Conscious control is associated with freezing of mechanical degrees of freedom during motor learning

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Abstract

This study investigated whether conscious control is associated with freezing of mechanical degrees of freedom during motor learning. Participants practiced a throwing task using either error-strewn or error-reduced practice protocols, which encourage high or low levels of conscious control, respectively. After 24 hours, participants engaged in a series of delayed retention and transfer tests. Furthermore, propensity for conscious control was assessed using participants' ratings and freezing was gauged through movement variability of the throwing arm. Performance was defined by mean radial error. In the error-strewn group, propensity for conscious control was positively associated with both freezing and performance. In the error-reduced group, propensity for conscious control was negatively associated with performance, but not with freezing. These results suggest that conscious control is associated with freezing of mechanical degrees of freedom during motor learning.

Key words: Motor learning; Motor control; Attention

Introduction

Everyday motor tasks, such as carrying objects or tossing them at targets, can be accomplished using a large variety of movements. According to Bernstein's (1967) "degrees of freedom problem" the nervous system cannot simultaneously process all these options. Instead, control may be achieved by "freezing mechanical degrees of freedom" – i.e., restricting joint ranges of motion and tightly coupling the motion of different joints. Due to these restrictions, freezing decreases movement variability (Higuchi, Imanaka, & Hatayama, 2002) and simplifies the degrees of freedom problem.

There is reason to suspect a relationship between conscious control and freezing during motor learning. Bernstein (1967) proposed that freezing is prevalent mainly during the early stages of motor learning, but gradually decreases as learning progresses. In the same year, Fitts and Posner (1967) proposed that early learning stages involve a high degree of conscious control, which subsequently decreases in later stages. The parallel between these ideas raises the question of whether conscious control and freezing are related.

A number of studies have tacitly endorsed the relationship. Newell and Ranganathan (2010) proposed, and Lee, Chow, Komar, Tan, and Button (2014) found, that technical instructions about movement execution constrain mechanical degrees of freedom. As other studies had already shown that technical instructions elicit conscious control (cf. Liao & Masters, 2001; Masters, 1992), the finding by Lee et al. (2014) hints at a relationship between conscious control and freezing. Furthermore, Ranganathan and Newell (2008) found that the use of visual feedback – possibly as a means conscious control – during a movement was associated with tight coupling between degrees of freedom. These studies suggest that conscious control may be associated with freezing.

Perhaps the strongest indication of a link between conscious control and freezing comes from a study by Malhotra, Poolton, Wilson, Omuro, and Masters (2015). They studied discovery learning of a golf putting task and found that participants with a high propensity for conscious control displayed lower trial-to-trial variability of club-ball contact than participants with a low propensity for conscious control. Although, it is difficult to infer with certainty whether variability in club-ball contact can reflect freezing, because club-ball contact captures the outcome of the putting motion rather than the motion itself, the findings of do strengthen the expectation that conscious control and freezing are related.

The current study investigated the effect of conscious control on freezing in three different ways: (1) by employing implicit motor learning interventions, (2) by measuring personality predispositions and (3) by including transfer tests that manipulate conscious control. Implicit motor learning interventions deliberately attempt to suppress conscious control (cf. Masters, 1992; Maxwell, Masters, & Eves, 2000; Poolton, Masters, & Maxwell, 2005). Compared to explicit learning, implicit learning limits accrual of verbal knowledge (e.g., Masters, 1992), reduces dependence on working memory (Maxwell, Masters, & Eves, 2003) and lowers cortical co-activation between verbal-analytic (T3) and motor planning (Fz) areas of the brain (Zhu et al., 2011a).

An effective method of promoting implicit motor learning is to limit the number of errors[1] throughout learning. Errors promote problem solving and thus may increase conscious control in an attempt to prevent future errors (Maxwell, Masters, Kerr, & Weedon, 2001), as evidenced by prolonged probe-reaction times (Lam, Maxwell, & Masters, 2010) and increased T3-Fz co-activation (Zhu, Poolton, Wilson, Maxwell, & Masters, 2011b). Hence, the occurrence of errors and thus conscious control can be influenced via manipulation of task

[1] Note that the term ‘error’ strictly means failure to achieve a specified performance goal. It should not be confused with quality of performance. High quality performance can result in an error, especially when the goal is challenging. Conversely, low quality performance can, in some cases, result in success, especially when the goal is not challenging.

constraints, such as target distance (e.g., Maxwell et al., 2001; Poolton et al., 2005; Zhu et al., 2011b) or size (Capio, Poolton, Sit, Eguia, & Masters, 2013; Capio, Poolton, Sit, Holmstrom, & Masters, 2013). In this study, participants learned an aimed throwing task under either error-reduced or error-strewn protocols.

As proposed by the theory of reinvestment (Masters & Maxwell, 2008; Masters, Polman, & Hammond, 1993), predisposition for conscious control is a personality trait (individual constraint) that can be reliably measured using the Movement Specific Reinvestment Scale (MSRS) (Masters, Eves, & Maxwell, 2005). Using the MSRS, studies have shown that individuals with a high propensity for conscious control tend to accrue more verbal knowledge (Maxwell, Masters, & Poolton, 2006) and show more T3-Fz co-activation (Zhu et al., 2011b) than individuals with a low propensity for conscious control.

As proposed by Schmidt and Bjork (1992), motor learning, understood as a relatively permanent change in the motor repertoire, ought to be investigated using retention and transfer tests. For this reason, the current study included a delayed retention test followed by four transfer tests designed to manipulate conscious control. These transfer tests were (1) secondary-task performance (Masters, 1992; Maxwell et al., 2000; Maxwell et al., 2001), which occupies working memory capacity and thus lowers the capacity for conscious control[2], (2) instructed skill-focused attention, which has been found to increase conscious control (Beilock & Carr, 2001; Beilock, Carr, MacMahon, & Starkes, 2002; Gray, 2004; Jackson, Ashford, & Norsworthy, 2006), (3) psychological pressure, which increases conscious control (Baumeister, 1984; Cooke, Kavussanu, McIntyre, & Ring, 2010; Masters, 1992; Masters et al., 1993; Van Loon, Masters, Ring, & McIntyre, 2001) and (4) changes in task-constraints, thought to induce conscious control (Beilock & Carr, 2001).

[2] The secondary task also served as a manipulation check of the type of learning promoted by error-strewn and error-reduced practice protocols (Maxwell, Masters, Kerr, & Weedon, 2001).

To assess the impact of conscious control interventions on the organization of mechanical degrees of freedom it is necessary to operationalize *freezing*. Although inter-joint correlations and joint ranges of motion have often been used (e.g. Caillou, Nourrit, Deschamps, Lauriot, & Delignieres, 2002; Konczak, Van der Velden, & Jaeger, 2009; Vereijken, Van Emmerik, Whiting, & Newell, 1992), other measures exist, such as cluster analysis (Lee et al., 2014), dimensionality of state space (Newell, Broderick, Deutsch, & Slifkin, 2003) and movement variability (Higuchi et al., 2002). Of these different options, movement variability best suits the current study for two reasons. First, it has been shown to be a function of task accuracy demands (Sidaway, Sekiya, & Fairweather, 1995). It therefore ties in with the implicit learning intervention, in which task accuracy demands are manipulated. Second, a broad measure of freezing is preferred, because the aim of this study is to investigate whether an association between conscious control and freezing exists. Although specific details of such a relationship may be interesting for further research, it all hinges on whether the relationship exists or not. Therefore, freezing was operationalized by means of movement variability.

It was hypothesized that participants in the error-strewn group and those with a high propensity for conscious control would have lower movement variability than those in the error-reduced group and with a low propensity for conscious control, respectively. During the retention and transfer phase, the secondary-task transfer test was expected to decrease freezing by occupying working memory capacity and thus lowering the capacity for conscious control. The other three transfer tests (i.e. skill-focus, pressure and changes in task characteristics) were expected to increase conscious control and thus promote freezing. Although not directly related to our research aim, it is customary to take motor performance into account. Therefore, the association between conscious control and performance was also investigated, and in line with previous studies (cf. Masters & Maxwell, 2008) conscious control was expected to be negatively associated with performance.

Methods

Ethics. Ethical approval was requested from and granted by the university's research ethics committee.

Participants. Forty students (19 male, 21 female; age *M* = 21.5, SD 3.17 years) participated. All had normal or corrected to normal vision and received HKD125 (+/- USD15) for participating.

Apparatus. See Appendix A for visual description of the apparatus used for kinematics. A six-camera Qualisys motion capture system (f = 120 Hz) recorded displacement of markers on participants' acromion process (shoulder), olecranon process (elbow) and radial styloid (wrist), as well as the displacement of golf balls that were covered by reflective tape. Participants were seated on a 30 cm high stool positioned 4 m from the middle of a target. The target was a 30 cm high square cardboard box with horizontal dimensions ranging between 20 and 95 cm in increments of 15 cm. A box containing 25 golf balls was placed comfortably within arm's reach. The Movement Specific Reinvestment Scale (MSRS) (Masters et al., 2005) was used to measure participants' propensity for conscious control. The MSRS is a 10 item 6-point Likert scale that ranges from "strongly disagree" to "strongly agree". The Scale comprises a Conscious Motor Processing (CMP) and a Movement Self-Consciousness (MS-C) subscale (Masters & Maxwell, 2008).

Procedure.

Practice. After signing informed consent, participants were fitted with the reflective markers. They were then seated on the stool with their shoulders aligned in the direction of the target and were instructed to throw golf balls towards the middle of the target box using an overhand throw. They were granted one practice throw. A successful throw was recorded if the ball entered the target box directly, without bouncing first and regardless of whether it bounced out afterwards. Any other outcome was considered an error.

Participants were randomly assigned to either an error-reduced (n = 20) or an error-strewn practice protocol group (n = 20). Both groups performed 6 blocks of 50 throws. Participants in the error-reduced group started throwing to the biggest target box (95 x 95 cm), after which the target size dimensions were reduced by 15 cm in each subsequent block of 50 throws. In the final block, participants in the error-reduced group threw to the smallest target box (20 x 20 cm). Participants in the error-strewn group threw to the smallest target box throughout practice. After the 25th throw in each block, participants had a one-minute break during which balls were collected. Between blocks, participants had a two-minute break, during which balls were collected and the target size was changed for participants in the error-reduced group.

Retention and Transfer. After a period of at least 24 hours, participants engaged in a series of retention and transfer tests. They were reminded about the procedure, re-fitted with reflective markers and completed an anxiety-thermometer (Houtman & Bakker, 1989), which required them to indicate their current anxiety level on a 10 cm line ranging from “not anxious at all” to “extremely anxious”.

Participants first performed 50 retention trials, in which the conditions were identical to the last block of the practice session – i.e., a target distance of 4 meters and horizontal target dimensions of 20 cm. Then – as changes in task characteristics promote conscious control (Beilock & Carr, 2001) – participants performed four blocks of 25 transfer trials in an A-B-B-A order in which the target was placed either 50 cm closer to or 50 cm further away from the target than the standard 4 m distance. The beginning distance (close or far) was counterbalanced between and randomized within experimental groups.

Subsequently, participants engaged in three more transfers tests – tone-counting, skill-focus and pressure – the order of which was counterbalanced between and randomized within groups. Based on Maxwell et al. (2001), the tone-counting test required participants to count the number of high pitch tones from a series of randomly generated high- and low-pitched tones. The accuracy of these estimations served as a manipulation check for whether errors during practice had indeed affected levels of conscious control - participants from the error-reduced group were expected to count tones more accurately than participants from the error-strewn group because they used less conscious control when throwing, which placed a smaller burden on working memory capacity. Furthermore, tone-counting decreases participants' capacity to use working memory to consciously control their movements. Therefore, the tone-counting task also served as a manipulation of conscious control.

Similar to Beilock and Gray (2012), the skill-focus test presented sounds in 10 randomly chosen throws out of 50. Participants were told that, after completion of each throw, they would be asked to verbally indicate the position of their forearm (in front or behind their elbow) at the moment the tone was played. This manipulation was designed to increase levels of conscious control.

In the pressure test, participants were informed that they could win up to 1000 HKD (+/- 125 USD) based on their performance. In order to ensure pressure for relatively proficient participants, 300 HKD was available for the best performance. To ensure pressure for less proficient participants, 200 HKD was available for the best improvement compared to block 6 of the practice session. Assuming less proficient participants had performed poorly during the practice session, they could more easily win the 200 HKD prize. There were also 10 prizes of

50 HKD available for the best performance in each set of 5 throws. This approach was chosen so that even the participants who performed very poorly during the early part of the pressure test would have an incentive and thereby continue to experience pressure. Directly after completing the pressure test, participants again completed an anxiety-thermometer to establish how anxious they had felt during the pressure test.

At the end of the procedure, participants completed the MSRS and were debriefed.

Data handling. Trial-to-trial movement variability was defined as the mean Euclidean distance between the throwing arm kinematics of all trials in a block. Euclidean distance is a standard, comprehensive measure of dissimilarity (Han, Kamber, & Pei, 2006) that is regularly applied in kinematic analyses of human movement (cf. Jaitner, Mendoza, & Schöllhorn, 2001; Schorer, Baker, Fath, & Jaitner, 2007). First, the trajectories over the last 200ms before ball release were selected. Subsequently, for each marker, the average of the absolute (i.e. Euclidean) distance between these trajectories was determined. By taking the average for all markers the final measure of mean Euclidean distance was obtained. Throws for which the forward acceleration phase was less than 200ms were excluded from analysis (< 0.1% of throws). Lower movement variability was deemed to reflect greater freezing. See Appendix A for a more comprehensive description of how the mean Euclidean distance measure was obtained.

Mean radial error (MRE)[3] – i.e., distance (cm) between the middle of the target and ball flight at a height of 30 cm - was taken as the measure of throwing performance. Lower MRE reflects better performance.

[3] We here reiterate that MRE is not the same as the number of errors made during practice. MRE is the average distance between the landing position of the ball and the center of the target. The number of errors is the number of times the ball failed to enter the target box. Although these two measures may be related, it is not unthinkable that a relatively accurate throw in the error-strewn group may still lead to an error, while a bad throw in the error-reduced group may not produce an error if the target is large enough.

Data Analysis. Shapiro-Wilk Tests were used to test for normality. An independent-samples *t*-test was used to compare the number of errors made by participants in the error-reduced and error-strewn groups. A paired-samples t-test compared anxiety-thermometer values from before and after the pressure test. Cronbach's alpha was used to test the internal consistency of the two factors of the MSRS and a Pearson correlation coefficient was calculated to evaluate their association. As tone-counting accuracy was not normally distributed, a Generalized Linear Mixed Model (GLMM) – the specifics of which are introduced below – was used to test for differences between the groups.

Initially, repeated measures analyses of variance (RM ANOVA) were used to analyze the movement variability. However, significant interactions between group (dichotomous variable) and MSRS score (continuous variable) were found, which potentially biased the main effects (West, Aiken, & Krull, 1996). Furthermore, 33% of the data was found to violate the assumption of normality, rendering ANOVA inappropriate. As an alternative, GLMMs were computed, because they are more suitable for handling interactions between dichotomous and continuous variables and do not require data to be normally distributed (Twisk, 2006).

As recommended by Twisk (2006), first a basic model was established that only included the main effects of group and MSRS score, after which the effect of practice block and interaction effects were entered in a stepwise fashion. Aikake's Information Criterion (AIC) was used to evaluate whether the inclusion of each added predictor improved the model's fit. A best fitting model was established by only including predictors that lowered the value of AIC by more than 2 points. Only the results of best fitting models are reported. If a particular variable or interaction is not mentioned in the results, this means that it was not part of the best fitting model and its effect was not significant. AIC values of all models can be found in Appendix B.

Bonferroni corrections were applied when multiple comparisons were made to follow up significant effects. As suggested by Nakagawa and Schielzeth (2013), partial (r^2) and semi-partial correlations (sr^2) are reported as measures of effect size. These measures were determined using log-transformed (base-10) data in order to adhere to the assumption of normality.

Results

Outliers. Three participants were excluded from analysis for having MRE values more than 3 standard deviations above the mean and one was excluded for having an MSRS score of more than 3 standard deviations below the mean.

MSRS. The internal consistency of the MSRS was acceptable (α = .790: MS-C α = .780; CMP α = .800) and the correlation between the MS-C and CMP sub-scales was high ($r = .685$, $p < .001$). Hence, for analysis of the propensity for reinvestment the total MSRS score was used (α = .795).

Manipulation checks. The practice protocol manipulation had its desired effect. During practice, participants from the error-strewn group made significantly more errors ($M = 256.17$, $SD = 19.47$) than participants in the error-reduced group ($M = 115.11$, $SD = 22.38$), ($t(34) = 20.18$, $p < .001$, $d = 6.72$, *95% CI* = [126.85 155.26]). During the tone counting transfer test, participants from the error-strewn group made significantly more tone counting errors ($M = 13.17$, $SD = 14.3$) than those in the error-reduced group ($M = 5.72$, $SD = 4.18$), ($F(1, 33) = 4.25$, $p < .05$, $sr^2 = .13$, $b(64) = 7.35$, $SE\ b = 3.56$, $t(64) = 2.06$, $p < .05$, *95% CI* = [.10 14.60]). During the pressured transfer test, scores on the anxiety-thermometer suggested that participants felt more anxious ($M = 5.08$, $SD = 2.85$) than before the test ($M = 2.69$, $SD = 2.43$), ($t(35) = 5.73$, $p < .001$, $d = .96$, *95% CI* = [1.55 3.24]).

Practice.

Learning curves regarding movement variability and mean radial error across practice blocks can be found in Figure 1.

Movement variability. The best fitting model predicting movement variability included the main effects of training block (F(5, 207) = 1.51, p = .19, sr^2 = .10)[4], group (F(1, 207) = 5.55, p < .05, sr^2 = .08), MSRS score (F(1, 207) = 15.72, p < .001, sr^2 = .06) and the interaction between group and MSRS score (F(1, 207) = 22.36, p < .001, sr^2 = .08). Participants from the error-strewn group (M = 1.76, SD = .35) had lower movement variability than participants from the error-reduced group (M = 1.88, SD = .40), (t(207) = 2.36, p < .05, *95% CI* = [.02-.24]). Additionally, higher MSRS scores corresponded with lower movement variability (b(207) = -.04, SE b = .007, t(207) = -5.02, p < .001, *95% CI* = [-.051 -.022]). Further exploration of the interaction effect revealed that MSRS score predicted movement variability in the error-strewn group (F(1, 101) = 32.29, p < .001, sr^2 = .18), but not in the error-reduced group (p > .05) (Figure 2). Higher MSRS scores in the error-strewn group corresponded with lower movement variability (b(101) = -.04, SE b = .006, t(101) = -5.68, p < .001, *95% CI* = [-.048 -.023]). The main effect of block entailed that movement variability decreased during the practice session (see Figure1).

[Insert Figure 1 and Figure 2 about here]

Performance. The best fitting model predicting MRE included the main effects of training block (F(5, 202) = 6.30, p < .001, sr^2 = .21), group (F(1, 202) = .27, p = .60, sr^2 < .01), MSRS score (F(1, 202) = 5.73, p < .05, sr^2 = .01) and the interactions between group and MSRS score (F(1, 202) = 28.60, p < .001, sr^2 = .07), as well as between group and training block (F(5, 202) = .66, p = .66, sr^2 < .01). In the first two practice blocks, MRE was higher than in the last three blocks (ps < .001). Comparisons between all blocks can be found in

[4] Note that the inclusion of a variable in the best fitting model does not guarantee statistical significance. As the effect of training block was not significant, post-hoc tests were not performed, as was the case for all other non-significant effects.

Appendix C. Higher MSRS scores were associated with lower MRE (b = -.36, SE b = .08, t = -4.47, p < .001, *95% CI* = [-.52 -.20]). Further exploration of the interaction between group and MSRS score revealed a significant effect of MSRS score in the error-strewn group (F(1, 101) = 18.24, p < .001, sr^2 = .08) as well as in the error-reduced group (F(1, 101) = 9.73, p < .01, , sr^2 = .07). However, these effects were in opposite directions (Figure 3), with higher MSRS scores associated with lower MRE in the error-strewn group (b = -.36, SE b = .09, t(101) = -4.27, p < .001, *95% CI* = [-.53 -.20]), but higher MRE in the error-reduced group (b = .13, SE b = .04, t(101) = 3.21, p < .01, *95% CI* = [.05 .21]).

[Insert Figure 3 about here]

Retention and Transfer.

Movement variability. The best fitting model predicting movement variability included the main effects of test (F(5, 208) = 4.22, p < .01, sr^2 = .08), group (F(1, 208) = 4.63, p < .05, sr^2 = .02) and MSRS score (F(1, 208) = 2.84, p = .09, sr^2 = .02). Participants from the error-strewn group (M = 1.62, SD = .27) displayed lower movement variability than participants from the error-reduced group (M = 1.75, SD = .40), (b = .25, SE b = .12, t = 2.15, p < .05, 95% CI = [.01 .23]) (Figure 4). In the pressure test (M = 1.43, SD = .64), movement variability was lower than in all other tests (ps < .05), followed by tone-counting (M = 1.59, SD = .75), far distance (M = 1.74, SD = .71), retention (M = 1.77, SD = .75), skill-focus (M = 1.77, SD = .75) and short distance (M = 1.77, SD = .77) (Figure 5). All other between-test comparisons can be found in Appendix D.

[Insert Figures 4 and 5 about here]

Performance. The best fitting model predicting MRE included the main effects of test (F(3, 200) = 15.72, p < .001, sr^2 = .23) (Figure 6), order of transfer tests (F(2, 200) = 1.10, p = .33, sr^2 < .001), group (F(1, 200) = 2.84, p = .09, sr^2 < .01), MSRS score (F(1, 200) = 1.06, p

= .31, $sr^2 < .001$), and the interactions between group and MSRS score ($F(1, 200) = 5.89$, $p < .05$, $sr^2 = .02$) (Figure 7) and between group and test ($F(5, 200) = .31$, $p = .91$, $sr^2 < .001$). Further exploration of the interaction between group and MSRS score revealed a main effect of MSRS score ($F(1, 101) = 11.49$, $p < .01$, $sr^2 = .08$) in the error-reduced group, with lower scores on the MSRS associated with lower MRE ($b(101) = .16$, $SE\ b = .05$, $t(101) = 3.39$, $p < .01$, *95% CI* = [.07 .26]). A main effect of MSRS score was absent in the error-strewn group ($F(1, 101) = .71$, $p = .40$, $sr^2 < .01$). MRE was lowest in the short distance test ($M = 21.53$, $SD = 4.08$), followed by pressure ($M = 22.19$, $SD = 4.22$), tone-counting ($M = 23.47$, $SD = 5.58$), skill-focus test ($M = 24.56$, $SD = 5.12$), retention ($M = 26.80$, $SD = 4.35$) and far distance ($M = 28.62$, $SD = 5.10$). In the pressure test, MRE was significantly lower than in retention, far distance and skill-focus (*ps* < .05). All other between-test comparisons can be found in Appendix D.

[Insert Figure 6 and 7 about here]

Discussion

This study investigated whether conscious control is associated with freezing of mechanical degrees of freedom during motor learning. It was expected that conscious control would be associated with freezing. To test this hypothesis: (1) participants engaged in 300 practice trials of an aimed throwing task using either error-strewn or error-reduced practice protocols – an established method by which to manipulate problem solving efforts and thereby conscious control during motor learning (Capio, Poolton, Sit, Eguia, et al., 2013; Capio, Poolton, Sit, Holmstrom, et al., 2013; Maxwell et al., 2001; Poolton et al., 2005; Zhu et al., 2011b), (2) propensity for conscious control was measured using the MSRS (Masters et al., 2005) and (3) participants were subjected to a number of manipulations of conscious control as part of a delayed retention and transfer phase. Freezing was gauged via movement variability. Performance was defined as mean radial error.

Results of this study generally support our hypothesis. During practice, associations between conscious control and freezing emerged as a negative association between propensity for conscious control and movement variability in the error-strewn group. During delayed retention and transfer, the relationship between conscious control and freezing surfaced as main effects of group and test. Participants in the error-strewn group had lower movement variability than participants in the error-reduced group. During the pressure test – which increases conscious control (Baumeister, 1984; Masters, 1992) – movement variability was lower than in the other retention and transfer tests. These results indicate that conscious control is associated with freezing of mechanical degrees of freedom during motor learning.

The current study is the first to purposely show an association between conscious control and freezing during learning. It therefore requires replication before conclusions can be drawn with confidence. There is still a chance that a factor other than conscious control was responsible for the observed effects. After all, no direct measure of conscious control currently exists. Even brain imagery, arguably the most direct method, does not support inference of cognitive processes (Poldrack, 2006, 2008). The current study does, however, contain abundant – and we argue sufficient – circumstantial evidence from which to infer that conscious control was responsible for the observed effects. First, propensity for conscious control and practice protocol manipulations are well-established methods of influencing conscious control (cf. Capio, Poolton, Sit, Eguia, et al., 2013; Capio, Poolton, Sit, Holmstrom, et al., 2013; Masters, 1992; Masters et al., 1993; Maxwell et al., 2000; Poolton et al., 2005). Second, the superior tone-counting accuracy displayed by the error-reduced group confirms that the practice protocol manipulation indeed influenced reliance on conscious control, rather than any other factor. It therefore seems likely that conscious control accounts for the observed effects.

Altogether, results of this study allow a re-interpretation of conscious control as a movement constraint rather than a prescription mechanism. The constraints-led perspective on motor learning (Davids, Button, & Bennett, 2008; Renshaw, Chow, Davids, & Hammond, 2010) proposes that learning emerges out of the interplay between individual, environmental and task constraints of practice. The interactions found between personality predispositions (i.e. individual constraints) and the implicit learning intervention (i.e. task constraints) align nicely with the constraints-led perspective. Results of this study therefore indicate that conscious control may emerge from the interplay between constraints and/or it may itself act as a constraint on the movement system, as attested by its association with freezing.

Although less relevant for the current research aim, some interesting effects of conscious control on motor performance emerged. During practice, conscious control propensity was positively associated with performance in the error-strewn group. However, during practice and during retention, conscious control propensity was negatively associated with performance in the error-reduced group. These results mimic speculations by Tse and van Ginneken (2017) that motor performance is best when trait and state levels of conscious control are aligned.

Future research is required to examine the association between conscious control and freezing in more detail. As many different measures of freezing are available – e.g. inter-joint correlations (Vereijken et al., 1992), joint ranges of motion (Caillou et al., 2002), cluster analysis (Lee et al., 2014), dimensionality of state space (Newell et al., 2003) and movement variability (Higuchi et al., 2002) – future studies could unpick freezing. It may for example be investigated whether freezing takes place uniformly or is concentrated in particular joints.

Through these efforts, it may be possible to investigate whether results of the current study can be replicated and better understood.

References

Baumeister, R. F. (1984). Choking under pressure: Self-consciousness and paradoxical effects of incentives on skillful performance. *Journal of Personality and Social Psychology, 46*(3), 610-620. doi:10.1037/0022-3514.46.3.610

Beilock, S. L., & Carr, T. H. (2001). On the fragility of skilled performance: What governs choking under pressure? *Journal of Experimental Psychology: General, 130*(4), 701-725. doi:10.1037/0096-3445.130.4.701

Beilock, S. L., Carr, T. H., MacMahon, C., & Starkes, J. L. (2002). When paying attention becomes counterproductive: Impact of divided versus skill-focused attention on novice and experienced performance of sensorimotor skills. *Journal of Experimental Psychology: Applied, 8*(1), 6-16. doi:10.1037/1076-898X.8.1.6

Beilock, S. L., & Gray, R. (2012). From attentional control to attentional spillover: A skill-level investigation of attention, movement, and performance outcomes. *Human Movement Science, 31*(6), 1473-1499. doi:10.1016/j.humov.2012.02.014

Bernstein, N. A. (1967). *The Coordination and Regulation of Movements*. Oxford: Pergamon Press.

Caillou, N., Nourrit, D., Deschamps, T., Lauriot, B., & Delignieres, D. (2002). Overcoming spontaneous patterns of coordination during the acquisition of a complex balancing task. *Canadian Journal of Experimental Psychology, 56*(4), 283-293. doi:10.1037/h0087404

Capio, C. M., Poolton, J. M., Sit, C. H., Eguia, K. F., & Masters, R. S. W. (2013). Reduction of errors during practice facilitates fundamental movement skill learning in children with intellectual disabilities. *Journal of Intellectual Disability Research, 57*(4), 295-305. doi:10.1111/j.1365-2788.2012.01535.x

Capio, C. M., Poolton, J. M., Sit, C. H., Holmstrom, M., & Masters, R. S. W. (2013). Reducing errors benefits the field-based learning of a fundamental movement skill in children. *Scandinavian Journal of Medicine & Science in Sports, 23*(2), 181-188. doi:10.1111/j.1600-0838.2011.01368.x

Cooke, A., Kavussanu, M., McIntyre, D., & Ring, C. (2010). Psychological, muscular and kinematic factors mediate performance under pressure. *Psychophysiology, 47*(6), 1109-1118. doi:10.1111/j.1469-8986.2010.01021.x

Davids, K. W., Button, C., & Bennett, S. J. (2008). *Dynamics of skill acquisition: A constraints-led approach*: Human Kinetics.

Fitts, P. M., & Posner, M. I. (1967). *Human performance*. Belmont, CA: Brooks/Cole.

Gray, R. (2004). Attending to the execution of a complex sensorimotor skill: Expertise differences, choking, and slumps. *Journal of Experimental Psychology: Applied, 10*(1), 42-54. doi:10.1037/1076-898X.10.1.42

Han, J., Kamber, M., & Pei, J. (2006). *Data mining, southeast asia edition: Concepts and techniques*. San Fransisco, CA: Morgan Kaufmann Publishers.

Higuchi, T., Imanaka, K., & Hatayama, T. (2002). Freezing degrees of freedom under stress: Kinematic evidence of constrained movement strategies. *Human Movement Science, 21*(5-6), 831-846. doi:10.1016/s0167-9457(02)00174-4

Houtman, I. L. D., & Bakker, F. C. (1989). The anxiety thermometer: A validation study. *Journal of Personality Assessment, 53*(3), 575-582.

Jackson, R. C., Ashford, K., & Norsworthy, G. (2006). Attentional focus, dispositional reinvestment, and skilled motor performance under pressure. *Journal of Sport & Exercise Psychology, 28*(1), 49-68. doi:10.1123/jsep.28.1.49

Jaitner, T., Mendoza, L., & Schöllhorn, W. (2001). Analysis of the long jump technique in the transition from approach to takeoff based on time-continuous kinematic data. *European Journal of Sport Science, 1*(5), 1-12. doi:10.1080/17461390100071506

Konczak, J., Van der Velden, H., & Jaeger, L. (2009). Learning to play the violin: Motor control by freezing, not freeing degrees of freedom. *Journal of Motor Behavior, 41*(3), 243 - 252. doi:10.3200/JMBR.41.3.243-252

Lam, W. K., Maxwell, J. P., & Masters, R. S. W. (2010). Probing the allocation of attention in implicit (motor) learning. *Journal of Sports Sciences, 28*(14), 1543-1554. doi:10.1080/02640414.2010.517543

Lee, M. C. Y., Chow, J. Y., Komar, J., Tan, C. W. K., & Button, C. (2014). Nonlinear pedagogy: An effective approach to cater for individual differences in learning a sports skill. *PloS one, 9*(8), e104744. doi:10.1371/journal.pone.0104744

Liao, C.-M., & Masters, R. S. W. (2001). Analogy learning: A means to implicit motor learning. *Journal of Sports Sciences, 19*(5), 307-319. doi:10.1080/02640410152006081

Malhotra, N., Poolton, J. M., Wilson, M. R., Omuro, S., & Masters, R. S. W. (2015). Dimensions of movement specific reinvestment in practice of a golf putting task. *Psychology of Sport and Exercise, 18*, 1-8. doi:10.1016/j.psychsport.2014.11.008

Masters, R. S. W. (1992). Knowledge, knerves and know□how: The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. *British Journal of Psychology, 83*(3), 343-358. doi:10.1111/j.2044-8295.1992.tb02446.x

Masters, R. S. W., Eves, F. F., & Maxwell, J. P. (2005). *Development of a movement specific reinvestment scale.* Paper presented at the ISSP 11th World Congress of Sport Psychology, Sydney, Australia.

Masters, R. S. W., & Maxwell, J. P. (2008). The theory of reinvestment. *International Review of Sport and Exercise Psychology, 1*(2), 160-183. doi:10.1080/17509840802287218

Masters, R. S. W., Polman, R. C. J., & Hammond, N. V. (1993). 'Reinvestment': A dimension of personality implicated in skill breakdown under pressure. *Personality and Individual Differences, 14*(5), 655-666. doi:10.1016/0191-8869(93)90113-H

Maxwell, J. P., Masters, R. S. W., & Eves, F. F. (2000). From novice to no know-how: A longitudinal study of implicit motor learning. *Journal of Sports Sciences, 18*(2), 111-120. doi:10.1080/026404100365180

Maxwell, J. P., Masters, R. S. W., & Eves, F. F. (2003). The role of working memory in motor learning and performance. *Consciousness and Cognition, 12*(3), 376-402. doi:10.1016/s1053-8100(03)00005-9

Maxwell, J. P., Masters, R. S. W., Kerr, E., & Weedon, E. (2001). The implicit benefit of learning without errors. *The Quarterly Journal of Experimental Psychology Section A, 54*(4), 1049-1068. doi:10.1080/02724980143000073

Maxwell, J. P., Masters, R. S. W., & Poolton, J. M. (2006). Performance breakdown in sport: The roles of reinvestment and verbal knowledge. *Research Quarterly for Exercise and Sport, 77*(2), 271-276. doi:10.1080/02701367.2006.10599360

Nakagawa, S., & Schielzeth, H. (2013). A general and simple method for obtaining R2 from generalized linear mixed□effects models. *Methods in Ecology and Evolution, 4*(2), 133-142. doi:10.1111/j.2041-210x.2012.00261.x

Newell, K. M., Broderick, M. P., Deutsch, K. M., & Slifkin, A. B. (2003). Task goals and change in dynamical degrees of freedom with motor learning. *Journal of Experimental Psychology: Human Perception and Performance, 29*(2), 379. doi:10.1037/0096-1523.29.2.379

Newell, K. M., & Ranganathan, R. (2010). Instructions as constraints in motor skill acquisition. In I. Renshaw, K. Davids, & G. J. P. Savelsbergh (Eds.), *Motor learning in practice: A constraints-led Approach* (pp. 17-32). London: Routledge.

Poldrack, R. A. (2006). Can cognitive processes be inferred from neuroimaging data? *Trends in Cognitive Sciences, 10*(2), 59-63. doi:10.1016/j.tics.2005.12.004

Poldrack, R. A. (2008). The role of fMRI in cognitive neuroscience: Where do we stand? *Current Opinion in Neurobiology, 18*(2), 223-227. doi:10.1016/j.conb.2008.07.006

Poolton, J. M., Masters, R. S. W., & Maxwell, J. P. (2005). The relationship between initial errorless learning conditions and subsequent performance. *Human Movement Science, 24*(3), 362-378. doi:10.1016/j.humov.2005.06.006

Ranganathan, R., & Newell, K. M. (2008). Online feedback and the regulation of degrees of freedom in motor control. *Human Movement Science, 27*(4), 577-589. doi:10.1016/j.humov.2008.01.002

Renshaw, I., Chow, J. Y., Davids, K., & Hammond, J. (2010). A constraints-led perspective to understanding skill acquisition and game play: A basis for integration of motor learning theory and physical education praxis? *Physical Education and Sport Pedagogy, 15*(2), 117-137. doi:10.1080/17408980902791586

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

Schorer, J., Baker, J., Fath, F., & Jaitner, T. (2007). Identification of interindividual and intraindividual movement patterns in handball players of varying expertise levels. *Journal of Motor Behavior, 39*(5), 409-421. doi:10.3200/JMBR.39.5.409-422

Sidaway, B., Sekiya, H., & Fairweather, M. (1995). Movement variability as a function of accuracy demand in programmed serial aiming responses. *Journal of Motor Behavior, 27*(1), 67-76.

Tse, A. C. Y., & van Ginneken, W. F. (2017). Children's conscious control propensity moderates the role of attentional focus in motor skill acquisition. *Psychology of Sport and Exercise*.

Twisk, J. W. R. (2006). *Applied multilevel analysis: A practical guide for medical researchers*: Cambridge University Press.

Van Loon, E. M., Masters, R. S. W., Ring, C., & McIntyre, D. B. (2001). Changes in limb stiffness under conditions of mental stress. *Journal of Motor Behavior, 33*(2), 153-164. doi:10.1080/00222890109603147

Vereijken, B., Van Emmerik, R. E. A., Whiting, H., & Newell, K. M. (1992). Free(z)ing degrees of freedom in skill acquisition. *Journal of Motor Behavior, 24*(1), 133-142. doi:10.1080/00222895.1992.9941608

West, S. G., Aiken, L. S., & Krull, J. L. (1996). Experimental personality designs: Analyzing categorical by continuous variable interactions. *Journal of personality, 64*(1), 1-48. doi:10.1111/j.1467-6494.1996.tb00813.x

Zhu, F. F., Poolton, J. M., Wilson, M. R., Hu, Y., Maxwell, J. P., & Masters, R. S. W. (2011a). Implicit motor learning promotes neural efficiency during laparoscopy. *Surgical Endoscopy, 25*(9), 2950-2955. doi:10.1007/s00464-011-1647-8

Zhu, F. F., Poolton, J. M., Wilson, M. R., Maxwell, J. P., & Masters, R. S. W. (2011b). Neural co-activation as a yardstick of implicit motor learning and the propensity for conscious control of movement. *Biological Psychology, 87*(1), 66-73. doi:10.1016/j.biopsycho.2011.02.004

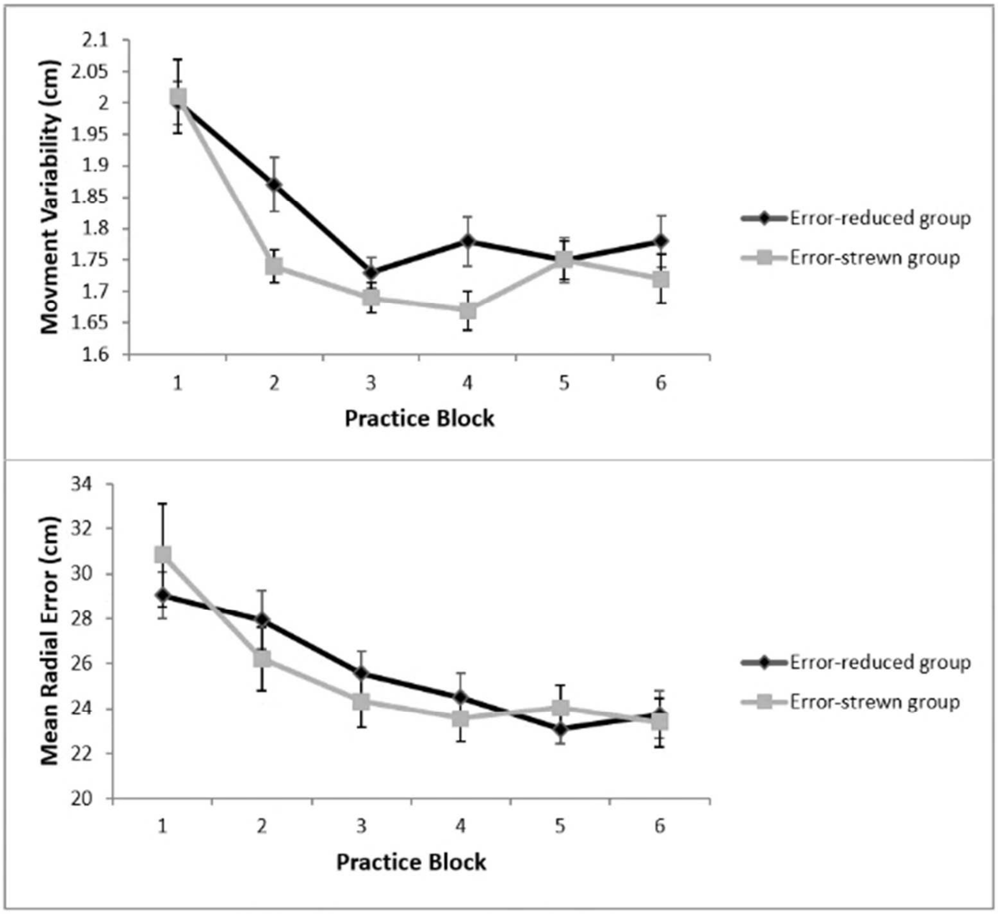

Figure 1. The learning curves both groups. Top: The development of movement variability across practice blocks. Bottom: The development of mean radial error across practice blocks. Error bars represent standard error.

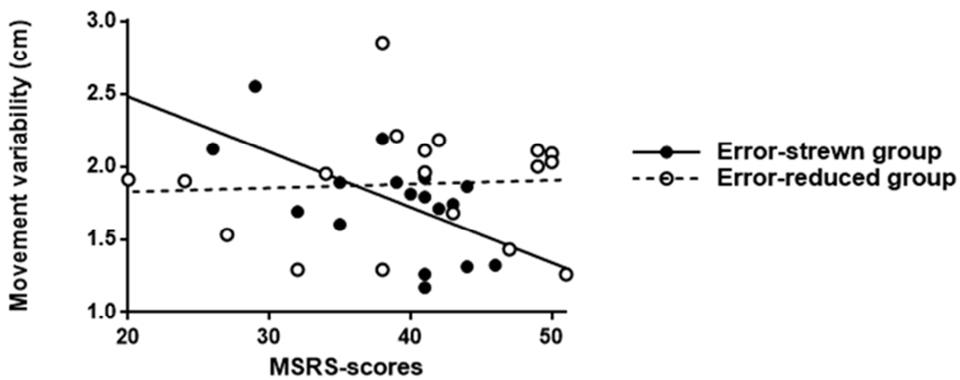

Figure 2. The interaction between group and MSRS score on movement variability during practice.

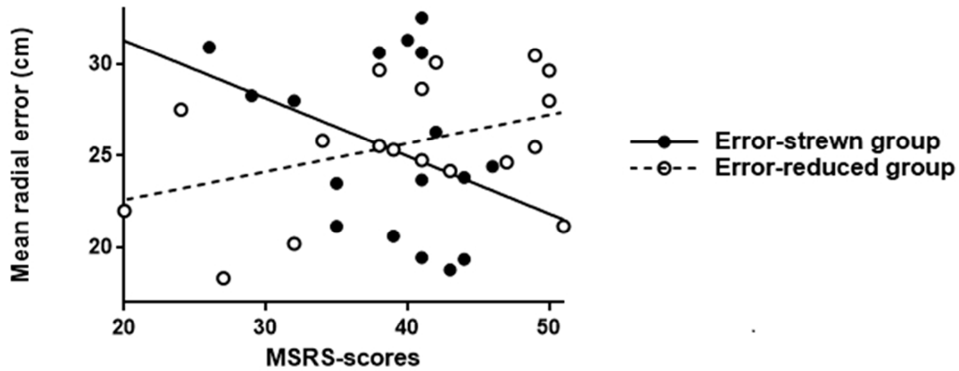

Figure 3. The interaction between group and MSRS score on performance during practice.

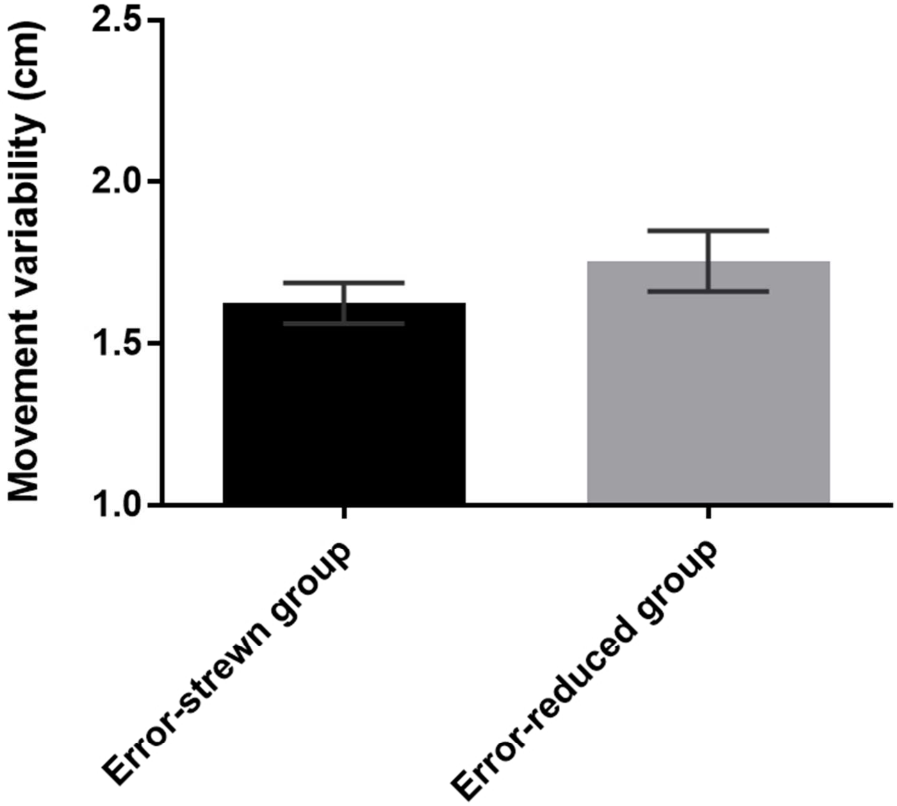

Figure 4. The main effect of group on movement variability during retention and transfer. Error bars represent standard error.

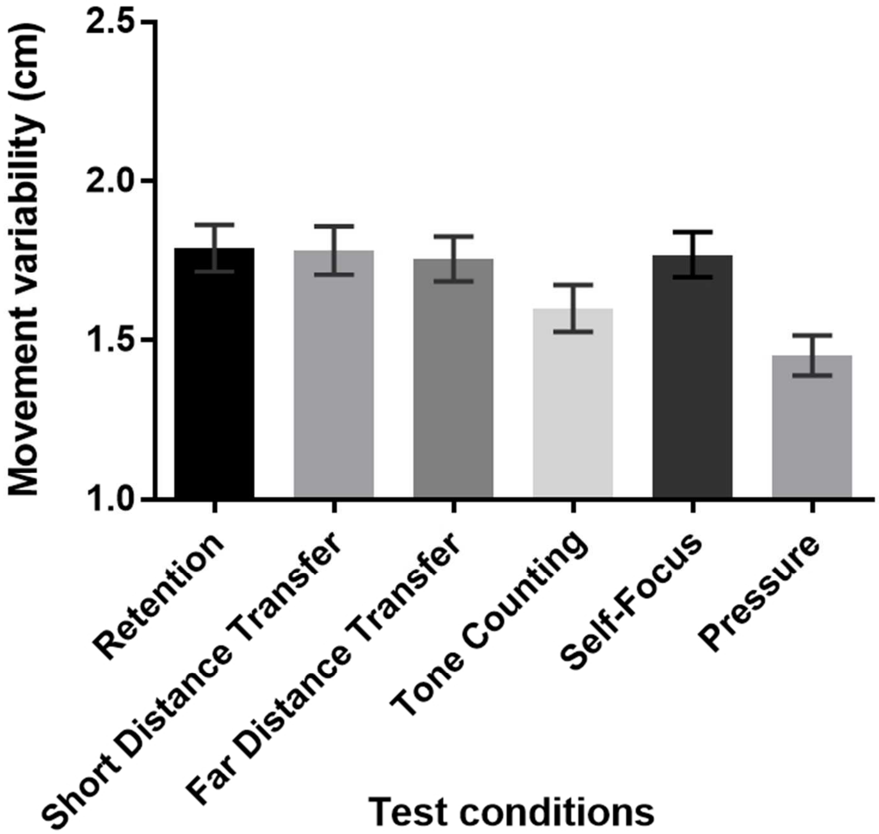

Figure 5. The main effect of test on movement variability during retention and transfer. Error bars represent standard error.

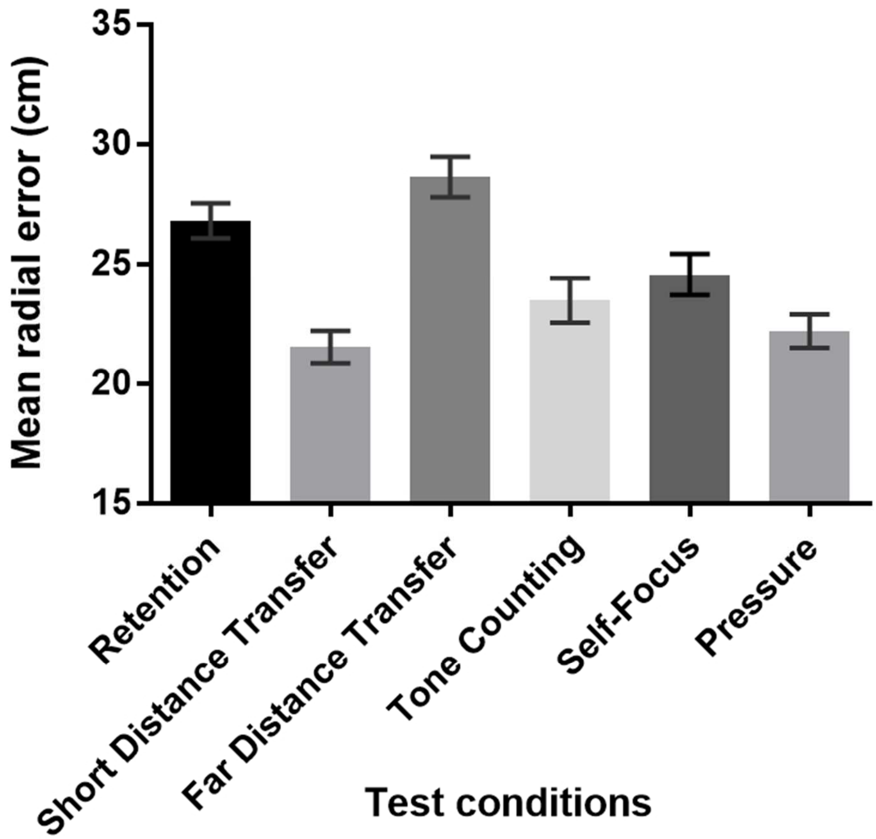

Figure 6. The main effect of test on performance during retention and transfer. Error bars represent standard error.

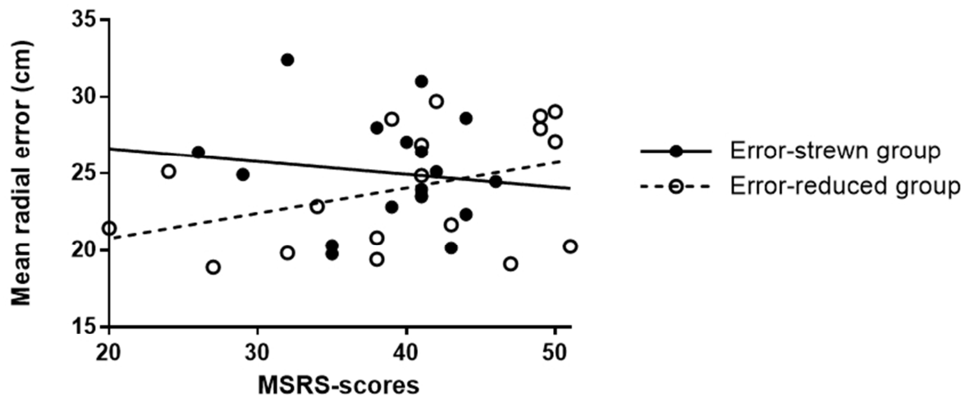

Figure 7. The interaction between group and MSRS score on performance during retention and transfer.

Appendix A – Movement Variability

This appendix describes how mean Euclidean distance (MUD) – our measure of movement variability – was determined. All kinematic data was processed using Matlab version R2012a. Position data of all markers on the body was low-pass filtered via a 2nd order Butterworth filter with a cutoff value of 10 Hz, preserving more than 99% of the signal.

Figure A1 shows the experimental setup and placement of the reflective markers. Figure A2 shows how the moment of release was determined. The raw data of the ball (Figure A2.A) contained kinematics of throw and flight. First, it was estimated which frames had a vertical acceleration equal to the gravitational acceleration of 9.81m/s^2. The first frame on this list – as indicated by the arrow in Figure A2.B was deemed to be reasonably close to the moment of release. Based on this estimation, frames were divided into before- and after release. In Figure A2.C the frames before release are indicated with a stick figure of the throwing arm. The data of the ball was then extrapolated to create an informed estimation of where the ball marker would have been had it not been released (Figure A2.D). This was done by fitting a second order polynomial through the ball marker data before release (Figure A2.E). The same was done for the ball marker data after release, with the exception that instead of extrapolating forward in time, the extrapolation was done backwards. Hence, it could be estimated where the ball would have been had it already been released. Similar to Lohse, Jones, Healy, and Sherwood (2014), the intersection between the two sets of extrapolated data was used to determine the moment of release, as indicated by the arrow in Figure A2.F.

Based on the moment of release, data of the last 200ms before release was selected for further analysis (Figure A3.A). To guard against the influence of changes in seating position, the origin of the reference frame was placed at the average position of the shoulder marker.

Throws for which the forward acceleration phase was less than 200ms were excluded from the analysis (< 0.1% of throws). By comparing the marker position of all markers between trials (see Figure A3.B to E), measures of Euclidean distance were obtained. The average of these comparisons within a block was the MUD (cm) for that block.

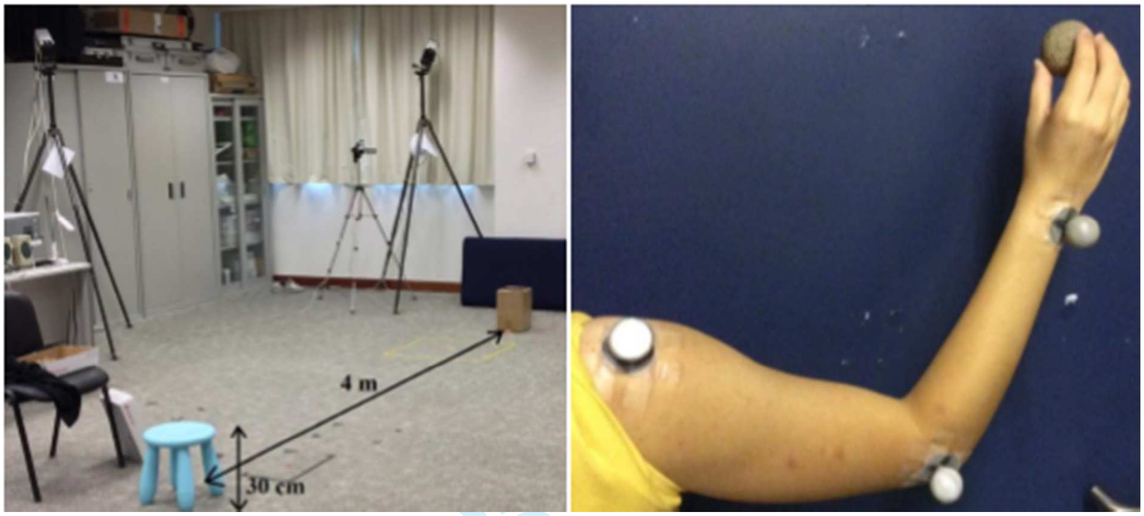

Fig. A1. (Left) The experimental setup showing the 30cm high stool, the smallest target box and 2 of the Qualysis cameras. (Right) The markers on shoulder and elbow (acromion- and olecranon process) and writst (radial styloid) as well as the hand (reflective golf-ball).

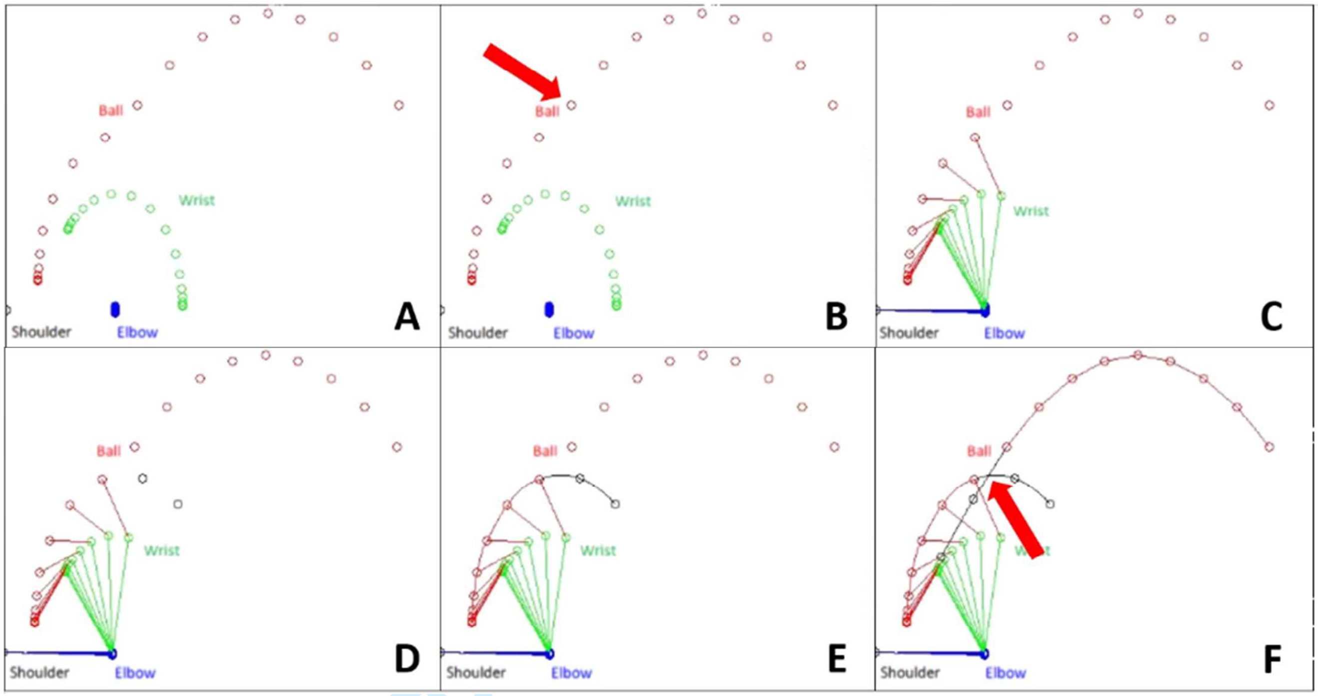

Fig. A2. Determination of the moment of release from A) the raw data, B) first frame where a vertical acceleration of $9.81 m/s^2$ was registered, C) a first approximation of frames before- and after release, D) and E) extrapolation of ball marker data and F) determination of release via cross section of extrapolated data before- and after release.

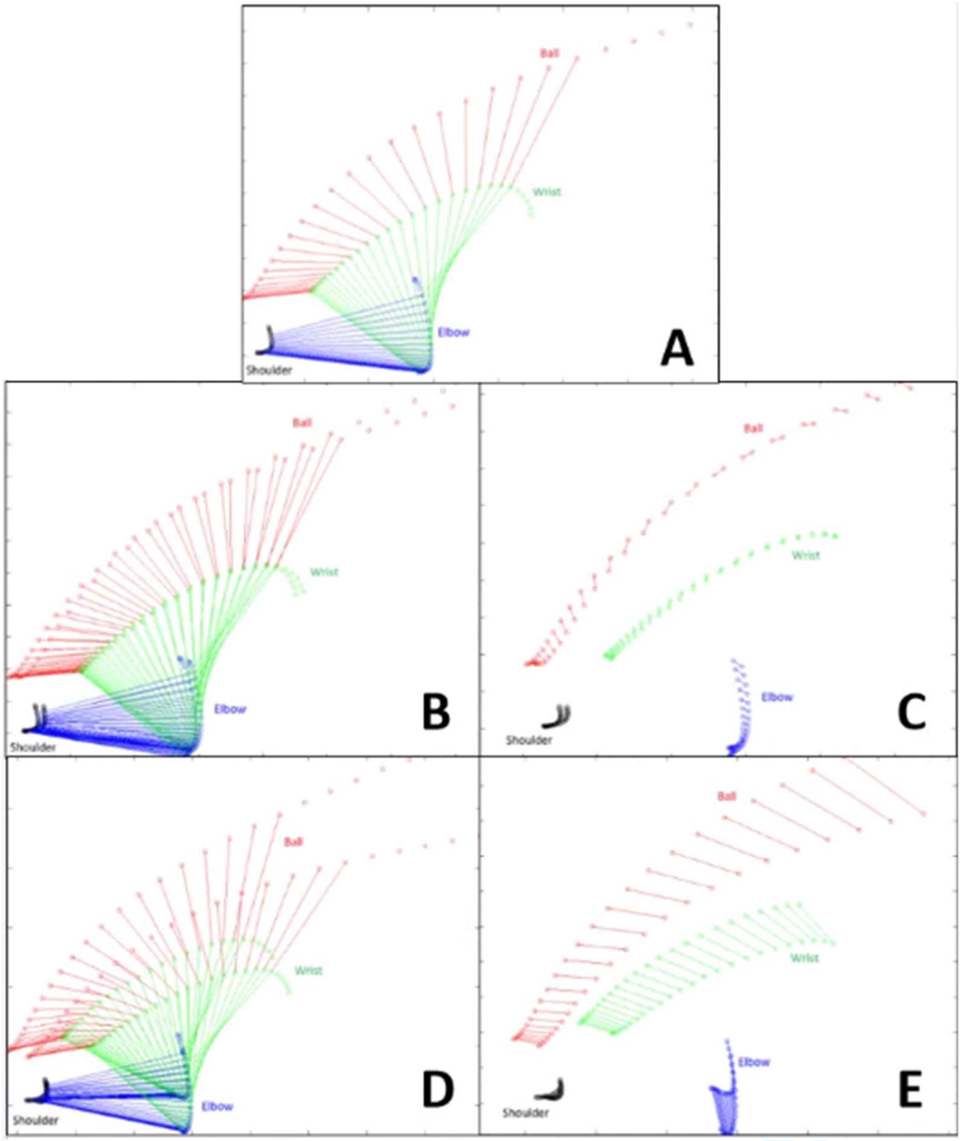

Fig. A3. Two example of Euclidean distance, with A) data of 1 trial, B) overlapping data of 2 similar trials with C) low Euclidean distance and D) overlapping data of 2 dissimilar trials with E) high Euclidean distance.

Appendix B – AIC values different models

This appendix describes AIC values obtained after adding factors to GLMMs performed in this study. In accordance with Twisk (2006), a main model incuding the effects of group and MSRS score was used first, after which effects of practice block, test condition, order and different interaction were added in a stepwise fashion. If a factor lowered AIC by 2 points, it was retained in the model. If it did not lower AIC by 2, it was removed from the model before the next factor was added. AIC values of factors included in the best-fitting model are written **bold**.

Practice

Practice	Movement Variability	Mean Radial Error
Main model: Group and MSRS scores	**300.29**	**1338.22**
Practice block	**291.97**	**1302.46**
Group x MSRS scores	**287.06**	**1279.29**
Group x Practice block	292.81	**1260.51**
MSRS scores x Practice block	318.86	1268.43
Group x MSRS scores x Practice block	344.59	1264.25

Retention and Transfer

Retention and Transfer	Movement Variability	Mean Radial Error
Main model: Group and MSRS scores	**284.79**	**1338.24**
Test condition	**281.08**	**1275.28**
Order	286.36	**1269.18**
Group x MSRS scores	283.72	**1266.15**
Group x Test condition	299.46	**1249.31**
MSRS scores x Test condition	312.52	1258.77
Group x Order	292.86	1251.21
MSRS scores x Order	303.99	1254.18
Test condition x Order	288.94	1261.53
Group x MSRS scores x Test condition	340.47	1258.81
Group x MSRS scores x Order	325.52	1259.93
Group x Test condition x Order	295.45	1266.78
MSRS scores x Test condition x Order	334.87	1257.35
Group x MSRS scores x Test condition x Order	379.28	1259.27

Tone counting accuracy

AICs for the models predicting tone-counting accuracy were 265.39 for the main model including only the main effects of group and MSRS scores and 264.71 when their interaction was added. The factor test condition and the order effect were irrelevant, as tone-counting accuracy was measured only in 1 of the transfer tests. The interaction effect was not included in the best-fitting model, because its inclusion decreased the AIC value by less than 2.

Appendix C – Learning Curves and between-block comparisons

This appendix contains information for those readers interested in the learning curves and between-block comparisons of mean radial error and movement variability during the practice phase. The between-block comparisons are provided using log transformed as well as untransformed data.

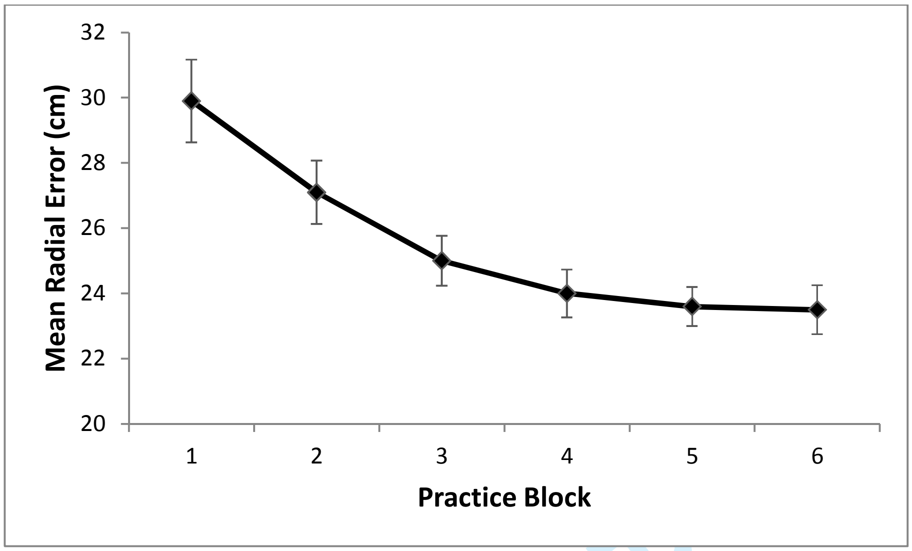

Fig. C1. Mean radial error in all blocks during practice. Error bars represent standard error.

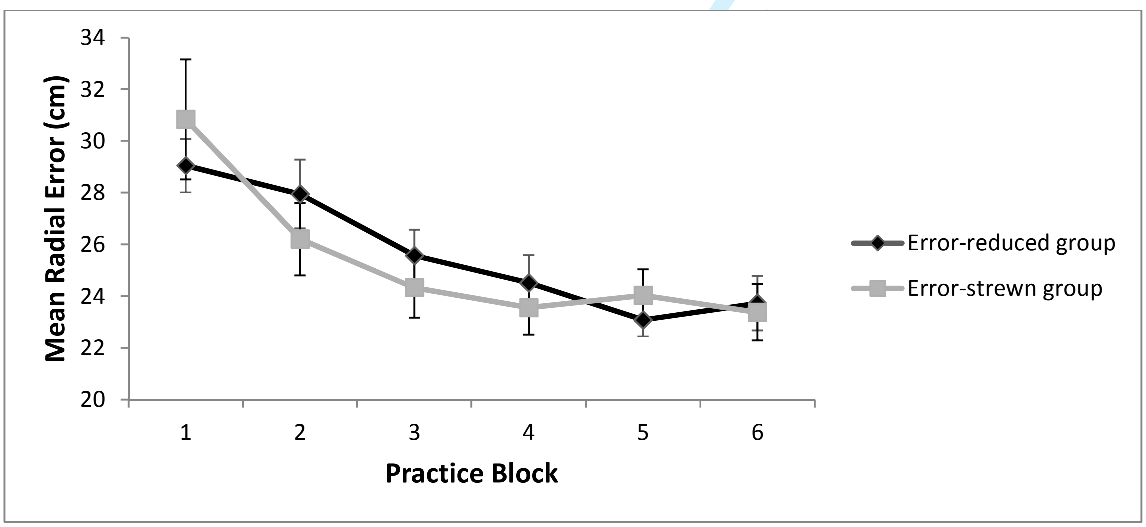

Fig. C2. Mean radial error of both groups in all blocks during practice. Error bars represent standard error.

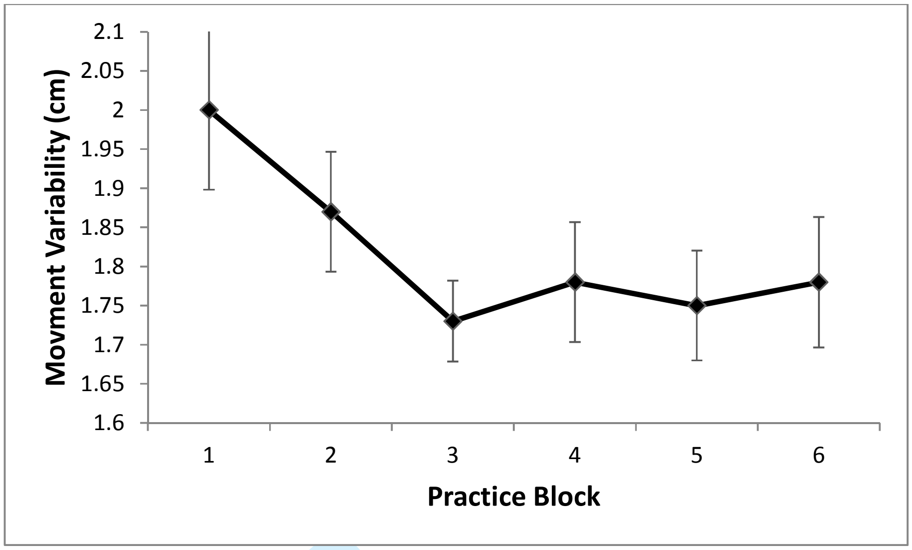

Fig. C3. Movement variability in all blocks during practice. Error bars represent standard error.

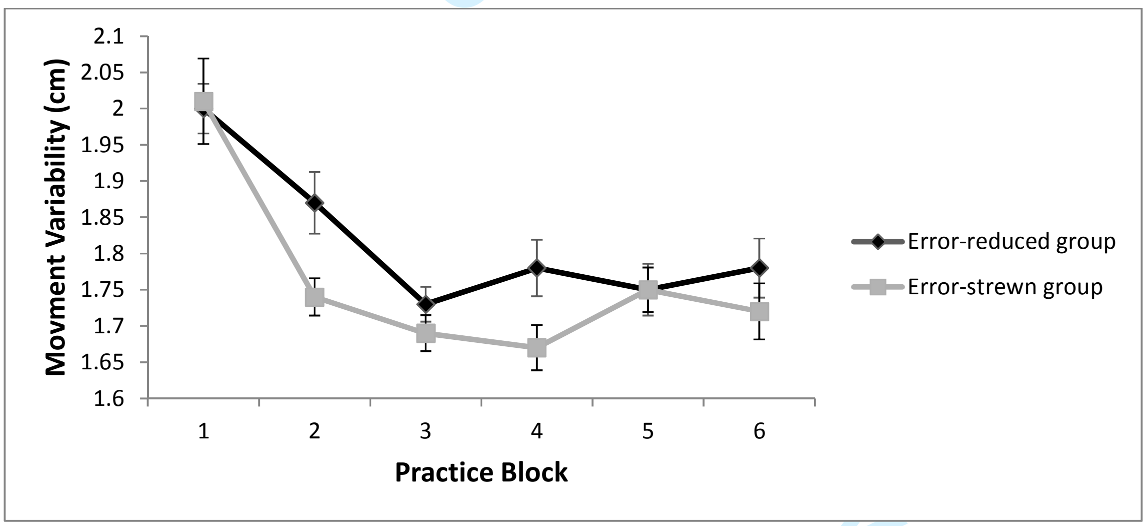

Fig. C4. Movement variability of both groups in all blocks during practice. Error bars represent standard error.

Practice Mean Radial Error (Untransformed)	Block 2 *M* = 27.08 *SD* = 5.79	Block 3 *M* = 24.95 *SD* = 4.56	Block 4 *M* = 24.03 *SD* = 4.44	Block 5 *M* = 23.55 *SD* = 3.57	Block 6 *M* = 23.55 *SD* = 4.48
Block 1 *M* = 29.95 *SD* = 7.57	*MD* = 2.87 *SEMD* = 1.08 *t* = 2.65 *p* < .05 *95% CI* = [.67 5.06]	*MD* = 5.00 *SEMD* = 1.20 *t* = 4.17 *p* < .001 *95% CI* = [2.57 7.43]	*MD* = 5.91 *SEMD* = 1.15 *t* = 5.12 *p* < .001 *95% CI* = [3.57 8.25]	*MD* = 6.39 *SEMD* = 1.22 *t* = 5.25 *p* < .001 *95% CI* = [3.92 8.87]	*MD* = 6.39 *SEMD* = 1.22 *t* = 5.22 *p* < .001 *95% CI* = [3.91 8.88]
Block 2		*MD* = 2.13 *SEMD* = .69 *t* = 3.08 *p* < .01 *95% CI* = [.73 3.54]	*MD* = 3.05 *SEMD* = .70 *t* = 4.32 *p* < .001 *95% CI* = [1.61 4.48]	*MD* = 3.53 *SEMD* = .81 *t* = 4.34 *p* < .001 *95% CI* = [1.88 5.18]	*MD* = 3.53 *SEMD* = .84 *t* = 4.19 *p* < .001 *95% CI* = [1.82 5.24]
Block 3			*MD* = .91 *SEMD* = .56 *t* = 1.58 *p* = .12 *95% CI* = [-.26 2.09]	*MD* = 1.39 *SEMD* = .60 *t* = 2.34 *p* < .05 *95% CI* = [.18 2.60]	*MD* = 1.39 *SEMD* = *t* = 2.27 *p* < .05 *95% CI* = [.15 2.64]
Block 4				*MD* = .48 *SEMD* = .55 *t* = .87 *p* = .39 *95% CI* = [-.65 1.161]	*MD* = .48 *SEMD* = .47 *t* = 1.02 *p* = .31 *95% CI* = [-.47 1.43]
Block 5					*MD* = .001 *SEMD* = .40 *t* = .01 *p* = .99 *95% CI* = [-.82 .82]

Table C1. All between-block comparisons for the mean radial error data

Practice Mean Radial Error (Transformed)	Block 2 *M* = 1.42 *SD* = .10	Block 3 *M* = 1.39 *SD* = .08	Block 4 *M* = 1.37 *SD* = .08	Block 5 *M* = 1.37 *SD* = .07	Block 6 *M* = 1.36 *SD* = .09
Block 1 *M* = 1.47 *SD* = .10	*MD* = .04 *SEMD* = .01 *t* = 3.00 *p* < .01 *95% CI* = [.01 .07]	*MD* = .08 *SEMD* = .01 *t* = 5.11 *p* < .001 *95% CI* = [.05 .11]	*MD* = .09 *SEMD* = .01 *t* = 6.23 *p* < .001 *95% CI* = [.06 .12]	*MD* = .10 *SEMD* = .02 *t* = 6.38 *p* < .001 *95% CI* = [.07 .13]	*MD* = .10 *SEMD* = .02 *t* = 6.31 *p* < .001 *95% CI* = [.07 .13]
Block 2		*MD* = .03 *SEMD* = .01 *t* = 2.78 *p* < .01 *95% CI* = [.01 .06]	*MD* = .05 *SEMD* = .01 *t* = 3.95 *p* < .001 *95% CI* = [.02 .07]	*MD* = .05 *SEMD* = .01 *t* = 4.13 *p* < .001 *95% CI* = [.03 .08]	*MD* = .06 *SEMD* = .01 *t* = 4.04 *p* < .001 *95% CI* = [.03 .09]
Block 3			*MD* = .02	*MD* = .02	*MD* = .03

			SEMD = .01 *t* = 1.69 *p* = .10 *95% CI* = [-.004 .04]	*SEMD* = .01 *t* = 2.27 *p* < .05 *95% CI* = [.002 .04]	*SEMD* = .01 *t* = 2.40 *p* < .05 *95% CI* = [.004 .05]
Block 4				*MD* = .01 *SEMD* = .01 *t* = .60 *p* = .55 *95% CI* = [-.01 .03]	*MD* = .01 *SEMD* = .01 *t* = 1.1 *p* = .28 *95% CI* = [-.01 .03]
Block 5					*MD* = .01 *SEMD* = .01 *t* = .44 *p* = .66 *95% CI* = [-.01 .02]

Table C2. All between-block comparisons for the log transformed mean radial error data

Practice Movement Variability (Untransformed)	Block 2 *M* = 1.87 *SD* = .46	Block 3 *M* = 1.74 *SD* = .31	Block 4 *M* = 1.78 *SD* = .46	Block 5 *M* = 1.75 *SD* = .42	Block 6 *M* = 1.78 *SD* = .50
Block 1 *M* = 2.00 *SD* = .61	*MD* = .13 *SEMD* = .10 *t* = 1.35 *p* = .19 *95% CI* = [-.06 .33]	*MD* = .26 *SEMD* = .08 *t* = 3.10 *p* < .01 *95% CI* = [.09 .43]	*MD* = .22 *SEMD* = .08 *t* = 2.65 *p* < .05 *95% CI* = [.05 .39]	*MD* = .25 *SEMD* = .08 *t* = 3.29 *p* < .01 *95% CI* = [.10 .41]	*MD* = .22 *SEMD* = .11 *t* = 2.10 *p* < .05 *95% CI* = [.01 .44]
Block 2		*MD* = .13 *SEMD* = .06 *t* = 2.15 *p* < .05 *95% CI* = [.01 .25]	*MD* = .09 *SEMD* = .06 *t* = 1.54 *p* = .13 *95% CI* = [-.03 .20]	*MD* = .12 *SEMD* = .06 *t* = 1.86 *p* = .07 *95% CI* = [-.01 .25]	*MD* = .09 *SEMD* = .07 *t* = 1.32 *p* = 20 *95% CI* = [-.05 .23]
Block 3			*MD* = -.04 *SEMD* = .05 *t* = -.81 *p* = .43 *95% CI* = [-.15 .06]	*MD* = -.01 *SEMD* = .06 *t* = -.21 *p* = .84 *95% CI* = [-.13 .10]	*MD* = -.04 *SEMD* = .06 *t* = -.69 *p* = .49 *95% CI* = [-.16 .08]
Block 4				*MD* = .03 *SEMD* = .04 *t* = .77 *p* = .45 *95% CI* = [-.05 .11]	*MD* = .002 *SEMD* = .07 *t* = .03 *p* = .98 *95% CI* = [-.13 .14]
Block 5					*MD* = -.03 *SEMD* = .07 *t* = -.42 *p* = .68 *95% CI* = [-.16 .11]

Table C3. All between-block comparisons for the movement variability data

Practice Movement Variability (Transformed)	Block 2 *M* = .26 *SD* = .10	Block 3 *M* = .23 *SD* = .08	Block 4 *M* = .24 *SD* = .11	Block 5 *M* = .23 *SD* = .10	Block 6 *M* = .23 *SD* = .13
Block 1 *M* = .29 *SD* = .11	*MD* = .03 *SEMD* = .02 *t* = 1.50 *p* = .14 *95% CI* = [-.01 .06]	*MD* = .05 *SEMD* = .01 *t* = 3.61 *p* < .01 *95% CI* = [.02 .08]	*MD* = .05 *SEMD* = .02 *t* = 3.18 *p* < .01 *95% CI* = [.02 .08]	*MD* = .05 *SEMD* = .01 *t* = 3.82 *p* < .01 *95% CI* = [.03 .08]	*MD* = .05 *SEMD* = .02 *t* = 2.70 *p* < .05 *95% CI* = [.01 .09]
Block 2		*MD* = .03 *SEMD* = .01 *t* = 2.14 *p* < .05 *95% CI* = [.001 .05]	*MD* = .02 *SEMD* = .01 *t* = 1.69 *p* = .10 *95% CI* = [-.005 .05]	*MD* = .03 *SEMD* = .01 *t* = 1.99 *p* = .054 *95% CI* = [-.001 .06]	*MD* = .03 *SEMD* = .02 *t* = 1.71 *p* = .10 *95% CI* = [-.005 .06]
Block 3			*MD* = -.004 *SEMD* = .01 *t* = -.35 *p* = .73 *95% CI* = [-.03 .02]	*MD* = .002 *SEMD* = .01 *t* = .15 *p* = .88 *95% CI* = [-.02 .03]	*MD* = .001 *SEMD* = .01 *t* = .05 *p* =.96 *95% CI* = [-.03 .03]
Block 4				*MD* = .006 *SEMD* = .01 *t* = .60 *p* = .55 *95% CI* = [-.01 .03]	*MD* = .005 *SEMD* = .01 *t* = .32 *p* = .75 *95% CI* = [-.03 .03]
Block 5					*MD* = -.001 *SEMD* = .02 *t* = -.09 *p* = .93 *95% CI* = [-.03 .03]

Table C4. All between-block comparisons for the log transformed movement variability data

Appendix D – Between-test comparisons

This appendix describes all between-test comparison in the retention and transfer phase regarding movement variability and mean radial error. The comparisons are provided for the log transformed as well as for the untransformed data.

Retention and Transfer Mean Radial Error (Untransformed)	Short Distance M = 21.53 SD = 4.08	Far Distance M = 28.62 SD = 5.10	Tone Counting M = 23.47 SD = 5.58	Skill Focus M = 24.56 SD = 5.12	Pressure M = 22.19 SD = 4.22
Retention M = 26.80 SD = 4.35	MD = 5.27 $SEMD$ = .76 t = 7.03 p < .001 *95% CI* = [3.75 6.79]	MD = -1.82 $SEMD$ = .75 t = -2.42 p < .05 *95% CI* = [-3.35 -.30]	MD = 3.33 $SEMD$ = .89 t = 3.75 p < .01 *95% CI* = [1.52 5.13]	MD = 2.24 $SEMD$ = .70 t = 3.19 p < .01 *95% CI* = [.81 3.66]	MD = 4.61 $SEMD$ = .62 t = 7.42 p < .001 *95% CI* = [3.35 5.88]
Short Distance		MD = -7.09 $SEMD$ = .90 t = -7.90 p < .001 *95% CI* = [-8.91 -5.27]	MD = -1.94 $SEMD$ = .72 t = -2.68 p < .05 *95% CI* = [-3.41 -.47]	MD = -3.03 $SEMD$ = .79 t = -3.83 p < .001 *95% CI* = [-4.64 -1.42]	MD = -.66 $SEMD$ = .69 t = -.95 p = .35 *95% CI* = [-2.05 .74]
Far Distance			MD = 5.15 $SEMD$ = 1.03 t = 5.00 p < .001 *95% CI* = [3.06 7.24]	MD = 4.06 $SEMD$ = .79 t = 5.11 p < .001 *95% CI* = [2.45 5.67]	MD = 6.43 $SEMD$ = .66 t = 9.70 p < .001 *95% CI* = [5.09 7.78]
Tone Counting				MD = -1.09 $SEMD$ = .85 t = -1.29 p = .21 *95% CI* = [-2.81 .63]	MD = 1.29 $SEMD$ = .75 t = 1.71 p = .10 *95% CI* = [-.24 2.81]
Skill Focus					MD = 2.38 $SEMD$ = .57 t = 4.17 p < .001 *95% CI* = [1.22 3.53]

Table D1. The between-test comparisons for the mean radial error data

Retention and Transfer Mean Radial Error (Transformed)	Short Distance M = 1.32 SD = .09	Far Distance M = 1.45 SD = .08	Tone Counting M = 1.36 SD = .10	Skill Focus M = 1.38 SD = .09	Pressure M = 1.34 SD = .08

Retention $M = 1.42$ $SD = .07$	$MD = .10$ $SEMD = .01$ $t = 6.90$ $p < .001$ *95% CI =* [.07 .13]	$MD = -.03$ $SEMD = .01$ $t = -2.14$ $p < .05$ *95% CI =* [-.05 -.003]	$MD = .06$ $SEMD = .01$ $t = 4.21$ $p < .001$ *95% CI =* [.03 .09]	$MD = .04$ $SEMD = .01$ $t = 3.35$ $p < .01$ *95% CI =* [.02 .07]	$MD = .08$ $SEMD = .01$ $t = 7.55$ $p < .001$ *95% CI =* [.06 .11]
Short Distance		$MD = -.12$ $SEMD = .02$ $t = -7.50$ $p < .001$ *95% CI =* [-.16 -.09]	$MD = -.03$ $SEMD = .01$ $t = -2.56$ $p < .05$ *95% CI =* [-.06 -.01]	$MD = -.06$ $SEMD = .01$ $t = -3.90$ $p < .001$ *95% CI =* [-.09 -.03]	$MD = -.01$ $SEMD = .01$ $t = -.97$ $p = .34$ *95% CI =* [-.04 .01]
Far Distance			$MD = .09$ $SEMD = .02$ $t = 5.36$ $p < .001$ *95% CI =* [.06 .12]	$MD = .07$ $SEMD = .01$ $t = 5.32$ $p < .001$ *95% CI =* [.04 .09]	$MD = .11$ $SEMD = .01$ $t = 9.40$ $p < .001$ *95% CI =* [.09 .14]
Tone Counting				$MD = -.02$ $SEMD = .01$ $t = -1.56$ $p = .13$ *95% CI =* [-.05 .01]	$MD = .02$ $SEMD = .01$ $t = 1.59$ $p = .12$ *95% CI =* [-.01 .05]
Skill Focus					$MD = .04$ $SEMD = .01$ $t = 4.45$ $p < .001$ *95% CI =* [.02 .06]

Table D2. The between-test comparisons for the log transformed mean radial error data

Retention and Transfer Movement Variability (Untransformed)	Short Distance $M = 1.78$ $SD = .46$	Far Distance $M = 1.75$ $SD = .43$	Tone Counting $M = 1.60$ $SD = .44$	Skill Focus $M = 1.77$ $SD = .43$	Pressure $M = 1.45$ $SD = .38$
Retention $M = 1.79$ $SD = .44$	$MD = .01$ $SEMD = .06$ $t = .13$ $p = .90$ *95% CI =* [-.11 .13]	$MD = .03$ $SEMD = .06$ $t = .64$ $p = .52$ *95% CI =* [-.08 .15]	$MD = .19$ $SEMD = .08$ $t = 2.25$ $p < .05$ *95% CI =* [.02 .36]	$MD = .02$ $SEMD = .07$ $t = .30$ $p = .77$ *95% CI =* [-.12 .16]	$MD = .34$ $SEMD = .06$ $t = 5.35$ $p < .001$ *95% CI =* [.21 .46]
Short Distance		$MD = .03$ $SEMD = .06$ $t = .47$ $p = .54$ *95% CI =* [-.09 .15]	$MD = .18$ $SEMD = .09$ $t = 1.96$ $p = .06$ *95% CI =* [-.01 .37]	$MD = .01$ $SEMD = .06$ $t = .21$ $p = .83$ *95% CI =* [-.11 .14]	$MD = .33$ $SEMD = .06$ $t = 5.80$ $p < .001$ *95% CI =* [.21 .45]
Far Distance			$MD = .16$ $SEMD = .08$ $t = 2.05$ $p < .05$	$MD = -.14$ $SEMD = .06$ $t = -.23$ $p = .82$	$MD = .30$ $SEMD = .05$ $t = 5.97$ $p < .001$

			95% CI = [.00 .31]	*95% CI* = [-.13 .11]	*95% CI* = [.20 .41]
Tone Counting				*MD* = -.17 *SEMD* = .09 *t* = -1.92 *p* = .06 *95% CI* = [-.35 .01]	*MD* = .15 *SEMD* = .07 *t* = 2.15 *p* < .05 *95% CI* = [.01 .29]
Skill Focus					*MD* = .32 *SEMD* = .06 *t* = 5.04 *p* < .001 *95% CI* = [.19 .44]

Table D3. The between-test comparisons for the movement variability data

Retention and Transfer Movement Variability (Transformed)	Short Distance *M* = .24 *SD* = .11	Far Distance *M* = .23 *SD* = .11	Tone Counting *M* = .19 *SD* = .11	Skill Focus *M* = .24 *SD* = .10	Pressure *M* = .15 *SD* = .12
Retention *M* = .24 *SD* = .11	*MD* = .003 *SEMD* = .01 *t* = .19 *p* = .95 *95% CI* = [.03 .03]	*MD* = .01 *SEMD* = .01 *t* = .65 *p* = .52 *95% CI* = [-.02 .03]	*MD* = .05 *SEMD* = .02 *t* = 2.60 *p* < .05 *95% CI* = [.01 .09]	*MD* = .004 *SEMD* = .02 *t* = .23 *p* = .82 *95% CI* = [-.03 .04]	*MD* = .09 *SEMD* = .01 *t* = 6.28 *p* < .001 *95% CI* = [.06 .12]
Short Distance		*MD* = .01 *SEMD* = .01 *t* = .40 *p* = .70 *95% CI* = [-.02 .03]	*MD* = .05 *SEMD* = .02 *t* = 2.15 *p* < .05 *95% CI* = [.003 .09]	*MD* = .001 *SEMD* = .02 *t* = .07 *p* = .95 *95% CI* = [-.03 .03]	*MD* = .09 *SEMD* = .01 *t* = 6.13 *p* < .001 *95% CI* = [.06 .12]
Far Distance			*MD* = .04 *SEMD* = .02 *t* = 2.38 *p* < .05 *95% CI* = [.01 .08]	*MD* = -.004 *SEMD* = .01 *t* = -.33 *p* = .74 *95% CI* = [-.03 .02]	*MD* = .08 *SEMD* = .01 *t* = 6.25 *p* < .001 *95% CI* = [.06 .11]
Tone Counting				*MD* = -.05 *SEMD* = .02 *t* = -2.44 *p* < .05 *95% CI* = [-.09 -.01]	*MD* = .04 *SEMD* = .02 *t* = 2.28 *p* < .05 *95% CI* = [.005 .08]
Skill Focus					*MD* = .09 *SEMD* = .02 *t* = 5.64 *p* < .001 *95% CI* = [.06 .12]

Table D4. The between-test comparisons for the log transformed movement variability data