by McKay et al. 2014). A
13 more recent estimate of this effect from a meta-analysis using a weight-function model was
14 $g = .11$, $95\%CI = [.047, .18]$ (McKay et al., 2021). This estimate was further reduced to
15 $g = .054$ after controlling for publication bias using the precision-effect estimate with
16 standard error (PEESE) method. Thus, both models seem to suggest a trivial effect for
17 self-controlled learning. Additional simulations included in the meta-analysis provided
18 plausible effect size estimates ranging from $g = -.11$ to $.26$ (i.e., it could even favour being
19 in the yoked group). In our experiment, the estimated effect size of self-controlled versus
20 yoked (collapsed across our Traditional and Explicit Yoked groups) was $g = 0.22$. While this
21 estimate is larger than those from the weight-function model and PEESE method, it does
22 fall within the range of plausible effect sizes (McKay et al., 2021). When the lack of a
23 self-controlled advantage in previous work and our current experiment are contextualized
24 within the findings of this recent meta-analysis, it is not as surprising that the so-called
25 self-controlled learning benefit was not replicated.

26 Despite the large sample size of the present experiment ($n/\text{group} = 50$) versus the

typical self-controlled motor learning experiment (median $n/\text{group} = 18$ based on the experiments included in the meta-analysis by McKay et al. 2021), the results of the primary analysis and the equivalence tests remain inconclusive. This, along with the effect size estimates in the recent meta-analysis, suggest enormous sample sizes are required to reliably detect an effect of a self-controlled learning advantage. Using the upper bound, $g = .26$, of the range of plausible effects, *253 participants* are required to have 80% power to detect this effect in retention using an independent-samples t -test. The number of participants jumps to *1300 per group*, if for instance the estimate from the weight-function model, $g = .11$, is accurate (McKay et al., 2021). Given the field of motor learning suffers from a lack of adequately powered designs (Lohse et al., 2016) and that underpowered designs are more likely to produce false positives and overestimated effect sizes (Button et al., 2013), we are skeptical of the replicability of the previous overwhelming support for the self-controlled learning advantage.

Lack of support for key predictions of the “OPTIMAL” theory of motor learning

Within the “OPTIMAL” theory (Wulf & Lewthwaite, 2016), it is predicted that practice conditions that promote autonomy-support and enhance expectancies contribute to a virtuous cycle that leads to superior motor performance and learning. In other words, significant group differences between self-controlled and yoked groups would be expected on measures related to these psychological constructs. As mentioned earlier, we found higher perceptions of autonomy-support in our Self-Controlled group relative to the Traditional and Explicit Yoked groups; however, this did not enhance motor learning as predicted within the virtuous cycle. Contrary to the “OPTIMAL” theory, we did not find an effect of group for perceived competence (i.e., enhanced expectancies) or intrinsic motivation. Perceived competence scores did increase across acquisition blocks, which mirrors the improved motor performance seen throughout acquisition. These results are in line with results of a path analysis that suggested self-efficacy (i.e., enhanced expectancies) and intrinsic motivation

were insufficient to explain self-controlled learning benefits (Ste-Marie et al., 2016). Overall, our results are inconsistent with key predictions of the “OPTIMAL” theory regarding autonomy-support and enhanced expectancies, and further question the causal role such manipulations play in motor learning.

In sum, we found that being able to control two aspects of one’s observation schedule during practice was perceived as autonomy-supportive relative to not having this same control opportunity. However, making participants in an Explicit Yoked group aware they would be denied a control opportunity during practice did not decrease perceptions of autonomy relative to participants in the Traditional Yoked group. Furthermore, we did not find evidence that an autonomy-supportive manipulation had any direct causal effect on learning and we also failed to replicate the typical self-controlled learning advantage. It is worth noting that in some situations autonomy-support in and of itself might be a desired affective outcome (Ste-Marie et al., 2020). In such circumstance, providing learners with choice opportunities may be a useful motivationally-protective outcome. However, such a tool should be used judiciously as it is typically motor outcomes in the form of relatively permanent performance changes that is the true goal of any motor learning intervention (Ste-Marie et al., 2020). Ultimately, our results add to a growing body of evidence that questions whether autonomy-supportive manipulations directly affect learning. One explanation for this lack of replicability is that the “*true*” effect of such manipulations are much smaller than previously estimated (McKay et al., 2021). Given the resources required (in terms of sample size) to reliably detect the tiny effects, we encourage motor learning scientists to invest their limited resources carefully—either studying practice conditions that have much bigger effects or devising ways to reduce variability and increase power through clever experimental design (McClelland, 2000).

Conflict of interest

The authors declare no competing interests.

Funding

This work was supported by the Natural Sciences and Engineering Research Council (NSERC) of Canada (RGPIN-2018-05589; MJC). LSG was also supported by an NSERC PGS-D scholarship.

Data and code availability

All material, data, and scripts to reproduce our analyses and figures can be accessed here: https://github.com/cartermaclab/expt_explicit-yoked.

R packages used in this project

R [Version 4.0.5; R Core Team (2021)] and the R-packages *cowplot* [Version 1.1.1; Wilke (2020)], *jmv* [Version 1.2.23; Selker et al. (2020)], *papaja* [Version 0.1.0.9997; Aust and Barth (2020)], *pwr* [Version 1.3.0; Champely (2020)], *tidyverse* [Version 1.3.1; Wickham et al. (2019)], and *TOSTER* [Version 0.3.4; Lakens (2017)].

References

- Abdollahipour, R., Palomo Nieto, M., Psotta, R., & Wulf, G. (2017). External focus of attention and autonomy support have additive benefits for motor performance in children. *Psychology of Sport and Exercise*, 32, 17–24. <https://doi.org/10.1016/j.psychsport.2017.05.004>
- Aiken, C. A., Fairbrother, J. T., & Post, P. G. (2012). The effects of self-controlled video feedback on the learning of the basketball set shot. *Frontiers in Psychology*, 3. <https://doi.org/10.3389/fpsyg.2012.00338>
- Altman, D. G., & Bland, J. M. (1995). Statistics notes: Absence of evidence is not evidence of absence. *BMJ*, 311(7003), 485. <https://doi.org/10.1136/bmj.311.7003.485>
- Andrieux, M., Danna, J., & Thon, B. (2012). Self-control of task difficulty during training enhances motor learning of a complex coincidence-anticipation task. *Research Quarterly for Exercise and Sport*, 83(1), 27–35. <https://doi.org/10.1080/02701367.2012.10599822>
- Aust, F., & Barth, M. (2020). *papaja: Create APA manuscripts with R Markdown*. <https://github.com/crsh/papaja>
- Barros, J. A. C., Yantha, Z. D., Carter, M. J., Hussien, J., & Ste-Marie, D. M. (2019). Examining the impact of error estimation on the effects of self-controlled feedback. *Human Movement Science*, 63, 182–198. <https://doi.org/10.1016/j.humov.2018.12.002>
- Button, K. S., Ioannidis, J. P. A., Mokrysz, C., Nosek, B. A., Flint, J., Robinson, E. S. J., & Munafò, M. R. (2013). Power failure: why small sample size undermines the reliability of neuroscience. *Nature Reviews Neuroscience*, 14(5), 365–376. <https://doi.org/10.1038/nrn3475>

- 1 Carter, M. J., Carlsen, A. N., & Ste-Marie, D. M. (2014). Self-controlled feedback is effective
2 if it is based on the learner's performance: A replication and extension of chiviawowsky
3 and wulf (2005). *Frontiers in Psychology*, 5. <https://doi.org/10.3389/fpsyg.2014.01325>
- 4 Carter, M. J., & Ste-Marie, D. M. (2017a). An interpolated activity during the
5 knowledge-of-results delay interval eliminates the learning advantages of self-controlled
6 feedback schedules. *Psychological Research*, 81(2), 399–406.
7 <https://doi.org/10.1007/s00426-016-0757-2>
- 8 Carter, M. J., & Ste-Marie, D. M. (2017b). Not all choices are created equal: Task-relevant
9 choices enhance motor learning compared to task-irrelevant choices. *Psychonomic*
10 *Bulletin & Review*, 24(6), 1879–1888. <https://doi.org/10.3758/s13423-017-1250-7>
- 11 Champely, S. (2020). *Pwr: Basic functions for power analysis*.
12 <https://CRAN.R-project.org/package=pwr>
- 13 Chiviawowsky, S. (2014). Self-controlled practice: Autonomy protects perceptions of
14 competence and enhances motor learning. *Psychology of Sport and Exercise*, 15(5),
15 505–510. <https://doi.org/10.1016/j.psychsport.2014.05.003>
- 16 Chiviawowsky, S., & Wulf, G. (2005). Self-controlled feedback is effective if it is based on the
17 learner's performance. *Research Quarterly for Exercise and Sport*, 76(1), 42–48.
18 <https://doi.org/10.1080/02701367.2005.10599260>
- 19 Chiviawowsky, S., & Wulf, G. (2002). Self-controlled feedback: Does it enhance learning
20 because performers get feedback when they need it? *Research Quarterly for Exercise and*
21 *Sport*, 73(4), 408–415. <https://doi.org/10.1080/02701367.2002.10609040>
- 22 Chiviawowsky, S., Wulf, G., & Lewthwaite, R. (2012). Self-controlled learning: The
23 importance of protecting perceptions of competence. *Frontiers in Psychology*, 3.
24 <https://doi.org/10.3389/fpsyg.2012.00458>

1 Chua, L.-K., Wulf, G., & Lewthwaite, R. (2018). Onward and upward: Optimizing motor
2 performance. *Human Movement Science*, 60, 107–114.

3 <https://doi.org/10.1016/j.humov.2018.05.006>

4 Deci, E. L., & Ryan, R. M. (2000). The "what" and "why" of goal pursuits: Human needs
5 and the self-determination of behavior. *Psychological Inquiry*, 11(4), 227–268.

6 https://doi.org/10.1207/S15327965PLI1104_01

7 Grand, K. F., Bruzi, A. T., Dyke, F. B., Godwin, M. M., Leiker, A. M., Thompson, A. G.,
8 Buchanan, T. L., & Miller, M. W. (2015). Why self-controlled feedback enhances motor
9 learning: Answers from electroencephalography and indices of motivation. *Human*

10 *Movement Science*, 43, 23–32. <https://doi.org/10.1016/j.humov.2015.06.013>

11 Grand, K. F., Daou, M., Lohse, K. R., & Miller, M. W. (2017). Investigating the Mechanisms
12 Underlying the Effects of an Incidental Choice on Motor Learning. *Journal of Motor*

13 *Learning and Development*, 5(2), 207–226. <https://doi.org/10.1123/jmld.2016-0041>

14 Hansen, S., Pfeiffer, J., & Patterson, J. T. (2011). Self-control of feedback during motor
15 learning: Accounting for the absolute amount of feedback using a yoked group with
16 self-control over feedback. *Journal of Motor Behavior*, 43(2), 113–119.

17 <https://doi.org/10.1080/00222895.2010.548421>

18 Harms, C., & Lakens, D. (2018). Making 'null effects' informative: Statistical techniques and
19 inferential frameworks. *Journal of Clinical and Translational Research*.

20 <https://doi.org/10.18053/jctres.03.2017S2.007>

21 Janelle, C. M., Barba, D. A., Frehlich, S. G., Tennant, L. K., & Cauraugh, J. H. (1997).

22 Maximizing performance feedback effectiveness through videotape replay and a

23 self-controlled learning environment. *Research Quarterly for Exercise and Sport*, 68(4),

24 269–279. <https://doi.org/10.1080/02701367.1997.10608008>

- 1 Lakens, D. (2021). *Sample size justification*. <https://doi.org/10.31234/osf.io/9d3yf>
- 2 Lakens, D. (2017). Equivalence tests: A practical primer for t-tests, correlations, and
3 meta-analyses. *Social Psychological and Personality Science*, 1, 1–8.
4 <https://doi.org/10.1177/1948550617697177>
- 5 Lakens, D., Scheel, A. M., & Isager, P. M. (2018). Equivalence Testing for Psychological
6 Research: A Tutorial. *Advances in Methods and Practices in Psychological Science*, 1(2),
7 259–269. <https://doi.org/10.1177/2515245918770963>
- 8 Leiker, A. M., Bruzi, A. T., Miller, M. W., Nelson, M., Wegman, R., & Lohse, K. R. (2016).
9 The effects of autonomous difficulty selection on engagement, motivation, and learning in
10 a motion-controlled video game task. *Human Movement Science*, 49, 326–335.
11 <https://doi.org/10.1016/j.humov.2016.08.005>
- 12 Lewthwaite, R., Chiviacowsky, S., Drews, R., & Wulf, G. (2015). Choose to move: The
13 motivational impact of autonomy support on motor learning. *Psychonomic Bulletin &*
14 *Review*, 22(5), 1383–1388. <https://doi.org/10.3758/s13423-015-0814-7>
- 15 Lohse, K., Buchanan, T., & Miller, M. (2016). Underpowered and Overworked: Problems
16 With Data Analysis in Motor Learning Studies. *Journal of Motor Learning and*
17 *Development*, 4(1), 37–58. <https://doi.org/10.1123/jmld.2015-0010>
- 18 McAuley, E., Duncan, T., & Tammen, V. V. (1989). Psychometric properties of the intrinsic
19 motivation inventory in a competitive sport setting: A confirmatory factor analysis.
20 *Research Quarterly for Exercise and Sport*, 60(1), 48–58.
21 <https://doi.org/10.1080/02701367.1989.10607413>
- 22 McClelland, G. H. (2000). Increasing statistical power without increasing sample size.
23 *American Psychologist*, 55(8), 963–964.
24 <https://doi.org/https://psycnet.apa.org/doi/10.1037/0003-066X.55.8.963>

- 1 McKay, B., Carter, M. J., & Ste-Marie, D. M. (2014). Self-controlled learning: A
2 meta-analysis. *Journal of Sport & Exercise Psychology*, 36, S43.
- 3 McKay, B., & Ste-Marie, D. M. (2020a). Autonomy support via instructionally irrelevant
4 choice not beneficial for motor performance or learning. *Research Quarterly for Exercise*
5 *and Sport*, 0(0), 1–13. <https://doi.org/10.1080/02701367.2020.1795056>
- 6 McKay, B., & Ste-Marie, D. M. (2020b). Autonomy support and reduced feedback frequency
7 have trivial effects on learning and performance of a golf putting task. *Human Movement*
8 *Science*, 71(1026124). <https://doi.org/10.1016/j.humov.2020.102612>
- 9 McKay, B., Yantha, Z. D., Hussien, J., Carter, M. J., & Ste-Marie, D. M. (2021).
10 *Meta-analytic findings in the self-controlled motor learning literature: Underpowered,*
11 *biased, and lacking evidential value.* <https://doi.org/10.31234/osf.io/8d3nb>
- 12 Patterson, J. T., & Carter, M. (2010). Learner regulated knowledge of results during the
13 acquisition of multiple timing goals. *Human Movement Science*, 29(2), 214–227.
14 <https://doi.org/10.1016/j.humov.2009.12.003>
- 15 Patterson, J. T., Carter, M., & Sanli, E. (2011). Decreasing the proportion of self-control
16 trials during the acquisition period does not compromise the learning advantages in a
17 self-controlled context. *Research Quarterly for Exercise and Sport*, 82(4), 624–633.
18 <https://doi.org/10.1080/02701367.2011.10599799>
- 19 R Core Team. (2021). *R: A language and environment for statistical computing.* R
20 Foundation for Statistical Computing. <https://www.R-project.org/>
- 21 Sanli, E. A., Patterson, J. T., Bray, S. R., & Lee, T. D. (2013). Understanding
22 self-controlled motor learning protocols through the self-determination theory. *Frontiers*
23 *in Psychology*, 3. <https://doi.org/10.3389/fpsyg.2012.00611>

- 1 Schuirmann, D. J. (1987). A comparison of the Two One-Sided Tests Procedure and the
2 Power Approach for assessing the equivalence of average bioavailability. *Journal of*
3 *Pharmacokinetics and Biopharmaceutics*, 15(6), 657–680.
4 <https://doi.org/10.1007/BF01068419>
- 5 Selker, R., Love, J., & Dropmann, D. (2020). *Jmv: The 'jamovi' analyses*.
6 <https://CRAN.R-project.org/package=jmv>
- 7 Simmons, J. P., Nelson, L. D., & Simonsohn, U. (2012). *A 21 Word Solution*.
8 <https://doi.org/10.2139/ssrn.2160588>
- 9 Simonsohn, U. (2015). Small Telescopes: Detectability and the Evaluation of Replication
10 Results. *Psychological Science*, 26(5), 559–569.
11 <https://doi.org/10.1177/0956797614567341>
- 12 Ste-Marie, D. M., Carter, M. J., Law, B., Vertes, K., & Smith, V. (2016). Self-controlled
13 learning benefits: Exploring contributions of self-efficacy and intrinsic motivation via
14 path analysis. *Journal of Sports Sciences*, 34(17), 1650–1656.
15 <https://doi.org/10.1080/02640414.2015.1130236>
- 16 Ste-Marie, D. M., Carter, M. J., & Yantha, Z. D. (2019). *Self-controlled learning: Current*
17 *findings, theoretical perspectives, and future directions* (3rd ed.). Routledge.
- 18 Ste-Marie, D. M., Lelievre, N., & Germain, L. S. (2020). Revisiting the applied model for
19 the use of observation: A review of articles spanning 20112018. *Research Quarterly for*
20 *Exercise and Sport*, 91(4), 594–617. <https://doi.org/10.1080/02701367.2019.1693489>
- 21 Ste-Marie, D. M., Vertes, K. A., Law, B., & Rymal, A. M. (2013). Learner-controlled
22 self-observation is advantageous for motor skill acquisition. *Frontiers in Psychology*, 3.
23 <https://doi.org/10.3389/fpsyg.2012.00556>

- Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L. D., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T. L., Miller, E., Bache, S. M., Müller, K., Ooms, J., Robinson, D., Seidel, D. P., Spinu, V., . . . Yutani, H. (2019). Welcome to the tidyverse. *Journal of Open Source Software*, 4(43), 1686. <https://doi.org/10.21105/joss.01686>
- Wilke, C. O. (2020). *Cowplot: Streamlined plot theme and plot annotations for 'ggplot2'*. <https://CRAN.R-project.org/package=cowplot>
- Wu, W. F. W., & Magill, R. A. (2011). Allowing learners to choose. *Research Quarterly for Exercise and Sport*, 82(3), 449–457. <https://doi.org/10.1080/02701367.2011.10599777>
- Wulf, G., & Lewthwaite, R. (2016). Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. *Psychonomic Bulletin & Review*, 23(5), 1382–1414. <https://doi.org/10.3758/s13423-015-0999-9>
- Wulf, G., Lewthwaite, R., Cardozo, P., & Chiviacowsky, S. (2018). Triple play: Additive contributions of enhanced expectancies, autonomy support, and external attentional focus to motor learning. *Quarterly Journal of Experimental Psychology*, 71(4), 824–831. <https://doi.org/10.1080/17470218.2016.1276204>
- Wulf, G., Raupach, M., & Pfeiffer, F. (2005). Self-controlled observational practice enhances learning. *Research Quarterly for Exercise and Sport*, 76(1), 107–111. <https://doi.org/10.1080/02701367.2005.10599266>