conscious processing of movements is associated with relatively errorless and errorful learning on learning the relative timing of a task the under dual-task condition

Saeed Nazari Kakvandi
Ferdowsi university of Mashhad
Alireza Saberi Kakhki
Ferdowsi university of Mashhad
Eduardo Bellomo
Bangor University
Hasan Rohbanfard
Bu-Ali Sina University
Morteza Homayounnia Firoozjah (mortezahomayoun@gmail.com)
Farhangian university
Mehdi Qorbanian Qohroudi
University of Science, Islamic Azad

Research Article

Keywords: Errorless learning, Errorful learning, Contextual Interference, Reinvestment theory, implicit learning, explicit learning.

Posted Date: July 16th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1808395/v1

Abstract

This study aimed to investigate the relatively explicit (errorful) or implicit (errorless) conditions on the learning the relative timing was a motor task. Healthy participants (N = 38, M_{age} = 22.6 years, SD_{age} = 3.2 years) were randomly assigned to one of three groups (control, errorful, errorless). We conducted the study in four phases: (1) Pretest; (2) Acquisition (group specific); (3) Retention at 10-minutes and 24-hours post-acquistion; (4) Transfer at 10-minutes and 24-hours post-acquisition. Each phase consisted of 10 trials, except for Acquisition, which consisted of 45 trials. The transfer tests and also the high correlation between scores the total MSRS scores with errorful and control schedules. participants were tested, in a novel total movement, timing creations and relative timing structure (1300 MS, 325 MS for each segment, respectively). In both the retention and transfer tests, the errorless group in the relative timing (RMSE) performed more accurately than other groups ($p \leq 0.05$). These results suggest that implicit learning in the form of errorless acquisition results is a smoother and more accurate motor performance for the retention and transfer tests. The results support previous findings that display an errorless learning paradigm, effectively minimize skill degradation under pressure conditions that are further consistent with the implicit learning and reinvestment theories.

Introduction

A primary reason a person practices skills is to improve their ability to perform in future situations (Schmidt & Lee, 2013; Magill, 2011). In the last 20 years, the motor control literature discussed how, besides practice time, also practice quality plays a crucial role (i.e., Magill, 2011; Masters, 1993). In other words, besides extensive practice, what matters is also how a specific skill is learned.

Errorful Versus Errorless Learning

Within the motor control literature, two major learning strategies seem to emerge. On the one hand, we have a more classical and somewhat sponateous type of learning, which we can call explicit or errorful (Fitts & Posner, 1967). This involves deliberate practice and, inevitably, performance errors that trigger in the learner movement specific hypothesis-testing, in an attempt to find and store a set of explicit, declarative rules for a proficient skill execution and performance. This skill-focused hypothesis-testing process, also known as conscious processing (i.e., Masters, 1992; Maxwell, Masters, & Eves, 2003), would happen within our working memory (Baddeley, 2012), a limited-resources system which is responsible for retrieving and manipulating consciously accessible declarative knowledge so to enable our motor (and cognitive) system to control movement online. On the other hand, we have implicit errorless learning, which, as the name suggests consists in a practice schedule whereby the chance for error is reduced and the learner acquires the skill without the involvement of working-memory mediated hypothesis testing and without the creation of explicit movement rules and therefore low conscious processing (Masters et al., 2014).

What are the advantages/disadvantages of these two strategies? Errorful learning, because of its explicit focus on the skill seems to have the advantage of granting an overall faster skill acquisition. For example, Bellomo, Cooke, and Hardy (2018) showed how errorful learning during a sequence learning-task led to faster chunking, reduced conscious reprocessing, and increased cortical efficiency (higher left-temporal high alpha power) compared to errorless learning. Some theorists additionally suggest that errorful learning might also contribute to create an autonomy-supportive environment that increases confidence and self-efficacy. Errorful learning gives learners the chance to make task-relevant choices. The Optimizing Performance via Intrinsic Motivation and Attention for Learning (OPTIMAL) theory of motor learning emphasizes learner autonomy through choice possibilities. (Lee et al., 2016; Wulf, Chiviacowsky, & Cardozo, 2014; Lee et al., 2016; Sanli, Lee, et al., 2015; Chien, & Chen, 2017;Levac, Galvez, Mercado, O'Neil,2017). According to Lee et al. (2016), incorrect acts follow the mechanisms proposed by the schema theory. Guided error-based learning elucidates a student's basic schema, allowing educators to better comprehend it and employ student-centered pedagogy. Furthermore, errors in motor skills exercises may result in the storage of response information about improper motions in the brain. The database of the recall schema will be used to hold the responsive information of improper motions. To enhance the relationship with the recognition schema, reaffirmation might be done by recalling the erring experience. Wrong actions can lead to an increase in skills self-efficacy and learning effectiveness in the acquisition phase, according to the mechanics of the generalized motor program in the schema theory. However, although explicit processes would be particularly advantageous crucial early in learning, they could also backfire at later stages, once the skill has been consolitated and automatized (Masters & Maxwell, 2008). This would happen in specific scenarios, usually characterized by increased pressure performance, where stakes for errors are high and skill-failure is not an option (e.g., important competitions)(Adams, 1971). In these situations, experienced performers might try to consciously control of the execution of automatized movements, thus de-automatizing them and, in most of the cases, hindering performance. This return to conscious control is also known as “reinvestment” (Masters & Maxwell, 1992) and is the pivotal concept of Reinvestment theory (Masters, 1992; Masters & Maxwell, 2008).

And here we come to the advantages of implicit, errorless learning. In fact, the theory additionally suggests that if motor skills are learned implicitly rather than explicitly, reinvestment and therefore motor performance impairment under pressure would be less likely (since little explicit and conscious motor skill knowledge has been stored; Masters, 1993). Although several implicit acquisition of motor skills schedules have been developed throughout the years (i.e., dual-task practice; Masters, 1992; Masters, Kerr, & Weedon, 2001, removing performance or providing subliminal feedback; Maxwell et al., 2003; Masters, Maxwell, & Eves, 2009, analogy learning; Lam et al., 2009; Liao & Masters, 2001; Poolton et al., 2006; Tse, Wange, Masters, 2017; North, Warren, & Runswick, 2017)errorless learning configures itself as the most popular and implemented implicit learning strategy (Masters et al., 2004; Masters, Poolton, & Maxwell, 2008; Maxwell et al., 2001; Poolton, Masters, & Maxwell, 2007; 2005; Capio, Poolton, Sit, Eguia, et al., 2013; North et al., 2017; Capio et al., 2017; Maxwell et al.2017) and scaling of equipment (Burton & Welch, 1990; Farrow & Reid, 2010; Buszard, Farrow, Reid,& Masters, 2014). In addition to its benefits for performance under pressure, implicit learning seems to ensure a more generalized motor program, which might have additional advantages in some high pressure situations (Van Ginneken and colleagues, 2014)

On the other hand, task type can be considered a factor that influences present and past research findings and solves the challenges and conflicts and generalizations of the research literature. The nature and type of the task is an under-explored variable in this field, Mount, Parker, et al., (2007) and Levac et al., (2017) argued that more research is needed to identify the characteristics of tasks, such as task complexity, motor versus non-motor tasks, and type of task (laboratory tasks or non-laboratory tasks) in errorless and errorful approaches. To the best of our knowledge, errorless and errorful practice approaches have been addressed just in fine tasks such as golf putting, button-press task (Maxwell, Masters et al., 2001; Poolton, Zachry, 2007; Zhu, Wilson, Maxwell, & Masters, 2011, Bellomo et al., 2018) or gross-motor tasks rugby throws,respectively (Masters, Poolton & Maxwell, 2008; Gabbet & Masters, 2011).

Although most researching work performed on errorless and errorful protocols has been somewhat confirmed in indicators such as distance from the target (e.g., Maxwell et al., 2001; Poolton et al., 2005; Zhu, Poolton et al., 2011; Maxwell, Capio et al., 2016; Sanli&Lee,2014 Experiment 2) or target size (Capio, Masters, et al., 2013; Masters et al., 2008; Ong, Lohse, Sze, & Hodges,2013; Sanli&Lee,2014 Experiment 1). However, some studies report limited evidence of the efficacy of error-reduced learning in field and laboratory setting (Sanli & Lee, 2014; Ong, Lohse, & Hodges, 2015; Lee, Eliasz, Gonzalez, Alguire, Ding, Dhallwal,2016).

In contrast, Sanli and Lee (2014) in studies in two experiments showed that skill training with the gradual progress from easy -to difficult (error reduced) did not consistently induce implicit learning processes and is not consistently beneficial to performance under secondary -task load. The experiment findings did not support the predictions based on schema theory and only partially supported the predictions based on reinvestment theory.

Sanli and Lee (2014) suggested that the timing of errors with task difficulty (functional difficulty) is probably an important factor in motor learning. but they also found minimal evidence to support previous claims that error-reduced approaches cause implicit motor learning. In this regard, Lee et al. (2015) in a study investigated the role of errors in learning a laboratory task of distinct keypress sequences that varied in the amounts of advance information (i.e., choice). Although these findings support the beneficial role of error in motor learning, they also suggest that not all errors are equal in the learning process. Instead, they distinguish between factors that cause errors that have a desirable effect on learning than those that have an undesirable effect. Ong et al. (2015) revealed that also participants throwing darts at a larger target (i.e., error reduced) did not differ in performance (radial error) during practice (90 trials) or under secondary task load, compared to those who are throwing at a small target (i.e., error-strewn).

Sanli and Lee (2014) suggested that the timing of errors in relation to task difficulty is likely to be a critical factor in motor learning. We selected a fine-motor task in a laboratory setting so that we could assess performance more precisely, such as the size and variability of error. We were also particularly interested in the impact of different implicit and explicit learning paradigms on immediate and delayed retention, dual-task, and transfer tests.Therefore, there are some criticisms of these papers; specifically, that the present research is seeking to study the effect of errorless and errorful practice on learning by manipulating relative timing as an unknown issue that is an invariant feature of the generalized motor program (Schmidt, 1975), rather than by emphasizing variabilities and parametric indicators. In the present research, a fine-motor task that has been used more in the early works (Lai & Shea, 1998; Lai & Shea et al., 2001; Rahbanfard & Proteau, 2011; Apolinário-Souza, Ferreira, Oliveira, Nogueira, Pinto and Lage,2020) was employed to provide the possibility of more accurate assessment of performance, such as size and variability of errors.Thus, given the challenges and contradictions in the past literature on the efficacy of errorless and errorful practice in learning tasks, there is a partial timing (Sanli et al., 2014; Lee et al., 2015) yet unclear or inconsistent and wholly understood.

Although most previous studies search implicit learning is useful in learning motor skills. but the new line of the present study is the study of retention and immediate transfer, assessments of delayed task recall and transfer have not been studied as extensively (Poolton & Zachry, 2007). The disadvantage of not having delayed retention and transfer tests is that the condition that is beneficial to performance during acquisition may be detrimental to learning in other situations.

Recent evidence suggests that some conscious processes may be beneficial to beginners during learning, but but detrimental in the performance under pressure. Therefore, the present study seeks to fill this gap. Based on previous research (bellomo et al., 2018), we hypothesized that participants in both groups show a timing task during acquisition, but the explicit group improves more rapidly. Also, based on the reinvestment theory (masters & Maxwell, 2008), we predicted that under pressure, the de-chunking would be greater in the explicit group, while the implicit group would be immune. we expected that in explicit group under dual-task load and under pressure following practice, pressure would elicit increases in conscious processing and possibly de-chunking of the movements therfore, we expected this to be less for implicit motor learning paradigm because implicit training should limit the rules of verbal-analytic rules required for reinvestment to occur. Moreover, In line with the retention phase findings, some studies have shown that implicit learning strategies are more stable and resilient and over time than those associated to explicit learning (Masters, Poolton, & Maxwell, 2008; Poolton, Masters, & Maxwell, 2007). Schmitz et al., (2014) believe errorless learning allows for faster automation of serial response time tasks compared to errorful learning in both alzheimer's disease healthy older subjects. This study investigated, in a controlled laboratory enviroment, the role of motor learning errors during practice, retention, and transfer using errorless and errorful practice schedules. Previous studies only have examined performance and retention conditions. no studies have examined the conditions of delayed retention and transfer. An important aspect of the present study is the study of delayed retention and transfer conditions. We expect more robust performance under dual task in the implicit learning.

Therefore, in this study, in line with the reinvestment theory and previous research, we hypothesized that practicing a task in an incremental difficulty paradigm (easy to difficult) leads to fewer errors and more stable learning of the relative timing (GMP) compared to difficult to eary / errorful and compared to control. We also expected relatively implicit learner (errorless) to report less explicit knowledge of the performance of timing task compared to explicit (declarative) learners. Moreover, we expected the amount of reported task-specific declarative knowledge to correlate with the Movement- Specific Reinvestment (MSRS) scores in the errorful group.

Method

Participants

A total of thirty-eight (N = 38, M_{age} = 22.6 years, SD_{age} = 3.2 years) healthy male participants from Buali Sina University of Hamden (Iran) were recruited by means of convenience sampling. All participants were right-handed, did not have a specific physical problem; had normal or corrected-to-normal vision, and were unfamiliar with the experimental task.

The required sample size was determined using the G*Power software with setting for mixed-model ANOVA (within-between interaction) at 95% confidence level, α = 0.05; power = 0.85, Group = 3 and r = 0.5, and medium effect size = 0.23 from similar research (Wong, 2019; de Oliveira et al. (2017). Recommended total sample size was 39 (Faul, Erdfelder, Lang, & Buchner, 2007). However, one participant from the control group was excluded from the data analysis process due to personal problems. Before partaking into the study, all participants signed an informed consent. Participants were randomly assigned to one of the experimental groups: Errorless (N = 13), Errorful (N = 13), and Control (N = 12).

Apparatus And Task

We employed the same the apparatus and four-part sequential timing task of Rohbanfard and Proteau (2011). As illustrated in Fig. 1, the apparatus consisted of a wooden base (45 × 45 cm) embedded with three wooden barriers (with the height of 11 cm and width of 8 cm) as vertical and a target (11× 8 cm) as horizontal. There was a start button in the middle of the horizontal target. The distance between the start button and the first barrier was 15 cm, and distances among the remaining parts of the task were 32 cm, 18 cm and 29 cm, respectively. Motor timing was controlled by microswitches placed under vertical barriers and horizontal target. The microswitches were connected to a computer via IO port and A-D convert. Participants sat in front of the apparatus. close to the start position. then, from the starting button began each trial with their right hand on the home position. articipants were asked to be as accurate as possible with the relative goal segment ratios. Four targets appeared on the screen and participants had to move towards each targets in a sequential order The participant was then asked to successivelly knock down the first, second, and third obstacles (thus releasing the microswitches) in a clockwise motion, and finally to hit the target. each segment of the task, depending on the training group, must be completed in a different intermediate time(ITS) for a 1200 ms TMT. The movement pattern, ITSand TMT are shown on a poster in front of the apparatus during all of experimental phases.

Procedure

This study was carried out in six experimental phases. During the first phase (pretest), each participant was asked to perform for 10 trials with the total time of 1200 MS and a relative time of 300 MS per segment (intermediate times) without receiving any feedback. During the Acquisition block participants performed the tast for a total of 45 trials. in all all the other blocks they performed the tast for 10 trials.

Table 1
Experimental groups and phases

<table>
<tr><th>Phase
Group</th><th>Pretest</th><th>ACQ</th><th>10–min RET</th><th>10-min TR</th><th>24-hr RET</th><th>24-hr TR</th></tr>
<tr><td>Errorless</td><td rowspan="3">Perform 10 trials (task B) without knowledge of results (KR)</td><td>3 sessions (45 trials each) Practicing respectively tasks A (15 trials), B (15 trials) & C (15 trials) in each session</td><td rowspan="3">Perform 10 trials (task B) without knowledge of results (KR)</td><td rowspan="3">Perform 10 trials (TMT = 1300 ms, 325 ms each segment)</td><td rowspan="3">Perform 10 trials (task B) without knowledge of results (KR)</td><td rowspan="3">Perform 10 trials (TMT = 1300 ms, 325 ms each segment) + Tone Counting</td></tr>
<tr><td>Errorful</td><td>3 sessions (45 trials each) Practicing respectively tasks C (15 trials), B (15 trials) & A (15 trials) in each session</td></tr>
<tr><td>Control</td><td>No practice</td></tr>
</table>

Task A (simple task): ITs = 200, 375, 300 & 325 MS; Task B (moderate task): ITs = 300, 300, 300 & 300 MS; Task C (difficult task): ITs = 300, 300, 240 & 360 Ms. TMT was 1200 MS for all tasks

Before performing the acquisition protocol, expected relative timing for performing fourth segments of the task was calculated using a pilot study equal to 17, 27, 25 and 31% for the first to the fourth segment. This task was as a simple task (Task A) in the practice protocol. Before starting the first trail, participants were asked to try to match the movement pattern as closely as possible(intermediate time) as well as gol segment ratios. Accordingly, a task with relative times of 25% per segment was a moderate task (Task B), because the participant then focuses on learning the first and last segments of the sequence. Also, a task with relative times of 25, 25, 20, and 30% was difficult (Task C).our assuption that the25% relative time was simpler to carry out the 25, 25, 20, and 30% relative time.In this case, in addition to the initial and final segment, the subject must also learn the task's middle sections. In the acquisition phase, as shown in Table 1, the errorless practice group started each training session with a simple task and ended with a complex task, while the errorful practice group acted reversely (from a difficult task to a simple task)(Bellomo et al., 2018). Finally, 10-min and 24-hr, after the acquisition phase, immediate and delayed retention, and transfer tests were performed. The pre-test, post-test and retention phases included attempting to complete the movement sequence for pre-instructed absolute and relative times without any augmented feedback(no augmented FB).

Retention tests were performed similarly to the pretest. In contrast, during the transfer tests, participants were: 1) asked to complete the same task but with a total movement time of 1300 milliseconds (ms); 2) performed it while two in dual-task condition while counting the total number of high (1000 Hz) pitched tones (simultaneous with the transfer of the 24-hour test). Crucially, the high pitch tones were alternated with low pitch (500Hz) tones. tones were presented in a randomised order at one-second intervals

Measures

Movement-specific conscious reinvestment scale. The English version Movement- Specific Reinvestment Scale (MSRS-C) was used to assess the participants' conscious control propensity (Masters et al., 1993; Masters et al., 2005; Wong et al., 2008, 2015, 2016, Chu& Wong,2018). This scale consists of 10 questions, consists of two sub-scales including Conscious Motor Processing (CMP) of and Movement Self-Consciousness (MSC) Each of which contains five questions (five items each) which measure propensity for control (e.g., "I am concerned about my style of moving") and conscious monitoring (e.g., "I was aware of the way my body was working"), respectively. Items are rated on a 6-point Likert scale from "strongly disagree" to "strongly agree" summed to a total Scores range from 10 to 60, with lower scores reflecting a lower trait propensity to consciously process movement and higher scores reflecting a greater trait propensity to process movement consciously. Its test – re-test reliability for two factors is *r* = 0.67, 0.76 and Cronbach's alpha for measuring its internal reliability for two factors was 0.71 and 0.78 (Masters et al.,2005). The internal consistency (Cronbach’s alpha) for the subtest of the conscious movement process is obtained 0.8, for self-consciousness movement subtest, which is attained 0.73 and for the total scale is 0.77. In the present study, the Cronbach's alpha coefficient for the total Reinvestment and subcomponents of conscious movement processes and movement-specific self-consciousness was 0.88, 0.73 and 0.72, respectively.

Verbal Protocols. At the end of each block, a verbal report protocol was used to assess the amount of declarative knowledge about the timing task's rules or reported hypothesis testing. Here, the participants were asked to recall and to describe any rules, strategies, methods or techniques that were associated with completing the timing task successfully; for example, how to adjust the speed of handing barriers according to the order time of each segment) when practice and testing (Liao & Masters, 2001; Maxwell et al., 2001; Maxwell et al., 2006), the number of rules and techniques reported by the participants in the practice sessions and during the learning phases were counted independently by the two blind raters. The average number of rules reported by the two raters was considered the verbal rule report protocol's individual score.

Relative timing. We computed the root mean square error (RMSE) for intermediate times, which presents in a single score how much each participant deviated from the prescribed relative timing pattern. For each trial: $RMSE = \sqrt{\sum_{Segment1}^{Segment4}\left(\frac{ITi - Target^2}{4}\right)}$ where ITI represents the intermediate time for segment, i and target is the goal movement time for each segment of the task (i.e., 300 MS for the immediately and delay retention trials and 325 MS for the transfer trials). Relative timing (RMSE) was computed as the sum of the absolute difference between the goal proportions and each segment's actual proportions.

Data analysis

Sphericity and normality checks were performed and controlled for whenneeded. When main effects or interactions were found, separate ANOVAs, post hoc tests (Bonferroni corrected) or polynomial trend analyses were performed.

The Shapiro-Wilk and Levene's tests confirmed the normality of distributing the data and the homogeneity of variance at all experimental phases, respectively (ps > 0.05). mixed-model ANOVAs were employed to analyze data. The multivariate method of reporting results was adopted as it minimizes the risk of violating sphericity and compound symmetry assumptions in repeated measures ANOVA (Vasey & Thayer, 1987). Effect sizes are reported as partial η squared (η p 2), with the values .01, .06 and .14 indicating relatively small, medium and large effect sizes, respectively (Cohen, 1988).

Acquisition Block

The acquisition data of the three experimetal groups were analysed with a 3 (group: errorless, errorful,) x9 blocks of trials (Blocks: 1–15, 16–30, 31–45, …121–135) mixed-model ANOVA with group (errorless, errorful).

Retention And Transfe Phases

Furthermore, in retention phase, data were compared by using compound ANOVA in a (within- between-subjects) design including 3 groups (between-subjects factor) (control, errorless, and errorful) x 3 phases (pretest, 10-min retention, and 24-hr retention) with within-subjects factor repeated measures on the last factor. Finally, one-way ANOVA was used to analyze groups' performances in different learning phases (transfer, 24-hr transfer, verbal reporting protocol, and accuracy of dual-task). A Pearson product-moment intra-class correlation coefficient was used to access the inter-rater reliability the number of rules reported in participants' verbal protocols and scores of the independent raters. multiple regression analysis were carried out for predicting the MSRS score and dual-task conditions.

When the assumption of sphericity was violated a Greenhouse-Geisser correction was used. Excel software (2016) was used to draw the graphs, and alpha (α) level was set at 0.05. For all significant effects, post hoc analyses using LSD were conducted ($P < 0.05$). The partial eta square (2) is the effect size reported for the significant main effects and interactions (Cohen, 1988).

Results

Relative timing error (RMSE). add results please

Acquisition (RMSE).The Group x Block mixed-model ANOVA on RMSE revealed a significant main effect of Block (F(8, 192) = 5.294, p = 0.001, 2 = 0.181), but neither main effect of group nor interactions were not significant. This effect was probed with LSD post-hoc test, which revealed the greater error in the first block relative to the last block of trials ($P < 0.05$). In other words, as shown in Fig. 2, RMSE decreased with practice in both groups during the acquisition phase.

Retention phases. As illustrated in Fig. 2b, ANOVA computed on (RMSE) in retention phases revealed significant main effects of Group (F (2, 35) = 6.793, p = 0.001, 2 = 0. 440) and Phase (F (2, 70) = 20.185, p = .001, 2 = 0. 366) and a significant interaction (F (4, 70) = 5.763, p = 0.001). LSD post hoc analyses revealed no significant differences between groups at pre-test.

The results obtained from post hoc LSD test are shown in Fig. 2 (Panel b) suggest that the groups and significant difference between errorless group and other groups (errorful, control) in both 10-min and 24-hr retention phases, respectively, so that errorless group performed with less relative timing error than two groups ($Ps < 0.05$).

Transfer (10-min) and 24hrTransfer tests (dual-task). For the Transfer test, the data related to the relative timing error in the transfer phase exhibited significant differences among the group (F (2, 35) = 17.86, p = .001). Based on the results obtained from LSD post hoc testing, a significant difference was found between the control group and the other two groups ($Ps \leq 0.05$). The data analyzed by the LSD test, showed in Fig. 2 (Panel b) as oval and star symbols demonstrated that errorless group had better performance relative to errorful and the control groups ($Ps \geq 0.05$). Besides, regarding the 24-hr transfer phase, the results' pattern was similar to that of 10-min one, implying that the groups were significantly different from each other F (2, 35) = 22.012, p = .001). LSD post hoc testing showed errorless practice group had a significantly smaller (RMSE) than the two practice groups.

Verbal protocols.

*P*articipants reported the number of task-relevant knowledge and rules that they used to about their movements during both) learning and test phases). The number of rules was analyzed using one way ANOVA and LSD post hoc tests. Pearson's product-moment correlation coefficient indicated a high inter-rater reliability (r = .88, n = 38, $p < .001$). The mean number of rules was reported by two independent raters blind to the experimental conditions under which each participant performed as a verbal protocol score.

The analysis with one-way analysis of variance (ANOVA) revealed significant group difference (F (2, 35) = 11.22, p = .001). LSD post hoc test showed a significant difference in the number of task-relevant knowledge and rules reported by the errorless compared to the control and errorful groups (p = .001, p = .001, respectively). There was no significant difference between the other groups in the paired comparison.

Mean number of explicit rules by the errorful (M = 3.30, SD = 2.9), errorless (M = 2, SD = .70), control groups (M = 3.08 SD = .66), respectively. Figures (3) illustrates the mean of the number of rules reported.

also, the results related to tone counting showed that there were no significant differences among all the groups ($F_{2, 35}$ = .978, P = 0.123) Mean and standard deviation values of tone counting absolute percentage accuracy were 94.36% and 4.31, 93.53% and 4.76, 94.58% and 2.79, and 92.13% and 3.17 for the errorless, errorful, and control groups, respectively.

The regression analysis results showed that the total scores of the Movement-Specific Reinvestment Scale (MSRS) positively correlated with the performance of groups in the dual-task conditions. (F (1, 36) = 12.27, p = .0012, R square = 0.254). As shown in Fig. 4, There was a positive correlation between the root mean square error (RMSE) with the errorless group in which participants performed significantly better with lower propensity for Reinvestment (MSRS score). In contrast, in the two errorful and control groups, this relationship was reversed. As these two groups scored higher on the Movement-Specific Reinvestment Scale (MSRS), they performed significantly worse in the dual-task conditions.

Discussion

The present research aimed to assess the role of errorless and errorful practices in acquisition and relative timing learning of a motor task. The research finding showed that both groups performed better in all retention and transfer tests than control one in relative timing (RMSE). The existence of a significant difference between practising groups and control shows the occurrence of learning. In the acquisition phase, the results revealed that practice, regardless of the type, led to performance progress. Lage et al. (2007) argue that the opportunity to remain steady during the early-stage trials of the practice schedules provided by some of the practice schedules allows the learner to be desirable in acquiring a movement's structure. Therefore, these practice conditions allow a learner to pay attention to relative timing structure by trial- to- trials stability during practice, the acquisition of skilled performance overall depends on the number of practice more practice leads to better performance. One possible reason for the lack of findings between the two groups was the relatively short period of acquisition phase in the current experiment (135 trials for each group consisting of three blocks of 45 trials in each session of different tasks). The main effect of block suggest regardless of practice type, performance improved with repetition (end of the acquisition phase). Both transfer and transfer tests were applied to separate the transitory effects of performance from learning. Since the retention and transfer tests allow access to learning phenomena with different dimensions, while the retention test confirmed the persistence of the performance improvement, the transfer test provided the ability to generalization the learned skill to another situation.Accordingly, success in doing relative timing in the early practice program helped learn the motor pattern and generalization in retention and transfer phases. This research's exciting results were observed in retention and transfer phases, in which the errorless group showed higher performance than the other practising groups. In fact, in the relative error measure, the errorless groups performed with a lower error than the errorful and control groups. According to prediction of reinvestment theory (master et al, 2008), enhancing trial-to-trial consistency during the acquisition phase is beneficial to the development of relative – timing (GMP). These findings are of high importance from the theoretical aspect. The errorless group's superiority over other groups is justified by the implicit learning literature and the reinvestment theory (Maxwell and Masters, 1992, 2008). underpins of implicit approaches to learning is the theory of reinvestment(Masters & Maxwell, 2008).

based on reinvestment theory (Masters & Maxwell, 2008), Conscious control of a movement movement execution causes it to return to an earlier, more cognitive stage of control, which is characterized by inconsistency, instability and inaccuracy (Sparks, Aussanu. Masters ,Ring,2021, Masters & Maxwell, 2008).

Success in the early practice program causes limitation in making errors so that participant errorless group the involvement rate of working memory is reduced and participants can acquire stable patterns implicitly without requiring a hypothesis test. Thus, consistent with the findings of Maxwell et al. (2001), Masters et al. (2008) and Miler (2014) learners in an easy-to-difficult practice progression (errorless group) would use fewer on working memory resources, results in implicit learning of new motor skill and later performing retention, and under secondary-task conditions should not have a problem with the task

The difference between practising blocks in practising groups became greater when cognitive demand for attention resources, and the need to hypothesis test increased. It seems that practising groups led to the improvement of performance in the acquisition phase.

The results of the current research in acquisition phase are in line with the results reported by the previous researcher (Masters, & Maxwell, 2001; Poolton, Masters, & Maxwell, 2006; Chauvel et al.; 2012; Abdoli et al., 2012, Savelsbergh et al., 2012; Wang, Masters et al.,2013, Capio, Poolton et al., 2013; Van Ginneken et al., 2014; Sanli et al., 2014; Maxwell et al.,2017; Kishawi, Khalaf,, Masters & Winning;2020). Errorless and errorful practice protocols caused an improvement in performance in the acquisition phase. It seems that the practice of working memory in errorless groups in the first blocks was less involved in correcting the errors, and that processing occurred implicitly. A possible explanation for these results may be the results of a the verbal reporting protocol. The results of the verbal protocol showed that the errorless group uses less declartive knowledge, so less working memory is used to learn the skill, so the task manipulation to show the effects of implicit and explicit learning It has been successful.as explained in the introduction, for example, Maxwell et al. (2001), constrained the environment to reduce the amount of errors that occurred during practice, thus reducing the necessity for working memory to be engaged in hypothesis testing because performance was successful.errorless- learners exhibited performances that seemed to be less reliant on explicit processes than errorful learners. they reported fewer rules than errorful learners. decreased capacity for verbally reporting of aspects of task performance has been one of the most consistently considered to be an indicators of reduced contriburtion from explicit processes (e.g. Masters Maxwell, 2004; Maxwell,Capio, Masters, 2016) and has been interpreted as reflecting a greater share of implicit processes in motor learning. (Masters 1992, Maxwell, Capio, Masters, 2016).the finding consistent with the learning stage model presented by Gentile (1972) states that the novice performer needs an opportunity to get the overall idea of the movement in the early stages of learning before enhancing the practice environment's more complexity (Porter & Magill, 2010). Therefore, in the errorless learners, limiting the acquisition phase errors resulted in reducing hypotheses to improve motor patterns in the retention and transfer tests. When the success in the relative timing of a task increases, the individual achieves the appropriate motor pattern and thus there is no need to correct the pattern in practice.The systematic reduction of learning errors sounds an influential tool in encouraging the implicit learning of motor skills (Capio, Sit, Abernethy, & Masters, 2012; Poolton et al., 2007). These findings are in consistence with the findings of many previous types of research (Masters, & Maxwell, 2001, 2008; Poolton, Masters, & Maxwell, 2007; Chauvel, Maquestiaux, Hartley, et al., 2012; Abdoli et al., 2102, Wang, Masters et al., 2013, Capio, Poolton, Sit, Euiga, & Masters, 2013; Ong et al., (second study) 2013; North et al., 2017; Van Ginneken, 2014: Capio, Poolton, Eguia, Choi, & Masters,2017; Haslam, Wagner, Wegener, & Malouf, 2017; Levac et al., 2017, Kishawi, Khalaf, Masters,2020).

In the present study, errorless and errorful practice schedules were used to progress through tasks in a different difficulty order (Sanli & Lee, 2015). Implicit learning (errorless practice) improves learning by reducing errors during the practice and reducing feedback on the performance consequences.

This study showed that mere variability and high error rates, cognitive attempt (errorful group) and challenging practice during practice do not lead to desirable learning. Continuous changes in errorful groups in the early stages of performance cause these groups' learners to be dependent on the accurate identification of the functional relationship between the performer and the environment. Maxwell et al. (2001) stated that this relationship might be difficult to establish when the number of errors is high. Significant resources may be selectively allocated to identify this functional relationship, thereby interfering with acquiring functional dynamics. Maxwell et al. (2001) argued that During practice, performers in errorless learning group, working memory was not required to perform the task and was therefore freely available for tone counting. Therefore, performers do not interfere with skill performance in these situations As previously mentioned, a slightly disrupted motor performance, when performing a secondary cognitive task during the motor performance, showed that no conscious processing resources were required to control performance. on the other hand,Skills learned explicitly using working memory for verbal analytical processing are impaired under dual task conditions, while acquired skills are implicitly robust under dual task conditions (e.g., Maxwell et al., 2003). Thus, it proves an implicit learning occurrence (Masters, Maxwell, 2004, 2008).

In the dual-task condition, the pattern of the results obtained from the secondary cognitive task was approximately similar to those of retention and transfer phases in the relative timing (RMSE). So that errorless group (task difficulty group from easy to challenging) showed a more stable performance at 24-hr transfer (simultaneously performing tone counting of the secondary task and the primary task). In contrast, errorful group were involved in the explicit learning process and using attentional capacity, thus with limitation of attentional capacity in performing two tasks, they could not distinguish between the two tasks and follow the controlled and conscious processing, thereby leading to the reduction of performance in the primary task. The overload resulting from the secondary task caused their attention to be transferred from the primary task to the secondary task. They also used the hypothesis testing process and more working memory resource, and as a result, they committed more errors in carrying out two tasks simultaneously.

However, errorless learners do not rely on the hypothesis test at the These results are similar to those reported by (Bellmoet al. 2018; 2020; Maxwell et al,2016).secondary task's simultaneous performance since they should correct a limited amount of errors during the practice. Thus, errorless learners implicitly learn the task, with less dependence on reinvestment processes. The findings of this study in the errorless group are in line with those of Masters (1992), Maxwell et al. (2001), Poolton et al. (2005), Capio et al., (2013), and Chauvel et al. (2012).

Masters et al. (1992) suggested that limiting the environment in the early stages of learning provides the advantages of procedural learning by reducing the load on working memory processes and prevents the hypothesis testing strategy. Advantages of implicit motor learning strategies explained Reinvestment's theory (Masters and Maxwell, 2008). The Reinvestment hypothesis states that errorful learners use a hypothesis testing strategy (an explicit knowledge) to correct errors and accumulate explicit knowledge associated with motor solutions in a large pool. As a result, the errorful group had a propensity to Reinvestment due to the accumulation of explicit knowledge, and thus they suffer from a performance disruption under the secondary task conditions. One of the reasons for the errorful group's poor performance was declarative knowledge in performing simultaneously two tasks.

Masters (1992) stated that implicit learning limited declarative knowledge accumulation and reduced reinvestment phenomenon opportunity. Masters and Maxwell (2004, 2008) argued that explicit knowledge is an indicator of dependency on working memory during learning. In this context, the Verbal Reporting Protocol was used to measure the amount of explicit knowledge. The errorless group reported significantly fewer unwritten rules of timing task in the verbal reporting protocol than control and errorful groups. The errorless group was dependent less on conscious processes compared to other groups.

This study's findings regarding verbal report agree with those of previous researchers (e.g., Liao and Masters, 2000; Masters, 1992; Masters & Maxwell &, Poolton, 2006; Poolton, Masters & Maxwell, 2007; Lam, Masters, & Maxwell, 2009; Maxwell et al., 2017; van Abswoude, Nuijen, van der Kamp, and Steenbergen, 2018). The number of explicit rules (explicit knowledge) is a significant factor in disrupting the secondary task's performance. Previous research has found a direct relationship between explicit rules and task-relevant knowledge and reduced performance under pressure.

Furthermore, there was no significant difference in tone counting among the groups. All the groups performed the task of tone counting relatively well to not ignore the secondary task (tone counting) for greater accuracy in performing timing tasks. Therefore, the allocation of attentional resources to the primary task of relative timing and the secondary task of tone counting does not explain the functional differences among the groups under secondary task conditions.

Collective findings have provided further support for errorless learning as implicit learning methods (Masters, 1992). The present study's findings showed that practice environments, providing the conditions for learners' success by reducing problem-solving/information processing requirements, decrease the learner's cognitive challenge in the acquisition phase of skill learning. Our results also showed that adding new information gradually increases more choice/error opportunities and enhances retention, while practice conditions emphasize success rather than errors (Masters & Maxwell, 2004; Poolton et al., 2005). Some of the limitations of this research should be considered in future research. The organization of practise schedules that reduce the error amount during the practice session leads to optimal learning in relative timing task as a new condition (contrary to parametric, size and distance of the target indicators). Some of the limitations of this research should be considered in future research. In the present study, the effect of errorless and errorful practices was created by generalized motor program modification (relative timing); this effect can also be created by parametric modifications (total movement time).

Future investigations are required to explore this subject. However, one of the remarkable results of the current study was, supported the implicit learning theory of Masters (1992), in which the organization of practice schedules that restricted the learning environment to allow early-stage practice trials to be free of error and consequently leads to optimal learning in relative timing task (contrary to parametric, size and distance of the target indicators).. It seems the errorless learning environment is an effective strategy to promote implicit learning.

Declarations

Consent for Publication

Not applicable.

Availability of Data and Materials

The datasets generated and analyzed during the current study are not publicly available, as individual privacy could be compromised, but are available from the corresponding author on reasonable request.

Competing Interests

The authors declare that they have no competing interests.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors’ Contributions

Saeed Nazari Kakvandi1, Alireza Saberi Kakhki2, Eduardo Bellomo 3, Hasan Rohbanfard4 , , Morteza Homayounnia Firoozjah5, Mehdi Qorbanian Qohroudi6

SNK contributed to the conceptualization, data curation, investigation, methodology, project administration, resources, supervision, validation, visualization, and writing (reviewing and editing) of the study. **ASK** contributed to the data curation, investigation, project administration, resources, supervision, writing (original draft, reviewing, and editing) of the study. **EB** and **MHF** contributed to the data curation, formal analysis, investigation, project administration, resources, supervision, validation, and writing (reviewing and editing) of the study. **HR and MQQ** contributed to the project administration, resources, and writing (reviewing and editing) of the study. All authors read and approved the final manuscript.

Acknowledgements

The authors wish to thank Alireza Saberi Kakhki, Ph.D., for serving as the statistical expert for this research, Morteza Homayounnia Firoozjah, for preparing the manuscript, the study participants for their contributions to this research, and the associated study research team.

References

1. Abdoli, B., Farsi, A., & Barani, F. H. (2012). Comparing the effects of Errorless and Errorful and fixed practices on learning of throwing task. European Journal of Experimental Biology, 2(5), 1800-1806.
2. Adams, J. A. (1971). A closed-loop theory of motor learning. Journal of motor behavior, 3(2), 111-150.
3. Albuquerque, M. R., Lage, G. M., Ugrinowitsch, H., Corrêa, U. C., & Benda, R. N. (2014). Effects of Knowledge of Results Frequency on the Learning of Generalized Motor Programs and Parameters under Conditions of Constant Practice. Perceptual and motor skills, 119(1), 69-81.
4. Apolinário-Souza, T., Ferreira, B. D. P., de Oliveira, J. R. V., Nogueira, N. G. D. H. M., Pinto, J. A. R., & Lage, G. M. (2020). Mental practice is associated with learning the relative timing dimension of a task. Journal of Motor Behavior, 1-11.
5. Alloway, T. P., Gathercole, S. E., Kirkwood, H., & Elliott, J. (2008). Evaluating the validity of the automated working memory assessment. Educational Psychology, 28(7), 725-734.
6. Andy, C. Y., Wong, T. W., & Masters, R. S. (2017). Examining motor learning in older adults using analogy instruction. Psychology of Sport and Exercise, 28, 78-84.
7. Baddeley, A. (2012). Working memory: theories, models, and controversies. Annual review of psychology, 63, 1-29.
8. Burton, A. W., & Welch, B. A. (1990). Dribbling performance in first-grade children: Effect of ball and hand size and ball-size. Physical Educator, 47(1), 4
9. Buszard, T., Farrow, D., Reid, M., & Masters, R. S. (2014). Scaling sporting equipment for children promotes implicit processes during performance. Consciousness and cognition, 30, 247-255.
10. Bellomo, E., Cooke, A., & Hardy, J. (2018). Chunking, conscious processing, and EEG during sequence acquisition and performance pressure: a comprehensive test of reinvestment theory. Journal of Sport and Exercise Psychology, 40(3), 135-145.

11. Bellomo, E., Cooke, A., Gallicchio, G., Ring, C., & Hardy, J. (2020). Mind and body: Psychophysiological profiles of instructional and motivational self-talk. Psychophysiology, 57(9), e13586.
12. Capio, C. M., Poolton, J. M., Sit, C. H. P., Euiga, 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, 295–305.
13. Capio, C., Poolton, J., Sit, C., Holmstrom, M., & Masters, R. (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.
14. Capio, C. M., Poolton, J. M., Eguia, K. F., Choi, C. S., & Masters, R. S. (2017). Movement pattern components and mastery of an object control skill with error-reduced learning. Developmental neurorehabilitation, 20(3), 179-183.
15. Capio, C. M., Sit, C. H., Abernethy, B., & Masters, R. S. (2012). The possible benefits of reduced errors in the motor skills acquisition of children. Sports Medicine, Arthroscopy, Rehabilitation, Therapy & Technology, 4(1), 1.
16. Chauvel, G., Maquestiaux, F., Hartley, A. A., Joubert, S., Didierjean, A., & Masters, R. S. (2012). Age effects shrink when motor learning is predominantly supported by nondeclarative, automatic memory processes: Evidence from golf putting. Quarterly Journal of Experimental Psychology, 65(1), 25-38.
17. Chien, K.-P., & Chen, S. (2017). The Influence of Guided Error-Based Learning on Motor Skills Self-Efficacy and Achievement. Journal of motor behavior, 1-10.
18. Clare, L., & Jones, R. S. (2008). Errorless learning in the rehabilitation of memory impairment: a critical review. Neuropsychology review, 18(1), 1-23.
19. De Oliveira, R. F., Raab, M., Hegele, M., & Schorer, J. (2017). Task Integration Facilitates Multitasking. Frontiers in Psychology, 8, 398. https://doi.org/10.3389/fpsyg.2017.00398
20. El-Kishawi, M., Khalaf, K., Masters, R., & Winning, T. (2020). Effect of errorless learning on the acquisition of fine motor skills in pre-clinical endodontics. Australian Endodontic Journal.
21. Farrow, D., & Reid, M. (2010). The effect of equipment scaling on the skill acquisition of beginning tennis players. Journal of Sports Sciences, 28, 723–732
22. Fitts, P. M., & Posner, M. I. (1967). Human performance. Belmont, CA: Brooks/Cole.
23. Gabbett, T., & Masters, R. (2011). Challenges and solutions when applying implicit motor learning theory in a high performance sport environment: Examples from Rugby League. International Journal of Sports Sciences & Coaching, 6(4), 567-575
24. Gathercole, S. E., Alloway, T. P., Kirkwood, H. J., Elliott, J. G., Holmes, J., & Hilton, K. A. (2008). Attentional and executive function behaviours in children with poor working memory. Learning and individual differences, 18(2), 214-223.
25. Gentile, A. M. (1972). A working model of skill acquisition with application to teaching. Quest, 17(1), 3-23.

26. Jones, R. S., Clare, L., MacPartlin, C., & Murphy, O. (2010). The effectiveness of trial-and-error and errorless learning in promoting the transfer of training. European Journal of Behavior Analysis, 11(1), 29-36.
27. Kornell, N., Hays, M. J., & Bjork, R. A. (2009). Unsuccessful retrieval attempts enhance subsequent learning. Journal of Experimental Psychology: Learning, Memory, and Cognition, 35(4), 989.
28. Lage, G. m., Alvesº, m. a. f., Aliveiraº, f. s., Palhare, l., Ugrinowitsch, h., & Benda, r. n. (2007). the combination of practice schedules: effects on relative and absolute dimensions of the. Journal of human movement studies, 52, 021-035.
29. Lai, Q., & Shea, C. H. (1998). Generalized motor program (GMP) learning: Effects of reduced frequency of knowledge of results and practice variability. Journal of motor behavior, 30(1), 51-59.
30. Lam, W. K., Masters, R. S., & Maxwell, J. P. (2010). Cognitive demands of error processing associated with preparation and execution of a motor skill. Consciousness and cognition, 19(4), 1058-1061.
31. Lee, T. D. (2012). Contextual interference: Generalizability and limitations Skill Acquisition in Sport (pp. 105-119): Routledge.
32. Lee, T. D., Eliasz, K. L., Gonzalez, D., Alguire, K., Ding, K., & Dhaliwal, C. (2016). On the role of error in motor learning. *Journal of motor behavior*, *48*(2), 99-115.
33. Lee, T. D., Eliasz, K. L., Gonzalez, D., Alguire, K., Ding, K., & Dhaliwal, C. (2016). On the role of error in motor learning. Journal of motor behavior, 48(2), 99-115.
34. Lee, T. D., & Magill, R. A. (1983). The locus of contextual interference in motor-skill cquisition. Journal of Experimental Psychology: Learning, Memory, and Cognition, 9(4), 730.
35. Lee, T. D., Magill, R. A., & Weeks, D. J. (1985). Influence of practice schedule on testing schema theory predictions in adults. Journal of motor behavior, 17(3), 283-299.
36. Liao, C. M., & Masters, R. S. (2001). Analogy learning: A means to implicit motor learning. Journal of sports sciences, 19(5), 307-319.
37. Levac, D., Driscoll, K., Galvez, J., Mercado, K., & O'Neil, L. (2017). OPTIMAL practice conditions enhance the benefits of gradually increasing error opportunities on retention of a stepping sequence task. Human movement science, 56, 129-138.
38. Mak, T. C., Young, W. R., & Wong, T. W. (2020). The role of reinvestment in conservative gait in older adults. Experimental gerontology, 133, 110855.
39. Magill, R. A. (2016). Motor learning and control. Concepts and Applications.
40. Magill, R. A. (1998). Knowledge is more than we can talk about: Implicit learning in motor skill acquisition. Research Quarterly for Exercise and Sport, 69,104–110.
41. Masters, R., & Maxwell, J. (2008). The theory of reinvestment. International Review of Sport and Exercise Psychology, 1(2), 160-183.
42. Masters, R. S. (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.

43. Masters, R. S. W., Poolton, J. M., & Maxwell, J. P. (2008). Stable implicit motor processes despite aerobic locomotor fatigue. Consciousness and Cognition, 17 (1), 335-338.
44. Masters, r. S. (2012). Advances in implicit motor learning Skill Acquisition in Sport (pp. 85-102): Routledge.
45. Masters, R. S., & Maxwell, J. P. (2004). 10 Implicit motor learning, reinvestment and movement disruption. Skill acquisition in sport: Research, theory and practice, 207.
46. Maxwell, J., Masters, R., & Eves, F. (2003). The role of working memory in motor learning and performance. Consciousness and cognition, 12(3), 376-402.
47. 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 Sport and Exercise, 77, 271-276.
48. Maxwell, J., Masters, R., Kerr, E., & Weedon, E. (2001). The implicit benefit of learning without errors. The Quarterly Journal of Experimental Psychology Section A, 54(4), 1049-1068.
49. Maxwell, J., Masters, R., & Poolton, J. (2006). Performance breakdown in sport: the roles of reinvestment and verbal knowledge. Research Quarterly for Exercise and Sport, 77(2), 271-276.
50. Maxwell, J., Masters, R., & Poolton, J. (2006). Performance breakdown in sport: the roles of reinvestment and verbal knowledge. Research Quarterly for Exercise and Sport, 77(2), 271-276.
51. Maxwell, J. P., Capio, C. M., & Masters, R. S. (2017). Interaction between motor ability and skill learning in children: application of implicit and explicit approaches. European journal of sport science, 17(4), 407-416.
52. Mak, T. C., & Wong, T. W. (2021). Do attentional focus instructions affect real-time reinvestment during level-ground walking in older adults?. Cognitive Processing, 1-8. a. Milanese, C., Corte, S., Salvetti, L., Cavedon, V., & Agostini, T. (2016). Correction of a technical error in the golf swing: Error amplification versus direct instruction. Journal of motor behavior, 48(4), 365-376.
53. Miller, A. (2014). The Effects of Easy-to-Difficult versus Difficult-to-Easy Practice Order on a Bimanual Lever-Positioning Task.
54. Mount, J., Pierce, S. R., Parker, J., DiEgidio, R., Woessner, R., & Spiegel, L. (2007). Trial and error versus errorless learning of functional skills in patients with acute stroke. NeuroRehabilitation, 22(2), 123-132.
55. North, J. S., Warren, S., & Runswick, O. R. (2017). Errorless learning and analogy instruction: Comparing implicit learning methods. Journal of Sport & Exercise Psychology, 39(3S), 168-168.
56. Ong, N. T., Lohse, K. R., Sze, A. F., & Hodges, N. J. (2013). Investigating the moderating influence of self-efficacy in an errorless learning protocol. Paper presented at the Journal of Sport & Exercise Psychology.
57. Ong, N. T. T. (2018). Perceptions of performance success and motor learning (Doctoral dissertation, University of British Columbia).
58. Porter, J. (2017). Practicing with gradual increases in contextual interference: methods for testing the predictions of the parallel development hypothesis. Kinesiology: international journal of

fundamental and applied kinesiology, 49(2), 273-275.

59. Porter, J. M., & Beckerman, T. (2016). Practicing with gradual increases in contextual interference enhances visuomotor learning. Kinesiology: International journal of fundamental and applied kinesiology, 48(2), 244-250.
60. Porter, J.M., & Magill, R.A. (2010). Systematically increasing contextual interference is beneficial for learning sport skills. Journal of Sports Sciences, 28, 1277-1285.
61. Poolton, J., Masters, R., & Maxwell, J. (2005). The relationship between initial errorless learning conditions and subsequent performance. Human movement science, 24(3), 362-378.
62. Poolton, J., Masters, R., & Maxwell, J. (2007). Passing thoughts on the evolutionary stability of implicit motor behaviour: Performance retention under physiological fatigue. Consciousness and cognition, 16(2), 456-468.
63. Poolton, J. M., & Zachry, T. L. (2007). So you want to learn implicitly. Coaching and learning through implicit motor learning techniques. International Journal of Sports *Science & Coaching, 2*(1), 67-78.
64. Reber, A. S. (1989). Implicit learning and tacit knowledge. *Journal of experimental psychology: General, 118*(3), 219.
65. Rendell, M. A., Masters, R. S., Farrow, D., & Morris, T. (2010). An implicit basis for the retention benefits of random practice. *Journal of motor behavior, 43*(1), 1-13.
66. Rohbanfard, H., & Proteau, L. (2011). Effects of the model's handedness and observer's viewpoint on observational learning. *Experimental brain research, 214*(4), 567.
67. Apolinário-Souza, T., Ferreira, B. D. P., de Oliveira, J. R. V., Nogueira, N. G. D. H. M., Pinto, J. A. R., & Lage, G. M. (2020). Mental practice is associated with learning the relative timing dimension of a task. Journal of Motor Behavior, 1-11.
68. Sparks, K. V., Kavussanu, M., Masters, R. S., & Ring, C. (2021). Conscious processing and rowing: a field study. International Journal of Sport and Exercise Psychology, 1-17.
69. Sanli, E. A., & Lee, T. D. (2014). What roles do errors serve in motor skill learning? An examination of two theoretical predictions. Journal of motor behavior, 46(5), 329-337.
70. Sanli, E. A., & Lee, T. D. (2015). Nominal and functional task difficulty in skill acquisition: Effects on performance in two tests of transfer. Human movement science, 41, 218-229.
71. Sanli, E. A., & Lee, T. D. (2014). What roles do errors serve in motor skill learning? An examination of two theoretical predictions. Journal of motor behavior, 46(5), 329-337.
72. Sanli, E. A., Slauenwhite, J., & Carnahan, H. (2017). The relationship between error production when performing motor skills in high and low-stakes situations. Theoretical Issues in Ergonomics Science, 18(4), 360-369.
73. Savelsbergh, G., Cañal-Bruland, R., & van der Kamp, J. (2012). Error reduction during practice: A novel method for learning to kick free-kicks in soccer. International *Journal of Sports Science &* Coaching, 7(1), 47-56.

74. Schmidt, R., & Lee, T. (2013). Motor Learning and performance, 5E with web study guide: from principles to application: Human Kinetics.
75. Schmidt, R. A. (1975). A schema theory of discrete motor skill learning. Psychological review, 82(4), 225.
76. Schmitz, X., Bier, N., Joubert, S., Lejeune, C., Salmon, E., Rouleau, I., & Meulemans, T. (2014). The benefits of errorless learning for serial reaction time performance in Alzheimer's disease. Journal of Alzheimer's Disease, 39(2), 287-300.
77. 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), 207-218.
78. Sekiya, H. (2006). Contextual interference in implicit and explicit motor learning. Perceptual and motor skills, 103(2), 333-343.
79. Shea, C. H., Lai, Q., Wright, D. L., Immink, M., & Black, C. (2001). Consistent and variable practice conditions: Effects on relative and absolute timing. *Journal of motor behavior, 33*(2), 139-152.
80. Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. Psychological Review, 84,127–190.
81. Sidaway, B., Ala, B., Baughman, K., Glidden, J., Cowie, S., Peabody, A., . Wright, D. L. (2016). Contextual interference can facilitate motor learning in older adults and in individuals with Parkinson's Disease. Journal of motor behavior, 48(6), 509-518.
82. Ong, N. T., Lohse, K. R., & Hodges, N. J. (2015). Manipulating target size influences perceptions of success when learning a dart-throwing skill but does not impact retention. Frontiers in psychology, 6, 1378.
83. Van Ginneken, W., Capio, C., Poolton, J., Choi, C., & Masters, R. (2014). The effect of errorless versus errorful learning on generalized motor program learning and parameterization learning. Paper presented at the 19th ECSS Annual Congress 2014.
84. van Abswoude, F., van der Kamp, J., & Steenbergen, B. (2018). The Roles of Declarative Knowledge and Working Memory in Explicit Motor Learning and Practice Among Children With Low Motor Abilities. Motor Control, 20(XX), 1-18.
85. Wong, A. W.-K., Tse, A. C.-Y., Ma, E. P.-M., Whitehill, T. L., & Masters, R. S. (2013). Effects of error experience when learning to simulate hypernasality. Journal of Speech, Language, and Hearing Research, 56(6), 1764-1773.
86. Wong, T. W. (2019). Examining conscious motor processing and the effect of single-task, dual-task and analogy training on walking during rehabilitation by older adults at risk of falling in Hong Kong: Design and methodology of a randomized controlled trial. Contemporary Clinical Trials Communications, 100398.
87. Wulf, G., Schmidt, R. A., & Deubel, H. (1993). Reduced feedback frequency enhances generalized motor program learning but not parameterization learning. Journal of

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

Figures

Figure 1

Illustration of the experimental setup from the perspective of the experimenter.

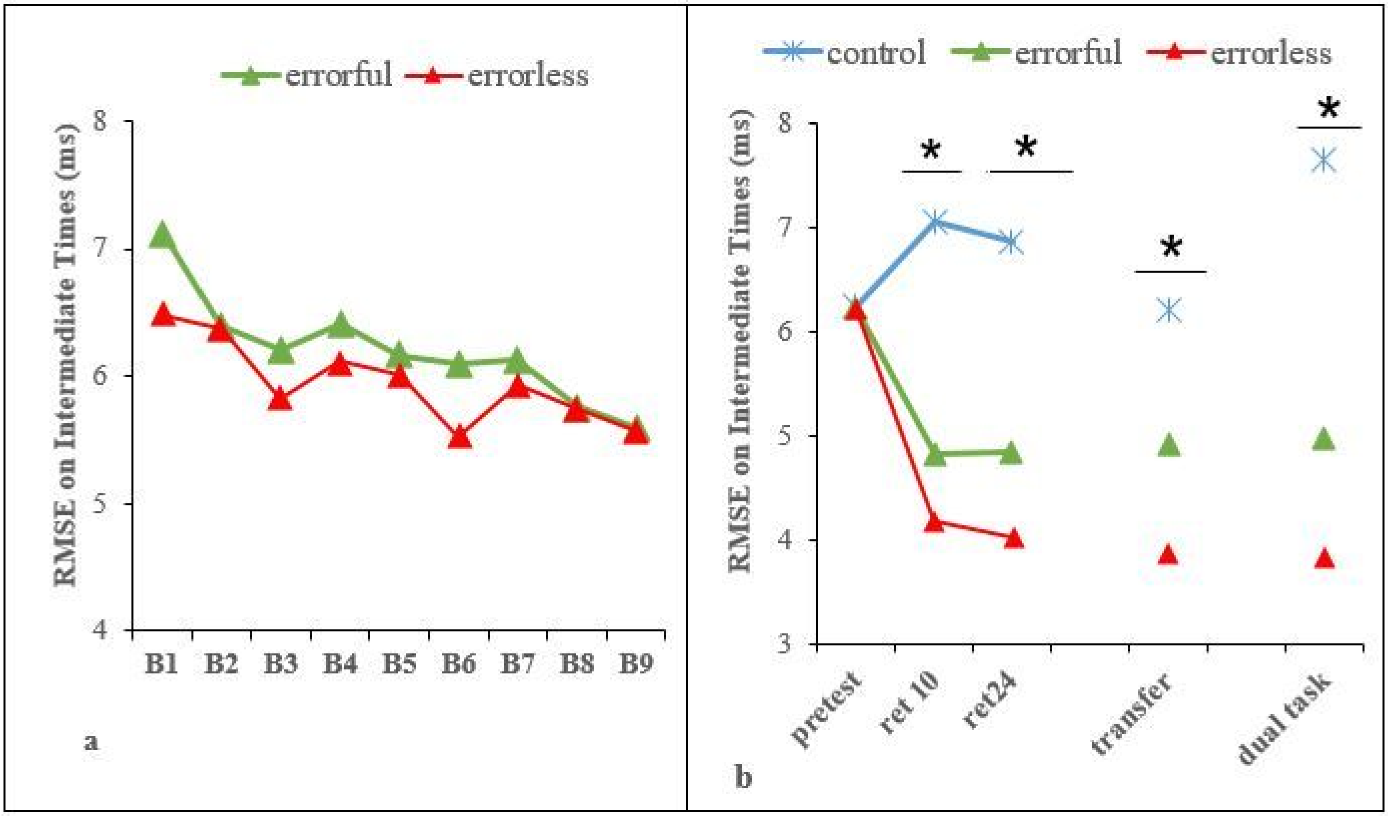

Figure 2

Root Mean Square Error (RMSE) in blocks of acquisition phase (**Panel a**) and other experimental phases including pretest, 10-min retention (ret10), 24-hr retention (ret 24), transfer and dual-task (24-hr transfer) (**Panel b**) for control, errorless and errorful groups.

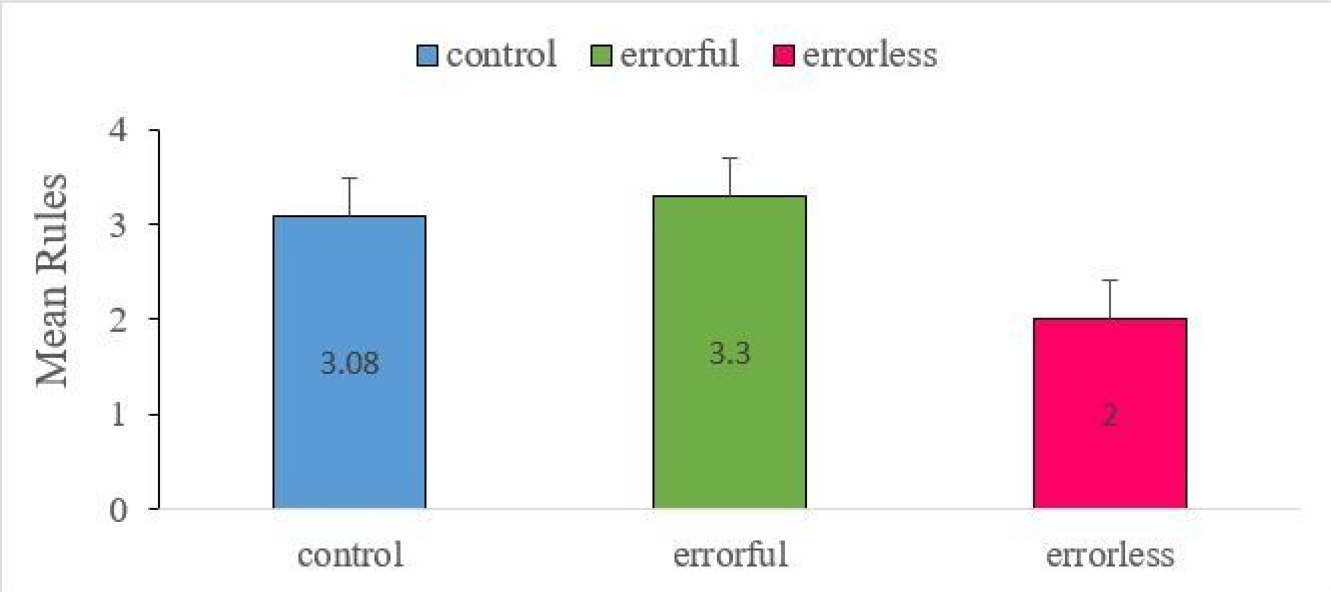

Figure 3

Mean number of explicit rules reported by participants in each group

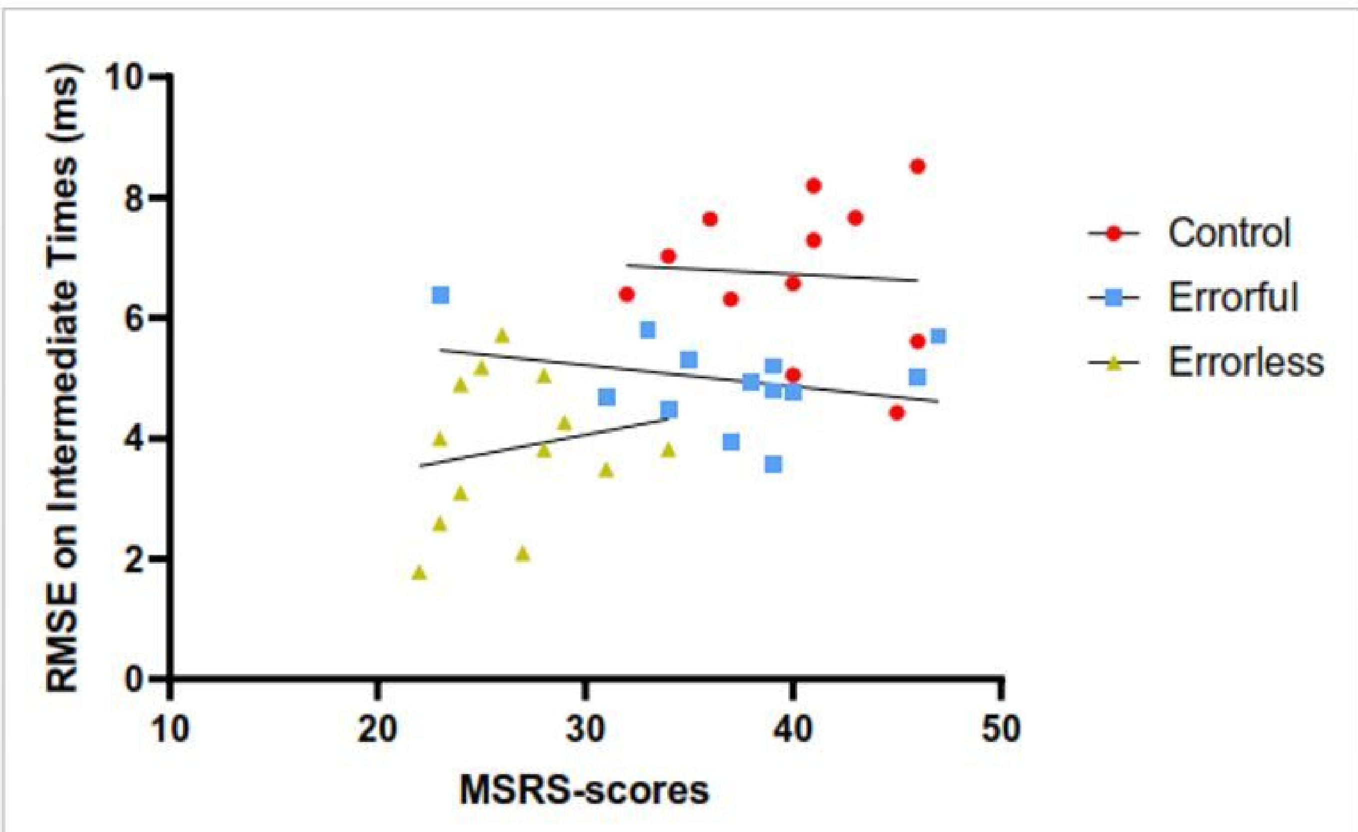

Figure 4

Relationships between groups and MSRS on performance under dual-task condition

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Onlinefloatimage4.png