Human Movement Science 45 (2016) 63–70

Contents lists available at ScienceDirect

Human Movement Science

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

Judgments of learning are significantly higher following feedback on relatively good versus relatively poor trials despite no actual learning differences

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ARTICLE INFO

Article history:
Received 26 June 2015
Revised 30 October 2015
Accepted 14 November 2015
Available online 19 November 2015

Keywords:
Skill acquisition
Motor learning
Knowledge of results
Metacognition

ABSTRACT

Studies have consistently shown that prospective metacognitive judgments of learning are often inaccurate because humans mistakenly interpret current performance levels as valid indices of learning. These metacognitive discrepancies are strongly related to conditions of practice. Here, we examined how the type of feedback (after good versus poor trials) received during practice and awareness (aware versus unaware) of this manipulation affected judgments of learning and actual learning. After each six-trial block, participants received feedback on their three best trials or three worst trials and half of the participants were made explicitly aware of the type of feedback they received while the other half were unaware. Judgments of learning were made at the end of each six-trial block and before the 24-h retention test. Results indicated no motor performance differences between groups in practice or retention; however, receiving feedback on relatively good compared to relatively poor trials resulted in significantly higher judgments of learning in practice and retention, irrespective of awareness. These results suggest that KR on relatively good versus relatively poor trials can have dissociable effects on judgments of learning in the absence of actual learning differences, even when participants are made aware of their feedback manipulation.

1. Introduction

In motor learning, knowledge of results (KR) refers to movement outcome information regarding the success of a motor response relative to a task goal that can be provided from an external source such as a coach, therapist, or teacher (Salmoni, Schmidt, & Walter, 1984; Schmidt & Lee, 2011). To date, much of the motor learning research concerned with the provision of KR has been theoretically driven by the guidance hypothesis (Salmoni et al., 1984). In a seminal review and reappraisal of the KR literature, Salmoni et al. (1984) acknowledged secondary motivational and associational functions of KR, but placed greater emphasis on the importance of the informational role of KR. The authors proposed that KR provided information to guide the performer to the goal response by resolving any discrepancies between the performer's intended movement and the actual movement outcome.

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http://dx.doi.org/10.1016/j.humov.2015.11.006
0167-9457/

More recently however, the guidance hypothesis has been criticized for overemphasizing the informational properties of KR at the expense of its motivational influences on motor learning (e.g., Chiviacowsky & Wulf, 2007; see Wulf, Shea, & Lewthwaite, 2010 for a review). For example, Chiviacowsky and Wulf (2007) investigated the effectiveness of providing KR about either the three best (i.e., "good") or the three worst (i.e., "poor") trials in a six trial block while participants learned to throw a beanbag toward a target without vision using their non-preferred hand. It was found that providing KR about relatively "good" rather than relatively "poor" trials was more advantageous for learning as measured by motor performance on a next-day retention test. The authors interpreted this finding to be incongruent with the guidance function (i.e., informational) of KR on the grounds that it would be expected that KR provided after larger errors (or poor trials) would be more beneficial for learning than KR after smaller errors (or good trials).[1] Instead, Chiviacowsky and Wulf (2007) proposed that KR after good, rather than poor trials, may have created a motivational success experience for the learners, which in turn enhanced the learning process. From this perspective, the motivational properties of KR might have a more direct and lasting influence on memory and learning than the indirect and transient effect originally proposed by Salmoni et al. (1984).

In recent years a number of experiments have replicated the motor learning benefits of providing KR on relatively good versus relatively poor trials with researchers associating KR after good trials with motivational factors such as increased self-confidence (Badami, VaezMousavi, Wulf, & Namazizadeh, 2012) and increased self-efficacy (Saemi, Porter, Ghotbi-Varzaneh, Zarghami, & Maleki, 2012). Moreover, researchers have also queried participants on whether the feedback they received during practice (i.e., after their 3 best or 3 worst trials) facilitated their motivation to learn the task with some researchers finding higher motivation for KR after good trials (Badami, VaezMousavi, Wulf, & Namazizadeh, 2011) while others have reported no differences (Patterson & Azizieh, 2012). The conclusions of Badami et al. (2011), in which they attributed the learning advantages of KR on relatively good trials to increased intrinsic motivation must be interpreted with caution because the authors did not report any behavioral data regarding motor performance and learning based on the KR manipulation. Thus, these higher levels of motivation may have only been a transient performance effect of the KR they received rather than having a relatively permanent effect on learning. In addition, only one out of the three subscales of the Intrinsic Motivation Inventory (McAuley, Duncan, & Tammen, 1989) that were used was found to be significantly different between the KR groups. Specifically, perceived confidence was found to be different between the groups but interest/enjoyment and effort/importance were not. As a result, it would be more accurate to conclude that KR on relatively good trials affected *perceived confidence* rather than intrinsic motivation per se.

In the KR on relatively good versus relatively poor trials literature, Patterson and Azizieh (2012) noted that participants have always been unaware that the KR they received was based on a relative performance distinction within a block of six trials. As a result, Patterson and Azizieh (2012) investigated whether the learning advantages of KR on relatively good rather than relatively poor trials would persist if participants were made aware that their KR reflected either their three best or three worst trials. Thus, four groups were created using a factorial combination of awareness (aware or unaware) and KR content (good or poor trials). It was found that being aware of the type of KR received throughout practice resulted in superior learning, independent of whether the KR reflected relatively good or relatively poor trials. No differences, however, were found between the groups who were unaware of their KR content, thus failing to replicate the results of others (e.g., Chiviacowsky & Wulf, 2007; Chiviacowsky, Wulf, Wally, & Borges, 2009). Based on these findings, the authors suggested that being aware may have provided the learners with a more meaningful referent to modulate future responses which optimized the learning process.

In the present experiment we examined whether the content of one's KR schedule (relatively good or relatively poor trials) and awareness (aware or unaware) of this manipulation would differentially impact motor performance and learning, as well as prospective metacognitive judgments. An important and widely used metacognitive index is the judgment of learning (Soderstrom & Bjork, 2015). A judgment of learning requires a participant to predict their ability to execute a task at a future time assuming they received no more practice. In other words, a judgment of learning is a subjective assessment of one's current level of learning. Research in both the motor learning and verbal learning literature has consistently revealed dissociations between judgments of learning and objective indices of learning as participants have a propensity to view immediate, yet potentially transient performance levels as valid indices of learning (see Jacoby, Bjork, & Kelley, 1994; Soderstrom & Bjork, 2015; Son & Simon, 2012 for respective reviews). For example, Simon and Bjork (2001) had participants practice three different 5-digit key pressing sequences with either a blocked (i.e., fixed-order) or random (i.e., interleaved) repetition schedule and examined how the order of practice repetitions influenced judgments of learning and actual motor learning as measured using a delayed 24-h retention test. Participants made a judgment of learning after each practice block (six in total) and one prior to the 24-h retention test. The results revealed that the participants who experienced a blocked schedule had more accurate performance during practice and also reported significantly higher judgments of learning than the participants that experienced a random schedule. When participants returned the following day and were asked to predict their upcoming retention performance for each key pressing sequence, the blocked schedule participants continued to

[1] In their seminal paper, Salmoni et al., 1984 did not state that based on their proposed informational role of KR that it would be more beneficial for learning after larger errors (i.e., poor trials) compared to smaller errors (i.e., good trials). Instead, they proposed that the informational role of KR was to guide the learner toward the correct response as KR provides information about response outcome which can be used to generate a new and more accurate response on future trials (p. 380). Therefore, error information based on response outcome is always present independent of whether KR is provided after relatively poor or relatively good trials. Based on this misinterpretation of the guidance hypothesis, the conclusions made in the KR after relatively good versus relatively poor trials literature have overemphasized their motivational role of KR while ignoring that the informational role is still present.

make significantly higher judgments of learning compared to the random schedule participants. However, a reversal in performance accuracy on the tasks was found in retention, with the random schedule participants performing with significantly less error than the blocked schedule participants. Interestingly, a strong mismatch or "illusion of competency" (Jacoby et al., 1994) was evident in the blocked schedule participants whose actual performance error was approximately double their predicted error (i.e., judgment of learning). The results of Simon and Bjork (2001) clearly demonstrate that participants, and to their disadvantage, use ease of practice performance as a heuristic for predicting future performance (see also Simon & Bjork, 2002). More recently, Abushanab and Bishara (2013) extended the findings of Simon and Bjork (2001, 2002) to experienced pianists (total formal music training of 10.6 ± 3.9 years) who were required to learn different piano melodies in both blocked-order and random-order conditions. The authors found that even experienced pianists fell victim to the artificially inflating performance effects of blocked-order practice relative to random-order practice. In other words, the judgments of learning data indicated a misbelief that this blocked practice would be more optimal for motor skill retention when in fact random practice was significantly more effective for long-term learning.

The metacognition and motor learning literature to date has demonstrated that although performance levels during practice are typically an imperfect metric to judge future performance on (i.e., learning), both novice and experienced performers fail to recognize the dissociation between performance and learning (see Kantak & Winstein, 2012; Schmidt & Bjork, 1992 for reviews on the learning-performance distinction). This raises the question of whether the information provided by one's KR schedule during practice leads to similar misconceptions of learning as that found in the contextual-interference literature (e.g., Abushanab & Bishara, 2013; Simon & Bjork, 2001, 2002). It is conceivable that a summary KR schedule that only reflects the three best or three worst trials in a six trial block could lead participants to incorrectly interpret this transient performance feedback as a valid indication of how well they are learning a task. Some support for this hypothesis exists as Badami et al. (2011) reported significantly higher perceived confidence on a golf putting task in participants that received KR on relatively good trials compared to those that received KR on relatively poor trials. Similarly, the self-controlled feedback literature has typically revealed that participants request KR after the trials they thought were good (e.g., Chiviacowsky & Wulf, 2002; Patterson & Carter, 2010) and Laughlin et al. (2015) recently reported that some participants explicitly request KR for motivational purposes when provided control. Thus participants engage in deliberate feedback request strategies which suggest that participants must engage in some sort of subjective performance evaluation when deciding to request feedback (e.g., Carter, Carlsen, & Ste-Marie, 2014). Based on knowledge, it is possible that differential effects on judgments of learning may emerge as a function of KR content, independent of actual motor learning. The purpose of the present experiment was to investigate how KR on relatively good versus relatively poor trials and being aware or unaware of this affects both prospective metacognitive judgments as well as motor learning. We hypothesized that KR on relatively good trials would lead to higher judgments of learning than KR on relatively poor trials; however, we anticipated that making participants aware of the type of KR they would receive throughout practice would mitigate any misconceptions of actual learning and result in more accurate judgments.

2. Methods

2.1. Participants

Forty adults (M_{age} = 22.72, SD = 1.65; F = 22, M = 18) volunteered to participate in the experiment. All participants provided informed consent and had no previous experience with the task. The experiment was approved and conducted in accordance with the ethical guidelines set by the Health Sciences and Science Research Ethics Board at the University of Ottawa.

2.2. Task and apparatus

The task involved participants performing an overhand toss with mini Koosh-balls (6.5 cm in diameter) at a circular target on the floor using their non-dominant arm (Oldfield, 1971) while wearing blacked out goggles that occluded vision. The target consisted of 10 concentric rings with the center (i.e., bullseye) of the target located 5.5 m away from where the participants completed their tosses. The innermost ring had a radius of 10 cm and each subsequent outer ring had a radius that was 10 cm more than its preceding ring (up to 100 cm). Each ring had a corresponding point value with a bullseye being awarded 100 points and each ring decreased in value by 10 points when moving outward from the bullseye. Any toss that did not land in one of the rings was awarded a score of zero.

2.3. Procedure

Participants were randomly assigned to one of four equal-sized groups (n = 10): KR-Good-Aware, KR-Poor-Aware, KR-Good-Unaware, or KR-Poor-Unaware. Participants were tested individually and were instructed that the goal of the task was to earn the highest possible score on each toss by having the mini Koosh-ball land in the bullseye. All groups were informed that at the end of each six trial block they would receive KR on their performance for three of the six trials. The KR-Good-Unaware received KR on their three best tosses, while the KR-Poor-Unaware received KR on their three worst tosses, but were not told why KR was provided for the three trials. The KR-Good-Aware and the KR-Poor-Aware groups were provided KR in the same manner, but were also informed at the start of practice that they would receive KR for their three best trials and their three worst trials, respectively.

At the start of each six trial block, participants were permitted to view the target to help them align themselves in their preferred position relative to the target. Once aligned and ready, the participant put on the blacked out goggles and a researcher placed the six mini Koosh-balls in their dominant hand. Once instructed that the six trial block started, the participant would transfer one mini-Koosh ball at a time from their dominant to their non-dominant hand and toss the mini-Koosh ball at the target. This process was repeated until all six mini Koosh-balls were tossed. Prior to KR delivery, the researcher would remove three of the six mini-Koosh balls according to the participant's experimental group. Following this, the participant was told to remove the goggles in order to receive visual KR, which lasted for 5 s. The KR consisted of seeing the exact landing spot of the three mini Koosh-balls as well as being told the point value for each toss. Similar to Patterson and Azizieh (2012), when KR was provided to the KR-Good-Aware and the KR-Poor-Aware groups the researcher prefaced the KR presentation by stating "these are your three best (or worst) trials".

After each six trial block during practice, participants were asked to make a judgment about how well they would perform the task at a later date. Similar to Simon and Bjork (2001, 2002), the exact question that all participants were asked was: "If practice ended right now and you received no more practice trials, how many points on average do you think you would earn if you were tested tomorrow? However, on this test, feedback regarding your tosses will not be provided". The judgment of learning was completed by having participants place a mini Koosh-ball in the ring that corresponded to the average number of points they thought they would earn. The practice phase consisted of 60 trials (10 blocks of six trials). All participants returned approximately 24 h after their practice phase to complete a delayed retention test consisting of two blocks of six trials without KR. Before each retention block, participants were asked to make a judgment of learning that represented how well they thought they would do on average in the upcoming block. The exact procedures for the participant to complete their judgment of learning were identical to the method used during practice on Day one.

2.4. Dependent measures and statistical analyses

In contrast to previous experiments using two-dimensional target tossing tasks that assessed performance and learning using a points system (e.g., Chiviacowsky & Wulf, 2007; Wulf, Chiviacowsky, & Drews, 2015), we computed two-dimensional error scores for each trial in practice and retention according to the procedures outlined by Hancock, Butler, and Fischman (1995). Specifically, we used mean radial error as our measure of throwing accuracy and bivariate variable error[2] as our measure of throwing variability (Hancock et al., 1995). The use of two-dimensional error scores to assess motor performance and learning on target tossing tasks as that used in the present experiment have not only been advocated in the past (e.g., Hancock et al., 1995; Reeve, Fischman, Christina, & Cauraugh, 1994), but was also the focus of a recent commentary on the continual use of inappropriate dependent measures (i.e., one-dimensional scores for two-dimensional tasks) in motor learning experiments (Fischman, 2015). Lastly, judgment of learning scores were computed using the same procedures as mean radial error.[3]

Mean radial error and judgments of learning for the practice phase were analyzed in separate 2 (KR type: Good, Poor) × 2 (Awareness: Aware, Unaware) × 10 (Block) mixed-model analyses of variance (ANOVA) with repeated measures on Block. For the retention test, mean radial error and judgments of learning were analyzed in separate 2 (KR type) × 2 (Awareness) × 2 (Block) mixed-model ANOVAs with repeated measures on Block. As a manipulation check, mean radial error for KR and no-KR trials during practice were analyzed in a 2 (KR type) × 2 (Trial type: KR, no-KR) × 10 (Block) mixed-model ANOVA with repeated measures on the last two factors to determine whether error on KR trials were actually significantly lower for the KR-Good groups relative to the KR-Poor groups. An alpha level of ⩽.05 was set for all analyses. Post-hoc tests were conducted using Tukey's HSD and effect sizes are reported as partial eta squared (η_p^2). In cases where sphericity was violated, Greenhouse–Geisser adjusted *p* values are reported.

3. Results

3.1. Practice

3.1.1. Mean radial error

All groups increased their accuracy across the practice blocks (see Fig. 1A, left side) which was supported by a significant main effect of Block ($F_{[9,\ 324]} = 15.294$, $p < .001$, $\eta_p^2 = .298$). All other comparisons failed to reach statistical significance (p values > .05).

[2] All analyses with bivariate variable error failed to reach significance in practice or retention and therefore, are not presented in the results section.

[3] Although participants were asked to place the ball based on the points system for their judgments of learning, we needed to assess the judgments of learning and performance in a similar manner to allow meaningful interpretations. Moreover, it is important that motor learning researchers use the appropriate 2-dimensional error scores to measure performance in 2-dimensional tasks, which is why we opted to use radial error for both performance and judgments of learning. We did record points for the judgments of learning as well and the analysis leads to the same conclusions as the analysis with radial error.

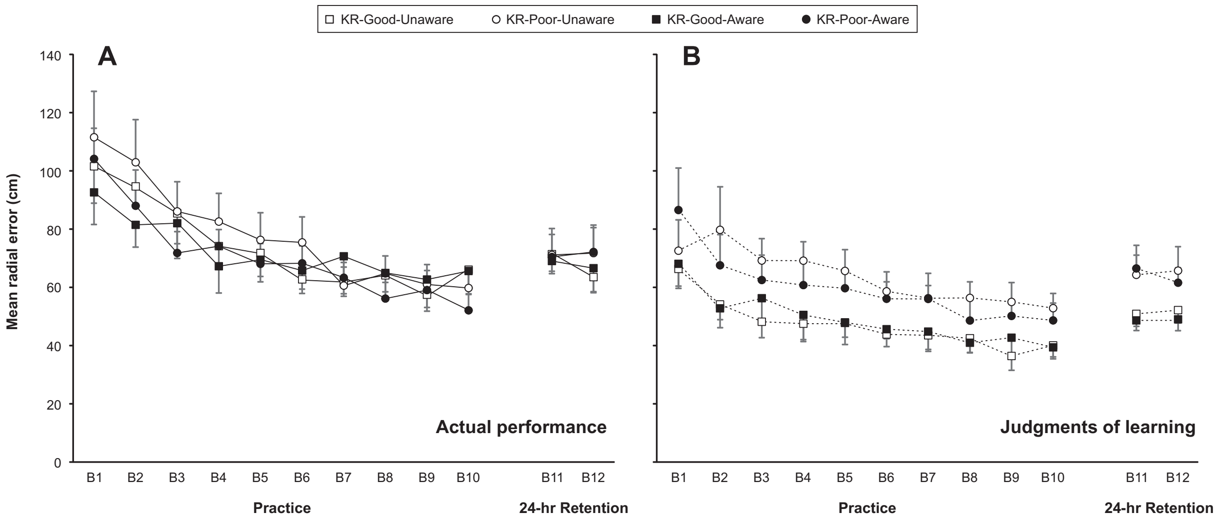

Fig. 1. Mean radial error (Panel A; solid lines) and judgments of learning (Panel B; dotted lines) during the practice (B1–B10) and retention (B11–B12) phases of the experiment for the KR-Good-Aware (filled squares), KR-Poor-Aware (filled circles), KR-Good-Unaware (open squares), and KR-Poor-Unaware (open circles). Errors bars are standard error.

3.1.2. Judgments of learning

The KR-Good-Aware and the KR-Good-Unaware groups tended to make judgments of learning throughout practice of higher proficiency compared to the KR-Poor-Aware and KR-Poor-Unaware groups (see Fig. 1B, left side), which was supported by a significant main effect of KR type ($F_{[1,\ 36]} = 7.589$, $p = .009$, $\eta_p^2 = .174$). There was also a significant main effect of Block ($F_{[9,\ 324]} = 10.519$, $p < .001$, $\eta_p^2 = .226$) whereby the JOLs made after each practice block reflected increased accuracy (i.e., less error) for all groups over practice. No other significant differences were found (p values > .05).

3.1.3. KR versus no-KR trials manipulation check

The analysis of mean radial error on KR versus no-KR trials during practice (see Fig. 2) revealed a significant interaction between KR type and Trial type ($F_{[1,\ 38]} = 212.743$, $p < .001$, $\eta_p^2 = .849$). Post hoc comparisons showed that the two KR-Good groups did in fact receive KR on relatively more accurate trials compared to the two KR-Poor groups that received KR on relatively less accurate trials, while the opposite was true for no-KR trials. Moreover, the KR trials for the KR-Good groups were significantly more accurate than their no-KR trials, whereas KR trials were significantly less accurate than no-KR trials for the KR-Poor groups. As in Chiviacowsky and Wulf (2007), these findings confirm that more accurate scores were reported to the KR-Group groups compared to the KR-Poor groups.

3.2. Retention

3.2.1. Mean radial error

All groups had similar accuracy scores in both retention blocks (see Fig. 1A, right side) and all analyses failed to reach statistical significance (p values > .05).

3.2.2. Judgments of learning

Similar to judgments of learning made during the practice phase, the two KR-Good groups made judgments of learning that reflected greater skill proficiency than the two KR-Poor groups (see Fig. 1B, right side), which was supported by a significant main effect of KR type ($F_{[1,\ 36]} = 7.074$, $p = .017$, $\eta_p^2 = .143$). All other comparisons failed to reach statistical significance (p values > .05).

4. Discussion

Past research has shown that one's perceived confidence with the task being learned is greater when KR reflects relatively good trials (Badami et al., 2011); however, no data regarding motor performance and learning was reported by the authors. As such, it is unknown if in addition to higher perceived confidence, KR after relatively good trials was also beneficial for learning in their experiment. Moreover, Patterson and Azizieh (2012) recently found that the main factor modulating learning differences was *not* the type of KR received during practice (i.e., good versus poor trials), but rather *being aware* relative to unaware of the type of KR received. In the present study we investigated whether participants, as a function of KR type (i.e.,

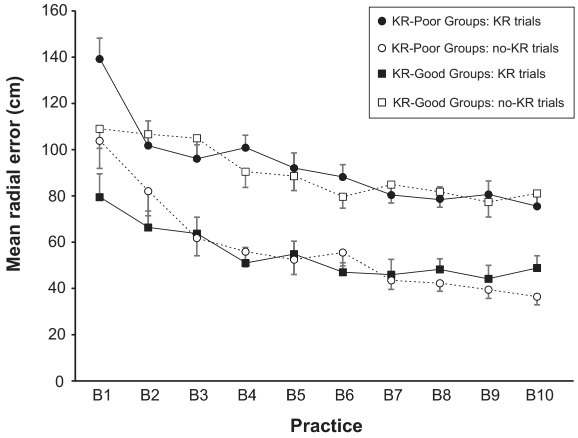

Fig. 2. Mean radial error collapsed across awareness for KR trials (filled symbols and solid lines) and no-KR trials (open symbols and dotted lines) for the groups that received KR on relatively good trials (squares) and relatively poor trials (circles). Errors bars are standard error.

good or poor trials) and awareness (i.e., aware or unaware) of this KR scheduling technique would be able to accurately dissociate their actual level of learning from the transient performance effects associated with their practice condition. We hypothesized that KR on relatively good trials would bias participants to make significantly higher judgments of learning compared to participants receiving KR on relatively poor trials; however, any misconceptions of learning were expected to be mitigated by making participants aware of the type of KR they were receiving during practice. Consistent with Patterson and Azizieh (2012) we expected that being aware of one's KR content would be the main factor determining motor learning, independent of the type of KR received during practice.

Our predictions regarding the judgment of learning data were partially supported as KR on relatively good trials resulted in significantly higher perceptions of learning compared to KR on relatively poor trials; however, awareness of one's KR scheduling technique did not mitigate this misperception of learning. Patterson and Azizieh (2012) suggested that making participants aware of the type of KR they received during practice provided these participants with a *meaningful referent* that facilitated a more optimal processing of the KR they received, which in turn enhanced motor skill retention. In a similar vein, we expected that this meaningful referent would help participants to more accurately judge one's actual level of learning. Specifically, we thought the added knowledge that the three trials they did not receive KR on in each block were more (or less) accurate than the three they did receive KR would have provided extra information that could be used to form a more realistic judgment of learning. This was not the case as our results showed that independent of awareness, receiving KR on relatively good trials compared to relatively poor trials resulted in significantly higher judgments of learning (i.e., less error) during practice. Moreover, the significant difference in judgments of learning as a function of KR type did not diminish with the passage of time as both KR-Good groups still predicted significantly more accurate retention performance 24-h after practice than both KR-Poor groups (see Fig. 1B). This persistence in judgments of learning over the retention interval in the present experiment is consistent with past studies (e.g., Simon & Bjork, 2001, 2002) and further highlights that transient performance information inherent in certain practice conditions can have lasting effects on prospective metacognitive judgments, even when the manipulation of the independent variable has been removed.

Although, significant differences in the participants' judgments of learning emerged as a function of KR type despite no actual performance differences between the groups in either acquisition or retention. Importantly, this lack of group differences was not the result of participants failing to improve task performance during practice (see Fig. 1A, left side) nor was it due to a failure of successfully providing KR on relatively good versus relatively poor trials to the respective groups (i.e., manipulation check analysis; see Fig. 2). Thus, contrary to past research we found no learning advantage of providing KR on relatively good over relatively poor trials (e.g., Chiviacowsky & Wulf, 2007; Chiviacowsky et al., 2009). This failure to replicate those findings is consistent with Patterson and Azizieh (2012) who also reported no learning advantage of KR on relatively good versus relatively poor trials. Our data, however, diverges from that of Patterson and Azizieh (2012) as we did not show motor learning benefits associated with being explicitly aware of the type of KR received during practice. Such differences may relate to the motor task used in the present experiment (i.e., non-dominant throwing) versus the task used in the Patterson and Azizieh (2012) study (i.e., force production task). In fact, the relative effectiveness of any practice condition is thought to depend on the interplay of the learner's characteristics, the classification and/or characteristics of the motor task, and task complexity (Guadagnoli & Lee, 2004; Wulf & Shea, 2002). As such, the lack of novelty in our throwing task may have contributed to our failure to replicate. Although we attempted to introduce novelty by having participant's complete the task with their non-dominant arm, it is possible that pre-existing knowledge of, and experience with, dominant arm throwing tasks resulted in sufficient bilateral transfer (e.g., Liu & Wrisberg, 2005; Teixeira, 2000) for the requirements of the relatively simple throwing task used in the present study. Perhaps the learning advantages of being aware of one's KR schedule would emerge in a throwing task that placed greater demands on the motor system of the learner (e.g., pitching).

The findings of the present experiment have important implications for motor learning theory, as well as practice in applied settings. From a theoretical perspective, we have extended the finding that participants' metacognitive assessments are subject to the performance-learning paradox (see Kantak & Winstein, 2012; Schmidt & Bjork, 1992 for a reviews) using a KR manipulation, whereas others have shown this with contextual interference (e.g., Abushanab & Bishara, 2013; Simon & Bjork, 2001). Thus, our findings suggest practitioners and coaches need to be cognizant that the transient effects associated with the feedback (i.e., information) they provide during training can have lasting effects on metacognitive assessments of learning that may not necessarily align with actual learning. Such findings emphasize the importance of continuing to identify the practice conditions that produce these metacognitive discrepancies, as well as ways to overcome and/or prevent them altogether.

A better understanding of metacognitive factors in motor learning becomes increasingly important when one considers that researchers have suggested that participants should be permitted control over their amount of practice to learn a new skill (for a review see Sanli, Patterson, Bray, & Lee, 2013). Based on the metacognition in motor learning literature, it is conceivable that allowing the learner to specify the number of practice trials to complete would be ineffective for learning as they could fall victim to interpreting transient performance information as accurate reflections of actual learning and in turn, choose to stop practice too early based on erroneous judgments of learning. Support for this idea has been provided by Post, Fairbrother, and Barros (2011). The authors allowed one group of participants to choose the number of practice trials they wished to complete to learn a dart throwing task (Self-controlled group), while a second group of participants were matched to a Self-controlled counterpart and completed the exact number of trials as their Self-controlled participant, without any choice (Yoked group). Thus, the Self-controlled group could stop practice at their discretion and for any reason, whereas the termination of practice was imposed on the Yoked group. Their results revealed no significant improvements in performance from the beginning to the end of practice; thus, allowing participants to self-select the amount of practice trials to complete was not advantageous for improving dart throwing performance in practice or for skill retention and transfer. Questionnaire data revealed that the two main reasons why the Self-controlled participants chose to terminate practice related to "satisfaction with current level of (perceived) proficiency" and "felt performance was no longer improving (or becoming less accurate)". Both of these reasons suggest these participants may have based their rationale for stopping practice on some type of metacognitive assessment of learning. Moreover, the fact that some participants terminated practice after a very low number of trials (e.g., 20), despite self-reporting that they felt proficient enough at the task, suggests a lack of commitment to actually learn the task. Thus, this tendency to overestimate skill level by the learner is also likely the results of adopting a "learning" goal that does not align with the expectations of the instructor or experimenter.[4] Interestingly, in a follow-up study Post, Fairbrother, Barros, and Kulpa (2014) found typical self-controlled learning advantages over a yoked condition when a *fixed amount* of practice was imposed on the learners. These studies strongly suggests that allowing learners to choose how much to practice rather than having this parameter specified by a coach or a therapist may be a suboptimal technique to facilitate long-term motor skill learning (e.g., Post et al., 2014).

In conclusion, research into metacognition during both verbal and motor skill learning has revealed that one's practice condition can have a profound effect on the accuracy of one's metacognitive assessments (Son & Simon, 2012), often resulting in false perceptions of learning or "illusions of competency" (Jacoby et al., 1994). The practical implications of inaccurate perceptions of learning relative to actual learning is potentially problematic as overconfident assessments could result in early termination of motor training in self-directed situations, while decreased perceptions could result in higher attrition rates in educational, vocational, recreational, and/or rehabilitation settings. Overall, further research is needed to better understand the relationship between KR schedules and metacognitive assessments during motor learning in both laboratory and applied settings.

Disclosures

The authors declare the research was conducted in the absence of any commercial or financial relationship that could be construed as a potential conflict of interest.

Acknowledgements

This research was supported by a Natural Sciences and Engineering Research Council of Canada (NSERC) Alexander Graham Bell Canada Graduate Scholarship awarded to MJC and a Faculty of Health Sciences Student Research Bursary from the University of Ottawa awarded to VS.

References

Abushanab, B., & Bishara, A. (2013). Memory and metacognition for piano melodies: Illusory advantages of fixed-over random-order practice. *Memory & Cognition, 41*(6), 928–937. http://dx.doi.org/10.3758/s13421-013-0311-z.

Badami, R., VaezMousavi, M., Wulf, G., & Namazizadeh, M. (2011). Feedback after good versus poor trials affects intrinsic motivation. *Research Quarterly for Exercise and Sport, 82*(2), 360–364.

[4] We credit an anonymous reviewer with these points.

Badami, R., VaezMousavi, M., Wulf, G., & Namazizadeh, M. (2012). Feedback about more accurate versus less accurate trials: Differential effects on self-confidence and activation. *Research Quarterly for Exercise and Sport, 83*(2), 196–203.

Carter, M. J., Carlsen, 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*, 1325. http://dx.doi.org/10.3389/fpsyg.2014.01325.

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*(4), 408–415.

Chiviacowsky, S., & Wulf, G. (2007). Feedback after good trials enhances learning. *Research Quarterly for Exercise and Sport, 78*(2), 40–47.

Chiviacowsky, S., Wulf, G., Wally, R., & Borges, T. (2009). Knowledge of results after good trials enhances learning in older adults. *Research Quarterly for Exercise and Sport, 80*(3), 663–668.

Fischman, M. G. (2015). On the continuing problem of inappropriate learning measures: Comment on Wulf et al. (2014) and Wulf et al. (2015). *Human Movement Science, 42*, 225–231. http://dx.doi.org/10.1016/j.humov.2015.05.011.

Guadagnoli, M. A., & Lee, T. D. (2004). Challenge point: A framework for conceptualizing the effects of various practice conditions in motor learning. *Journal of Motor Behavior, 36*(2), 212–224. http://dx.doi.org/10.3200/Jmbr.36.2.212-224.

Hancock, G. R., Butler, M. S., & Fischman, M. G. (1995). On the problem of two-dimensional error scores: Measures and analyses of accuracy, bias, and consistency. *Journal of Motor Behavior, 27*(3), 241–250. http://dx.doi.org/10.1080/00222895.1995.9941714.

Jacoby, L. L., Bjork, R. A., & Kelley, C. M. (1994). Illusions of comprehension, competence, and remembering. In D. Druckman & R. A. Bjork (Eds.), *Learning, remembering, believing: Enhancing human performance* (pp. 57–80). Washington, DC: National Academy Press.

Kantak, S. S., & Winstein, C. J. (2012). Learning-performance distinction and memory processes for motor skills: A focused review and perspective. *Behavioural Brain Research, 228*(1), 219–231. http://dx.doi.org/10.1016/j.bbr.2011.11.028.

Laughlin, D. D., Fairbrother, J. T., Wrisberg, C. A., Alami, A., Fisher, L. A., & Huck, S. W. (2015). Self-control behaviors during the learning of a cascade juggling task. *Human Movement Science, 41*, 9–19. http://dx.doi.org/10.1016/j.humov.2015.02.002.

Liu, J., & Wrisberg, C. A. (2005). Immediate and delayed bilateral transfer of throwing accuracy in male and female children. *Research Quarterly for Exercise and Sport, 76*(1), 20–27. http://dx.doi.org/10.1080/02701367.2005.10599258.

McAuley, E., Duncan, T., & Tammen, V. V. (1989). Psychometric properties of the Intrinsic Motivation Inventory in a competitive sport setting: A confirmatory factor-analysis. *Research Quarterly for Exercise and Sport, 60*(1), 48–58.

Oldfield, R. C. (1971). The Assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia, 9*(1), 97–113. http://dx.doi.org/10.1016/0028-3932(71)90067-4.

Patterson, J. T., & Azizieh, J. (2012). Knowing the good from the bad: Does being aware of KR content matter? *Human Movement Science, 31*(6), 1449–1458. http://dx.doi.org/10.1016/j.humov.2012.04.004.

Patterson, J. T., & Carter, M. (2010). Learner regulated knowledge of results during the acquisition of multiple timing goals. *Human Movement Science, 29*(2), 214–227. http://dx.doi.org/10.1016/j.humov.2009.12.003.

Post, P. G., Fairbrother, J. T., & Barros, J. A. C. (2011). Self-controlled amount of practice benefits learning of a motor skill. *Research Quarterly for Exercise and Sport, 82*(3), 474–481.

Post, P. G., Fairbrother, J. T., Barros, J. A. C., & Kulpa, J. D. (2014). Self-controlled practice within a fixed time period facilitates the learning of a basketball set shot. *Journal of Motor Learning and Development, 2*, 9–15.

Reeve, T. G., Fischman, M. G., Christina, R. W., & Cauraugh, J. H. (1994). Using one-dimensional task error measures to assess performance on two-dimensional tasks: Comments on "Attentional control, distractors, and motor performance". *Human Performance, 7*(4), 315–319.

Saemi, E., Porter, J. M., Ghotbi-Varzaneh, A., Zarghami, M., & Maleki, F. (2012). Knowledge of results after relatively good trials enhances self-efficacy and motor learning. *Psychology of Sport and Exercise, 13*(4), 378–382. http://dx.doi.org/10.1016/j.psychsport.2011.12.008.

Salmoni, A. W., Schmidt, R. A., & Walter, C. B. (1984). Knowledge of results and motor learning: A review and critical reappraisal. *Psychological Bulletin, 95*(3), 355–386. http://dx.doi.org/10.1037//0033-2909.95.3.355.

Sanli, E. A., Patterson, J. T., Bray, S. R., & Lee, T. D. (2013). Understanding self-controlled motor learning protocols through the Self-Determination Theory. *Frontiers in Psychology, 3*, 611. http://dx.doi.org/10.3389/fpsyg.2012.00611.

Schmidt, R. A., & Bjork, R. A. (1992). New conceptualizations of practice: Common principles in three paradigms suggests new concepts for training. *Psychological Science, 3*(4), 207–217. http://dx.doi.org/10.1111/j.1467-9280.1992.tb00029.x.

Schmidt, R. A., & Lee, T. D. (2011). *Motor control and learning: A behavioral emphasis* (5th ed.). Champaign, IL: Human Kinetics.

Simon, D. A., & Bjork, R. A. (2001). Metacognition in motor learning. *Journal of Experimental Psychology-Learning Memory and Cognition, 27*(4), 907–912. http://dx.doi.org/10.1037//0278-7393.27.4.907.

Simon, D. A., & Bjork, R. A. (2002). Models of performance in learning multisegment movement tasks: Consequences for acquisition, retention, and judgments of learning. *Journal of Experimental Psychology-Applied, 8*(4), 222–232. http://dx.doi.org/10.1037/1076-898x.8.4.222.

Soderstrom, N. C., & Bjork, R. A. (2015). Learning versus performance: An integrative review. *Perspectives on Psychological Science, 10*(2), 176–199. http://dx.doi.org/10.1177/1745691615569000.

Son, L. K., & Simon, D. A. (2012). Distributed learning: Data, metacognition, and educational implications. *Educational Psychology Review, 24*(3), 379–399. http://dx.doi.org/10.1007/s10648-012-9206-y.

Teixeira, L. A. (2000). Timing and force components in bilateral transfer of learning. *Brain and Cognition, 44*(3), 455–469. http://dx.doi.org/10.1006/brcg.1999.1205.

Wulf, G., Chiviacowsky, S., & Drews, R. (2015). External focus and autonomy support: Two important factors in motor learning have additive benefits. *Human Movement Science, 40*, 176–184. http://dx.doi.org/10.1016/j.humov.2014.11.015.

Wulf, G., & Shea, C. H. (2002). Principles derived from the study of simple skills do not generalize to complex skill learning. *Psychonomic Bulletin & Review, 9*(2), 185–211. http://dx.doi.org/10.3758/Bf03196276.

Wulf, G., Shea, C., & Lewthwaite, R. (2010). Motor skill learning and performance: A review of influential factors. *Medical Education, 44*(1), 75–84. http://dx.doi.org/10.1111/j.1365-2923.2009.03421.x.