Journal of Motor Behavior, Vol. 50, No. 3, 2018

RESEARCH ARTICLE

Lassoing Skill Through Learner Choice

Gabriele Wulf[1], Takehiro Iwatsuki[1], Brittney Machin[1], Jessica Kellogg[1], Clint Copeland[1], Rebecca Lewthwaite[2,3]

[1]Department of Kinesiology and Nutrition Sciences, University of Nevada, Las Vegas. [2]Rancho Los Amigos National Rehabilitation Center, Downey, California. [3]Division of Biokinesiology and Physical Therapy, University of Southern California, Los Angeles.

ABSTRACT. The authors examined several issues related to the motor learning benefits resulting from giving learners choices. In 2 experiments, participants practiced a novel task, throwing a lasso. In Experiment 1, giving learners a choice ostensibly irrelevant to performance (color of mat under target) resulted in enhanced learning relative to a control group. The choice group also reported more positive affect. Experiment 2 compared the effectiveness of task-irrelevant (mat color) versus task-relevant (video demonstrations of the skill) choices. In both choice groups, each participant was yoked to a participant in the other group, and each received the same mat color or saw the video demonstration, respectively, as chosen by their counterpart in the other group. In the control group, participants were yoked to their respective counterparts in each of the choice groups. On a retention test, the 2 choice groups did not differ from each other, but both outperformed the control group. The affective and learning effects seen when learners are given choices, and the fact that task-relevant and task-irrelevant choices resulted in similar learning benefits, are consistent with a content-neutral mechanism for the effects of choice on learning, as described in the OPTIMAL theory of motor learning (Wulf & Lewthwaite, 2016).

Keywords: autonomy support, motivation, self-control

Over the past 20 years, many studies have shown that the learning of motor skills is enhanced when learners are given control over aspects of their practice conditions (for a review, see Wulf & Lewthwaite, 2016). Since the first demonstration that learner- or self-controlled feedback benefited learning (Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Janelle, Kim, & Singer, 1995), other studies have confirmed those findings (e.g., Chiviacowsky & Wulf, 2002; Patterson & Carter, 2010). In addition, the effects of self-control have been shown to generalize to different tasks and variables controlled by the learner. Whether it is the use of assistive devices (e.g., Chiviacowsky, Wulf, Lewthwaite, & Campos, 2012; Hartman, 2007; Wulf & Toole, 1999), amount of practice (Post, Fairbrother, & Barros, 2011), movement demonstrations (e.g., Wulf, Raupach, & Pfeiffer, 2005), task difficulty (Andrieux, Danna, & Thon, 2012), task order (Wulf & Adams, 2014), or other factors, learning is typically enhanced when learners are given the opportunity to make decisions with respect to these factors compared with yoked control participants (for reviews, see Sanli, Patterson, Bray, & Lee, 2013; Wulf, 2007).

Recently, this line of research has been broadened further by demonstrations that the factors controlled by learners need not be task-relevant. In a recent meta-analysis of the effects of choice on intrinsic motivation and related behavior, Patall, Cooper, and Robinson (2008) compared the effects of instructionally relevant choices to those deemed instructionally irrelevant. Instructionally irrelevant choices were found to have stronger effects on intrinsic motivation and behavior, including task performance, than did those choices more integral to the task. In several studies in the motor domain, learning was enhanced when participants were given choices with respect to variables that were incidental to the task (Lewthwaite, Chiviacowsky, Drews, & Wulf, 2015; Wulf, Chiviacowsky, & Cardozo, 2014). For instance, even though the color of a ball to be thrown would arguably not influence throwing accuracy, letting performers choose the ball color resulted in more effective learning of a novel throwing task than did a prescribed ball color (yoked control condition) (Wulf et al., 2014). In another study by Lewthwaite et al. (Experiment 1), choice of golf ball color enhanced the learning of a putting task. Perhaps even more interesting, choices ostensibly unrelated to the task have been shown to facilitate learning. In one study (Lewthwaite et al., 2015, Experiment 2), learners who were given two incidental choices (i.e., which task to perform after practice of the primary task; which of two pictures the experimenter should hang in the lab) learned a balance task more effectively than did control participants who were simply informed of the next task and picture to be hung in the lab.

How can these results be explained? The notions of self-controlled practice, autonomy support, or choice have been approached from several distinct conceptual or theoretical perspectives, often accompanied by assumptions that limit further testing. In the self-controlled practice literature within motor learning, for example, assumptions until recently have assigned informational or strategic value to the superiority of learner-controlled (*self-controlled* in this literature) over yoked group participants (e.g., Patterson & Lee, 2010). In this literature, the typical contrast is between groups of learners with and without control over some task-integral aspect of their practice. Not surprisingly, discussion has centered on what informational value had been derived from that learner control. A much larger theoretical and empirical line of research around self-determination theory has developed in social psychology over the last number of decades (see Deci & Ryan, 2000, 2008; Ryan &

Correspondence address: Gabriele Wulf, Department of Kinesiology and Nutrition Sciences, University of Nevada, Las Vegas, 4505 Maryland Pkwy, Las Vegas, NV 89154-3034. e-mail: gabriele.wulf@unlv.edu

Deci, 2000). Within this perspective, the value of a learner's choice lies in its potential to satisfy the fundamental psychological need for autonomy or self-determination. Not surprisingly in a theory centered on fulfillment of organismic needs, choice under the self-determination rubric was philosophically assumed to involve meaningful forms, and the impact of "trivial" or incidental choices was, therefore, not formally explored. In yet another stream of research involving choice, behavioral and neural evidence suggests that small and incidental choices may suffice for benefit (e.g., Cordova & Lepper, 1996; Leotti & Delgado, 2011; Patall et al., 2008; Tafarodi, Milne, & Smith, 1999). In fact, rather than the content or execution of the choice per se, it appears that it is the opportunity for an impending choice that may be most critical. In particular, the fact that incidental choice can positively affect learning is consistent with the notion that choice per se is intrinsically rewarding (Leotti & Delgado, 2011; Murayama, Izuma, Aoki, & Matsomoto, 2017), such that anticipation of choice activates reward-related neural circuitry (Leotti, Cho, & Delgado, 2015; Leotti & Delgado, 2011; Murty, DuBrow, & Davachi, 2015); this circuitry is associated with dopaminergic response. When dopamine is paired with task experience, memory is enhanced (Kawashima et al., 2012; Murty et al., 2015). For example, the opportunity to choose which of two occluding screens to remove for object viewing activated striatal (reward) circuitry before the screen choice and affected memory for eventually presented objects compared with no choice over screen removal (Murty et al., 2015). Behavioral findings consistent with these enhancements have been reported in other contexts. For example, naming the characters in a computer game benefited learning of arithmetic tasks (Cordova & Lepper, 1996), or choosing the names to be used in a short story facilitated reading comprehension (Tafarodi et al., 1999). Patall et al. (2008) suggested that incidental choices, or those that do not appear to have direct relevance to task performance may be experienced as meaningful ways for performers to express their personal preferences or individuality. However, small choices may also signal that further choice (and control) is likely.

Enhanced motivation to learn (Chiviacowsky et al., 2012) and an increase in positive affective reactions (Hooyman, Wulf, & Lewthwaite, 2014; Reeve & Tseng, 2011) under autonomy-supportive relative to control conditions are presumably a reflection of the rewarding nature of having control. Learner autonomy is considered a key variable in the OPTIMAL theory of motor learning, and one route to enhancing expectations of positive experience (Wulf & Lewthwaite, 2016).

The purpose of the present experiments was threefold. First, we deemed it important to provide further evidence for the impact of incidental choices on motor skill learning. Given that self-controlled practice benefits for learning have frequently been interpreted from an information-processing perspective (e.g., Carter, Carlson, & Ste-Marie, 2014; Carter & Ste-Marie, 2016), with limited regard for rewarding-motivational explanations, further experimental evidence for learning enhancements through choices not directly related to the task seemed desirable (Experiments 1 and 2). Second, none of the previous studies in which learners were provided incidental choices (Lewthwaite et al., 2015; Wulf et al., 2014) assessed learners' affective reactions to the practice conditions. Positive affective responses are anticipated when the situation is perceived as rewarding or positive (Wulf & Lewthwaite, 2016). In Experiment 1, we therefore measured affect as a function of (incidental) choice or no choice. Third, we wanted to examine whether task-relevant and task-irrelevant choices would differ in their effectiveness for learning. If learning advantages of self-controlled practice conditions are conveyed through valuable informational content, task-relevant choices may be more effective than task-irrelevant choices. Alternatively, if the main function of choice is to signal that one will have some control over future experiences or outcomes—arguably a more generally promising circumstance than uncertainty or clear lack of control (Leotti, Iyvengar, & Ochsner, 2010)—the type of choice should matter less than the opportunity for choice. Thus, in Experiment 2, we included choices relevant or not relevant to task performance.

Experiment 1

Evidence that task-irrelevant choices can enhance motor skill learning is still relatively limited (Lewthwaite et al., 2015; Wulf et al., 2014). Thus, we considered it important to replicate the previously seen effects with a different task and incidental choice, as such a finding would provide additional support for the motivational (rewarding) nature of the effects of choice on learning. Furthermore, practice conditions that support learners' need for autonomy or signal reward versus those that do not seem to differ in terms of performers' affective reactions. This has been shown, for example, in studies examining autonomy-supportive versus controlling instructional language (Hooyman et al., 2014; Reeve & Tseng, 2011). Hooyman et al. found that learning of a cricket bowling action was enhanced with autonomy-supportive instructions (e.g., "You may want to cradle and deliver the ball in a windmill fashion so the ball travels over the shoulder and not to an angle or to the side.") compared with controlling instructions (e.g., "You must cradle the ball so it travels in a circular pattern. At the apex of the pitch the ball must be directly over the shoulder. Do not throw it at a side angle."). Autonomy-supportive language that gives performers a sense of choice has been found to increase emotional engagement (Reeve & Tseng, 2011) or positive affect (Hooyman et al., 2014) compared with controlling language. The latter may be more than a pleasant side effect of having choices. Positive affect may be a cause, effect, or marker of dopamine release. Dopamine responses temporally linked to practice attempts may facilitate performance (Wulf & Lewthwaite, 2016), and dopamine-dependent long-term potentiation presumably contributes to memory consolidation (for a review, see Wise, 2004) and perhaps to the motor learning benefits seen when learners have choices. Differences in positive affect between groups with an incidental choice versus no choice might shed further light on the role of choice and its underlying mechanisms for motor learning. We used the Self-Assessment Manikin (SAM; Bradley & Lang, 1994) to determine positive affect (or "pleasure") as a function of practice conditions.

The motor task participants were asked to learn, throwing a lasso over a cone, was relatively challenging as it required the acquisition of a new, complex coordination pattern. Briefly, it involves swinging the noose around the wrist over the head, with a speed that is sufficient to create a "wheel" and that allows the performer to guide the noose. The proper timing for making the cast is important: As the noose comes around from back to front, the hand moves forward and downward, with the palm facing down, while the arm extends to full length. Releasing the rope in a fluid motion at the right time is critical for lassoing the target. In Experiment 1, one group (choice) was provided the opportunity to choose the color of a mat placed under the target (cone), while participants in another group were yoked to the mat color choices of their counterparts in the choice group. Learning was measured by a retention test one day later.

Method

Participants

Thirty-two undergraduate students (22 men, 10 women) between 18 and 40 years old participated in this experiment. Participants were not aware of the purpose of the study. They had no or little prior experience with the experimental task. All participants gave their informed consent. The study was approved by the university's institutional review board.

Apparatus and Task

Participants were asked to throw a lasso over an orange plastic cone (height: 28″) that was located at a distance of 10 feet from a line behind which the participant stood. A 22 × 28″ mat was placed under the cone. The color of the mat (blue, green, or pink) varied during the practice phase (see Procedure), but was white during the pretest and retention test. Scores for throwing accuracy were awarded as follows: If the lasso was thrown over the cone, 2 points were awarded. If it only touched the cone, 1 point was given. No points were given for complete misses.

Procedure

Participants were randomly assigned to either the choice or control group. In both groups, participants were first shown a 2 min 16 s video demonstration of how to throw a lasso (https://www.youtube.com/watch?v=8TVvBAUQrBA). They then performed a five-trial pretest. During the pretest, a white mat was placed under the cone. Subsequently, participants completed a 15-trial practice phase. Choice group participants were informed that they would be able to choose the color of the mat under the cone before each block of three trials. Control group participants were told that the experimenter might change the mat under the cone before a three-trial block. Each participant in that group was yoked to one participant in the choice group, and the mat color was based on what his or her counterpart had chosen on the respective block. One day later, learning was assessed by a retention test consisting of 10 trials from the same distance. During the retention test, the white mat was put under the cone for all participants. The Self-Assessment Manikin (Bradley & Lang, 1994) was used to assess participants' affective state. The scale consisted of nine faces with different degrees of smiling, neutral, and frowning expressions (from left to right). Numbers were placed under each face and equidistant between faces, resulting in a 9-point rating scale. Before the pretest, at the end of practice, and before the retention test, participants were asked to indicate which number best reflected their current mood, with lower numbers representing more positive affect.

Data Analysis

The pretest scores were averaged across all five trials and analyzed in a univariate analysis of variance (ANOVA). For the practice phase, scores were averaged across three trials (with the same mat color) and analyzed in a 2 Group × 5 Block ANOVA with repeated measures on the last factor. The retention data were averaged across five trials and analyzed in 2 Group × 2 Block ANOVA, with the pretest score used as covariate. Affect was analyzed in separate ANOVAs for each phase of the experiment (before pretest, after practice, before retention). Pretest scores were included as covariates in the latter two analyses. Finally, we conducted linear regression analyses to determine whether affect at the end of practice or before the retention test predicted learning (i.e., retention test performance).

Results

Throwing Accuracy

Scores on the pretest were similar for both groups (see Figure 1, left). The main effect of group was not significant, $F(1, 30) < 1$. Throughout the practice phase, the choice

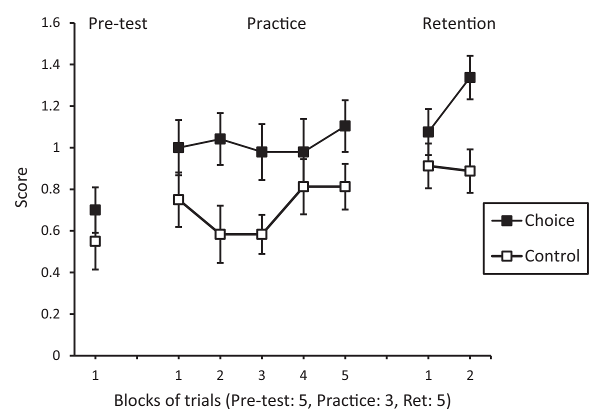

FIGURE 1. Lasso-throwing accuracy in Experiment 1 (higher scores reflect greater accuracy). Error bars indicate standard errors.

group outperformed the control group (Figure 1, middle). The main effect of group, $F(1, 30) = 6.00$, $p < .05$, $\eta_p^2 = .17$, was significant. The main effect of block and the interaction of group and block were not significant, Fs(4, 120) < 1. On the retention test one day later, the choice group demonstrated higher scores than did the control group (Figure 1, right). The group effect was significant, $F(1, 29) = 5.72$, $p < .05$, $\eta_p^2 = .17$. The main effect of block was not significant, $F(1, 29) < 1$. The interaction of group and block was significant, $F(1, 29) = 4.26$, $p < .05$, $\eta_p^2 = .13$. Follow-up analyses indicated that the choice group increased their scores from block 1 to block 2 ($p = .033$), whereas the control group showed no change across blocks ($p = .852$).

Affect

There were no significant differences between groups before the pretest, $F(1, 30) < 1$. Both groups reported relatively positive affect (see Figure 2), with a score of 5 representing neutral affect. At the end of the practice phase, the choice group (1.81) showed more positive affect relative to the control group (3.00). The Group effect was significant, $F(1, 29) = 4.36$, $p < .05$, $\eta_p^2 = .13$. One day later immediately before the retention test, the choice group again reported more positive affect than did the control group (Figure 2, right). The effect of group was significant, $F(1, 29) = 5.75$, $p < .05$, $\eta_p^2 = .17$.

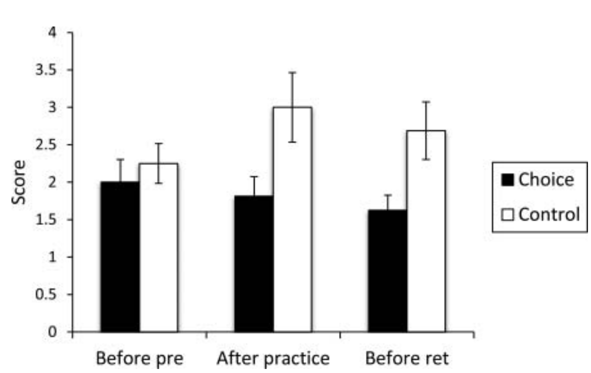

FIGURE 2. Ratings of affect on a scale from 1 to 9 in Experiment 1 (lower scores indicate more positive affect). Error bars indicate standard errors.

Regression Analyses

Affect, assessed at the end of the practice phase, predicted performance on the retention test, $F(1, 30) = 9.75$, $p < .01$, $r = .50$, explaining 25% of the variance. Affect before the retention test was not a significant predictor of retention performance, $F(1, 30) < 1$.

Discussion

One minor incidental choice (i.e., color of mat under the target), offered five times throughout the practice phase, led to more effective learning of the novel lasso-throwing task than did not having this choice. This finding confirms recent results (Lewthwaite et al., 2015; Wulf et al., 2014) and provides further evidence for the notion that the rewarding circumstance of having some control or autonomy in one's learning conditions may explain the benefits of learner- or self-controlled practice (for a meta-analysis, see McKay, Carter, & Ste-Marie, 2014). The relationship between the degree of positive affect following the practice phase and subsequent retention-test performance may potentially index the impact of dopamine response on motor learning and memory processes. The timing of our second affect assessment, after the practice phase, however, did not allow determination of whether the affective consequence was due to choice per se (see Leotti et al., 2010) or the relative task performance success experienced by the choice group, as that performance was also affected by choice condition.

While Experiment 1 provided evidence that task-irrelevant choices can be sufficient to enhance motor skill learning, we wanted to directly compare the effectiveness of task-irrelevant and task-relevant choices in a second experiment. If, as we suspected, the primary reason for the learning benefits of practice conditions that provide learners with a sense of choice is that they support their autonomy (i.e., enhance motivation), task-irrelevant and task-relevant choices should yield similar learning benefits. In contrast, if choices that are directly relevant to task performance (e.g., allowing learners to choose feedback, skill demonstrations, assistive devices, or task difficulty) impact learning by enhancing information processing, one would expect practice conditions that involve a task-relevant choice to result in more effective learning than those with task-irrelevant choices.

Experiment 2

In the second experiment, we compared the influence of task-irrelevant and task-relevant choices on learning. The task-irrelevant choice was the same as the one used in Experiment 1 (mat color). In the task-relevant choice condition, learners were able to view additional video demonstrations of the novel skill during practice. Learner-controlled demonstrations have previously been shown to enhance learning relative to yoked conditions (Aiken, Fairbrother, & Post 2012; Wulf et al., 2005). This effect has been attributed to the opportunity to extract more, or more relevant, information from the demonstration when learners are able to request it. For instance, in contrast to yoked control participants, learners who can choose when to watch a demonstration may pay more attention to certain aspects of the movement pattern, in an attempt to identify opportunities to improve their performance. However, enhanced information processing under learner-controlled relative to yoked practice conditions might simply be the result of increased intrinsic motivation associated with autonomy support (Grand et al., 2015), rather than being the source of the learning differences. Thus, from a motivational perspective one would not necessarily expect to see differences in learning as a function of the type of choice (Wulf & Lewthwaite, 2016). The purpose of the present experiment was to elucidate this issue by comparing the effectiveness for learning of task-irrelevant and task-relevant choices, relative to no choice.

Method

Participants

Forty-two undergraduate students (22 women, 20 men) with an average age of 22.86 years ($SD = 4.35$ years) participated in this experiment. All participants gave their informed consent. They were not aware of the exact study purpose and had no or little experience with the lassoing task. The study was approved by the university's institutional review board.

Apparatus, Task, and Procedure

The apparatus and task were similar to those used in Experiment 1. However, the video demonstration of the skill was shortened to 60 s (https://www.youtube.com/watch?v=M3caOqN5ejg). All participants were first shown the demonstration and subsequently completed a five-trial pretest, with a white mat under the cone. They then performed 18 practice trials under one of three different conditions. Choice-mat group participants (task-irrelevant choice) were able to select the color of a mat (blue, green, or pink) to be placed under the cone before each block of three trials, as described in Experiment 1. The choice-video group (task-relevant choice) was able to view the 60-s video demonstration at their request before each three-trial block. Importantly, participants in the choice-mat group were yoked to those in the choice-video group and were provided with video demonstrations before the same trials that were chosen by their counterparts. Similarly, choice-video group participants were yoked to participants in the choice-mat group in terms of the mat color that was used on the respective practice blocks. Finally, in a control group without choice, participants were yoked to participants in each of the other two groups and were provided with the mat color and video demonstrations that were chosen by their counterparts. The only necessary exception to this yoking procedure involved the first (choice-mat) participant who, by virtue of having no counterpart, was provided with two video demonstrations that were chosen by the experimenter (before Trials 7 and 13). The average number of times choice-video participants chose to view the demonstration was 1.3. Two days after the practice phase, participants performed a retention test consisting of 10 trials. As in Experiment 1, a white mat was put under the cone during this test.

Data Analysis

The pretest scores were averaged across all 5 trials and analyzed in a univariate ANOVA. For the practice phase, scores were averaged across six trials and analyzed in a 3 Group $\times$ 3 Block ANOVA with repeated measures on the last factor. The retention data were averaged across five trials and analyzed in a 3 Group $\times$ 2 Block ANOVA, with the pretest score used as covariate.

Results

Throwing accuracy scores on the pretest were similar for all groups (see Figure 3). The main effect of group was not significant, $F(2, 39) < 1$. There was a general increase in accuracy across the practice phase. The main effect of

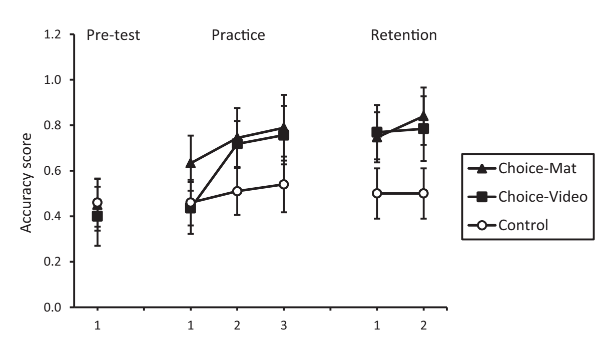

FIGURE 3. Lasso-throwing accuracy in Experiment 2 (higher scores reflect greater accuracy). Error bars indicate standard errors.

block was significant, $F(2, 78) = 4.27$, $p < .05$, $\eta_p^2 = .10$. While the two choice groups tended to show a greater improvement across practice relative to the control group, the main effect of group, $F(2, 39) = 1.34$, $p > .05$, and interaction of group and block, $F(4, 78) < 1$, were not significant. On the retention test, the choice-mat and choice-video groups demonstrated higher throwing accuracy than did the control group. The group effect was significant, $F(2, 38) = 4.22$, $p < .05$, $\eta_p^2 = .18$. Post hoc tests, with Bonferroni adjustments for multiple comparisons, indicated that the choice-mat and choice-video groups did not differ from each other ($p = 1.0$), but both had significantly higher scores than the control group did (ps $< .05$). The main effect of block, $F(1, 38) < 1$, and the interaction of group and block, $F(2, 38) < 1$, were not significant.

Discussion

The type of choice learners were provided—relevant to the task (video demonstration) or incidental (mat color)—did not differentially affect the learning of the skill. Both choice conditions showed similar learning benefits relative to the no-choice control condition. Even though all three conditions were essentially identical in terms of the mat colors used on given practice blocks as well as the number and timing of video demonstrations provided, learners who were given a choice demonstrated more effective skill learning than those without a choice (control group). This pattern of results is in line with views that choice is intrinsically rewarding and its anticipation potentially beneficial to learning. The notion that choice is rewarding is not inconsistent with the perspective that satisfaction of performers' need for autonomy would be rewarding (Murayama et al., 2017), although it would appear that many forms of choice can convey this benefit. At least in this instance, putatively task-relevant and task-irrelevant choices did not differ in their learning advantages, consistent with the perspective that it may not be the extraction of insights or strategy that fueled the effects.

General Discussion

Both experiments provided consistent evidence that the beneficial effect of choice—incidental or task-related—in the context of motor learning may be primarily motivational, rather than informational in nature. In Experiment 1, a choice incidental to the task (color of mat under target) resulted in superior learning relative to a yoked control condition. This learning advantage is arguably not accounted for through enhanced information processing or valuable provision of task-related information due to the execution of the task-relevant choice. In Experiment 2, this effect was replicated. Moreover, we found that a task-relevant choice (video demonstration of the skill) yielded very similar benefits as the task-irrelevant choice. Thus, both experiments provide converging evidence that (small) choices are sufficient to enhance learning.

Whether task-relevant information might provide additional benefit to learning is not at issue. Indeed, we presume that there are many exemplars of value-added informational effects, such as an external focus of attention conveyed through instructions or postresponse feedback (e.g., Wulf, 2013). Rather, findings from the incidental-choice line of inquiry (e.g., Lewthwaite et al., 2015; Wulf et al., 2014) suggest that the source of learner-controlled benefits is not related to the content of the choice per se but to the opportunity for choice and its consequences provided close to performance (Wulf & Lewthwaite, 2016). The task-relevant versus task-irrelevant comparison deserves further investigation with other tasks and other demonstrably important forms of task-relevant choices, as well as other representations of autonomy support (e.g., instructional language).

An important question is: What are the underlying mechanisms through which being able to choose influences learning? Choice, or merely the anticipation of choice, seems to be inherently rewarding (Fujiwara et al., 2013; Leotti & Delgado, 2011, 2014). Choice has been shown to be associated with increased activity of brain regions directly involved in reward processing (Fujiwara et al., 2013; Leotti & Delgado, 2011, 2014), and temporally earlier than the execution of choice or the values of choices could be experienced. Rewards, including intrinsic rewards, can trigger dopaminergic responses (Hosp & Luft, 2013; Leotti et al., 2010; Schultz, 2013) and support memory consolidation processes (Abe et al., 2011; Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabrieli, 2006; Sugawara, Tanaka, Okazaki, Watanabe, & Sadato, 2012; Wise, 2004). Further, conditions that offer a sense of heightened control can enhance a sense of agency, performance expectations, and affective reward (Aarts, Custers, & Marien, 2009; Leotti et al., 2015; Leotti et al., 2010).

Clearly, more directly examining the effects of learner choice in terms of the anticipation or expectation of the reward that is to follow, and its potential intrinsic neuromodulation of motor performance and learning must involve indices of neural activation and timing. Aside from measures of learning, future studies might use measures of affect, including intrinsic motivation (e.g., interest, enjoyment, engagement, satisfaction) to examine the rewarding nature of choices offered. Furthermore, opportunities for choice or agency intriguingly appear to enhance expectations for positive experience and outcomes, including self-efficacy (Hooyman et al., 2014; Lemos, Wulf, Lewthwaite, & Chiviacowsky, 2017; Murayama et al., 2017; Wulf & Lewthwaite, 2016) even when they do not directly target the provision of evidence for performance accomplishments. Further efforts to integrate or distinguish the effects of anticipating the intrinsic reward of choice (or more generally, autonomy support) or the enhancement of expectancies for the intrinsic reward of performance improvement (competence) may be warranted. Regardless, offering choice, particularly when it need not be consequential, or when the extent of learners' skills and insights are unknown, appears to be a useful approach or adjunct strategy for teachers and coaches to make the most of motor learning opportunities for individuals seeking to acquire motor skills.

REFERENCES

Aarts, H., Custers, R., & Marien, H. (2009). Priming and authorship ascription: When nonconscious goals turn into conscious experiences of self-agency. *Journal of Personality and Social Psychology*, *96*, 967–979.

Abe, M., Schambra, H., Wassermann, E. M., Luckenbaugh, D., Schweighofer, N., & Cohen, L. G. (2011). Reward improves long-term retention of a motor memory through induction of offline memory gains. *Current Biology*, *21*, 557–562. https://doi.org/10.1016/j.cub.2011.02.030.

Adcock, R. A., Thangavel, A., Whitfield-Gabrieli, S., Knutson, B., & Gabrieli, J. D. E. (2006). Reward-motivated learning: Mesolimbic activation precedes memory formation. *Neuron*, *50*, 507–517.

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*, Article 338. https://doi.org/10.3389/fpsyg.2012.00338.

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*, 27–35.

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: The self-assessment manikinand the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry*, *25*, 49–59.

Carter, M. J., Carlson, A. N., & Ste-Marie, D. M. (2014). Self-controlled feedback is effective if it is based on the learner's performance: A replication and extension of Chiviacowsky and Wulf (2005). *Frontiers in Psychology*, *5*, Article 1325. https://doi.org/10.3389/fpsyg.2014.01325.

Carter, M. J., & Ste-Marie, D. M. (2016). An interpolated activity during the knowledge-of-results interval eliminates the learning advantages of self-controlled feedback schedules. *Psychological Research*, *81*, 399–406. https://doi.org/10.1007/s00426-016-0757-2.

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

Chiviacowsky, S., Wulf, G., Lewthwaite, R., & Campos, T. (2012). Motor learning benefits of self-controlled practice in persons with Parkinson's disease. *Gait & Posture*, *35*, 601–605.

Cordova, D. I., & Lepper, M. R. (1996). Intrinsic motivation and the process of learning: Beneficial effects of contextualization, personalization, and choice. *Journal of Educational Psychology*, *88*, 715–730.

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

Deci, E. L., & Ryan, R. M. (2008). Self-determination theory: A macrotheory of human motivation, development, and health. *Canadian Psychology*, *49*, 182–185.

Fujiwara, J., Usui, N., Park, S. Q., Williams, T., Iijima, T., Taira, M., . . . Tobler, P. N. (2013). Value of freedom to choose encoded by the human brain. *Journal of Neurophysiology*, *110*, 1915–1929.

Grand, K. F., Bruzi, A. T., Dyke, F. B., Godwin, M. M., Leiker, A. M., Thompson, A. G., . . . Miller, M. W. (2015). Why self-controlled feedback enhances motor learning: Answers from electroencephalography and indices of motivation. *Human Movement Science*, *43*, 23–32.

Hartman, J. M. (2007). Self-controlled use of a perceived physical assistance device during a balancing task. *Perceptual and Motor Skills*, *104*, 1005–1016.

Hooyman, A., Wulf, G., & Lewthwaite, R. (2014). Impacts of autonomy-supportive versus controlling instructional language on motor learning. *Human Movement Science*, *36*, 190–198.

Hosp, J. A., & Luft, A. R. (2013). Dopaminergic meso-cortical projections to M1: Role in motor learning and motor cortex plasticity. *Frontiers in Neurology*, *4*, Article 145. https://doi.org/10.3389/fneur.2013.00145.

Janelle, C. M., Barba, D. A., Frehlich, S. G., Tennant, L. K., & Cauraugh, J. H. (1997). Maximizing performance effectiveness through videotape replay and a self-controlled learning environment. *Research Quarterly for Exercise and Sport*, *68*, 269–279.

Janelle, C. M., Kim, J., & Singer, R. N. (1995). Subject-controlled performance feedback and learning of a closed motor skill. *Perceptual and Motor Skills*, *81*, 627–634.

Kawashima, S., Ueki, Y., Kato, T., Matsukawa, N., Mima, T., Hallett, M., . . . Ojika, K. (2012). Changes in striatal dopamine release associated with human motor-skill acquisition. *PLoS One*, *7*, e31728. https://doi.org/10.1371/journal.pone.0031728.

Lemos, A., Wulf, G., Lewthwaite, R., & Chiviacowsky, S. (2017). Autonomy support enhances performance expectancies, positive affect, and motor learning. *Psychology of Sport and Exercise*, *31*, 28–34.

Leotti, L. A., Cho, C., & Delgado, M. R. (2015). The neural basis underlying the experience of control in the human brain. In P. Haggard & B. Eitam (Eds.), *The sense of agency* (pp. 145–176). Oxford, UK: Oxford University Press.

Leotti, L. A., & Delgado, M. R. (2011). The inherent reward of choice. *Psychological Science*, *22*, 1310–1308.

Leotti, L. A., & Delgado, M. R. (2014). The value of exercising control over monetary gains and losses. *Psychological Science*, *25*, 596–604.

Leotti, L. A., Iyvengar, S. S., & Ochsner, K. N. (2010). Born to choose: The origins and value of the need for control. *Trends in Cognitive Science*, *14*, 457–463.

Lewthwaite, R., Chiviacowsky, S., Drews, R., & Wulf, G. (2015). Choose to move: The motivational impact of autonomy support on motor learning. *Psychonomic Bulletin & Review*, *22*, 1383–1388.

McKay, B., Carter, M. J., & Ste-Marie, D. (2014). Self-controlled learning: A meta-analysis. *Journal of Sport & Exercise Psychology*, *36*(Supplement), S43.

Murty, V. P., DuBrow, S., & Davachi, L. (2015). The simple act of choosing influences declarative memory. *Journal of Neuroscience*, *35*, 6255–6264.

Murayama, K., Izuma, K., Aoki, R., & Matsuyama, K. (2017). "Your choice" motivates you in the brain: The emergence of autonomy neuroscience. In J. Reeve, S. Kim, & M. Bong (Eds.), *Advances in motivation and achievement: Recent developments in neuroscience research on motivation* (Vol. *19*, pp. 95–125). Bingley, UK: Emerald Group.

Patall, E. A., Cooper, H., & Robinson, J. C. (2008). The effects of choice on intrinsic motivation and related outcomes: A meta-analysis of research findings. *Psychological Bulletin*, *134*, 270–300.

Patterson, J. T., & Carter, M. (2010). Learner regulated knowledge of results during the acquisition of multiple timing goals. *Human Movement Science*, *29*, 214–227.

Patterson, J. T., & Lee, T. D. (2010). Self-regulated frequency of augmented information in skill learning. *Canadian Journal of Experimental Psychology*, *63*, 33–40.

Post, P. G., Fairbrother, J. T., & Barros, J. A. C. (2011). Self-controlled amount of practice benefits learning of a motor skill. *Research Quarterly of Exercise and Sport*, *82*, 474–481.

Reeve, J., & Tseng, C. M. (2011). Cortisol reactivity to a teacher's motivating style: The biology of being controlled versus supporting autonomy. *Motivation and Emotion*, *35*, 63–74.

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist*, *55*, 68–78.

Sanli, E. A., Patterson, J. T., Bray, S. R., & Lee, T. D. (2013). Understanding self-controlled motor learning protocols through self-determination theory. *Frontiers in Psychology*, *3*, Article 611. https://doi.org/10.3389/fpsyg.2012.00611.

Schultz, W. (2013). Updating dopamine reward signals. *Current Opinion in Neurobiology*, *23*, 229–238.

Sugawara, S. K., Tanaka, S., Okazaki, S., Watanabe, K., & Sadato, N. (2012). Social rewards enhance offline improvements in motor skill. *PLoS One*, *7*, e48174. https://doi.org/10.1371/journal/pone.0048174.

Tafarodi, R. W., Milne, A. B., & Smith, A. J. (1999). The confidence of choice: Evidence for an augmentation effect on self-perceived performance. *Personality and Social Psychology Bulletin*, *25*, 1405–1416.

Wise, R. A. (2004). Dopamine, learning and motivation. *Nature Reviews Neuroscience*, *5*, 1–12.

Wulf, G. (2007). Self-controlled practice enhances motor learning: Implications for physiotherapy. *Physiotherapy*, *93*, 96–101.

Wulf, G. (2013). Attentional focus and motor learning: A review of 15 years. *International Review of Sport and Exercise Psychology*, *6*, 77–104.

Wulf, G., & Adams, N. (2014). Small choices can enhance balance learning. *Human Movement Science*, *38*, 235–240.

Wulf, G., Chiviacowsky, S., & Cardozo, P. (2014). Additive benefits of autonomy support and enhanced expectancies for motor learning. *Human Movement Science*, *37*, 12–20.

Wulf, G., & Lewthwaite, R. (2016). Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. *Psychonomic Bulletin & Review*, *23*, 1382–1414. https://doi.org/10.3758/s13423-015-0999-9.

Wulf, G., Raupach, M., & Pfeiffer, F. (2005). Self-controlled observational practice enhances learning. *Research Quarterly for Exercise and Sport*, *76*, 107–111.

Wulf, G., & Toole, T. (1999). Physical assistance devices in complex motor skill learning: Benefits of a self-controlled practice schedule. *Research Quarterly for Exercise and Sport*, *70*, 265–272.

Received July 11, 2016
Revised March 3, 2017
Accepted April 4, 2017