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Difficulty manipulation and feedback strategies on performance during a novel fine motor coordination task

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Abstract: Improving the acquisition and retention of a new motor skill is of great importance. The present study (i) investigated the effects of difficulty manipulation strategies (gradual difficulty), combined with different modalities of feedback (FB) frequency on performance accuracy and consistency when learning a novel fine motor coordination task, and (ii) examined relationships between novel fine motor task performance and executive function (EF), working memory (WM), and perceived difficulty (PD). Thirty-six, right-handed, novice physical education students volunteered to participate in this study. Participants were divided into three progressive difficulty groups (PDG), 100% visual FB (FB1), 50% FB (FB2), and 33% FB (FB3). Progressive difficulty was increased by the manipulation of the distance to the target; 2 m, 2.37 m, and 3.56 m. Three FB modalities were investigated (i.e.: 100% visual FB (100% FB), 50% reduced feedback condition (50% RFB), and 33% reduced feedback conditions (33% RFB)). Performance assessments were conducted following familiarization, acquisition, and retention learning phases. Two stress-conditions of dart throws were investigated (i.e.: free condition (FC) and time pressure condition (TPC)). After the learning intervention, data showed that, under the free condition, the 100% FB group had a significant improvement in accuracy during all learning phases. Under time pressure condition, for the 50% RFB and the 33% RFB group, the measured variable (accuracy and consistency) showed a significant linear improvement in performance. The association between the percentage of RFB frequencies and the task difficulty (50% group) may be a more appropriate and manageable cognitive load compared to the 33% RFB and the 100% FB group. The present findings could have practical implications for practitioners because, while strategies are clearly necessary for improving learning, the efficacy of the process appears to be essentially based on the characteristics of the learners.

Keywords: motor learning; fine motor coordination task; difficulty level; reduced feedback frequency; time pressure.

1. Introduction

Skilled movement is fundamental for success across many activities, however, the learning of such movements can be impacted by numerous conditions. Factors, such as amount of practice, type of feedback, practice schedule [1], specificity, positioning, and timing [2], are all vital in skill acquisition. However, it is perhaps more important to understand how to optimize learning, as well as identify factors associated with the acquisition and retention in motor learning [3].

Manipulation of difficulty level is a learning strategy used to improve motor task performance [4,5] and task difficulty (TD) is defined as a subjective perception assessed by task doers [6]. Task complexity is sometimes used in an interchangeable sense with TD. It is assumed that the more complex a task, the greater the negative effect on response time and accuracy [7]. Earlier findings have shown that difficulty manipulation leads to durable throwing accuracy and consistency [8]. These authors reported that the durability in accuracy and performance was related to a significant decrease in perceived difficulty for the same learned task. Additionally, Sawers and Hahn [9] investigated the influence of gradual vs. sudden training during retention performance, concluding that large difficulty increases in sudden protocol training may not be necessary when learning a novel locomotor task. Despite the fact that further explanation was provided regarding the complex relationships with the learner, the task, and the practice variables, the concept of TD remains an elusive construct [10]. Moreover, there is no well-known approach to adjusting practice conditions such that the functional difficulty of the task corresponds to the optimal challenge point [11]. In addition, the most efficient mechanism to adjust the functional difficulty that can match the optimal challenge point is still unknown [12].

Although numerous studies have investigated how different sources of feedback optimize learning [13], there remains a paucity of evidence in the area of motor learning in children [14]. Previous studies demonstrate that providing augmented feedback, information related to the achievement of a motor skill, improves performance during motor learning [15,16]. The knowledge of results (KR), provided by extrinsic augmented feedback, is effective in facilitating student engagement, promoting a positive ability perception, and improving performance in challenging tasks [17]. According to the guidance hypothesis, frequent KR leads to negative effects on motor learning [18]. Providing frequent visual feedback, has been widely investigated as a modality that may improve skill acquisition [19,20] and when evaluating a subjects skill and hypothesis, allows them to modify their own errors [21]. In addition, frequent use of extrinsic feedback may enable learners to use relevant sources of information, develop improved capacity of intrinsic feedback evaluation [20], and improve future performance [22]. Contrary wise, it appears that while the guidance effect of extrinsic feedback benefits immediate skill learning, it does not contribute to a persistent performance in retention. Results show subjects who practiced a motor task with reduced FB performed better in a delayed retention test compared to subjects who practiced with augmented feedback during or following every practice trial [23,24]. Based on augmented FB manipulation, it has been demonstrated that TD and task-related experience may interact with number of trials and that RF frequencies can benefit the learning of a simple striking task for both novice and experienced participants [25]. However, the concept of withholding feedback could increase TD, thus making practice more challenging and allowing for improvement in error detection and correction [26]). With regard to complex skill learning (involving bimanual coordination), research suggests that frequent visual FB (100 %) may be beneficial [27,26]. In addition, it is well known that frequent visual FB promotes strong feedback dependency, particularly for simple tasks [28]. However, contradiction still exists when considering the same concept for complex tasks. It has been demonstrated that performance on the delayed retention test was better after a reduced FB condition vs. every trial practice condition [23,24,28]. In addition, the effectiveness of online visual FB has been demonstrated in retention tests after practicing complex tasks [29]; however, in contrast, Fujji et al. [30] reported better performance retention in the 100% FB condition. Several studies have replicated the finding that frequent visual feedback (100%) can be beneficial in complex skill learning (e.g. involving bimanual coordination) [27,26], as well as in the acquisition, retention, and transfer tests (e.g. dart throwing task) [31].

Previously, it has been concluded that children use feedback in a different manner from that of adults and that children may require longer periods of practice, with gradual feedback reduction [14]. The learning method through reduced FB could improve performance in throwing tasks via enhancement of the implicit process [14]. In addition, previous studies have suggested that learning acts independent from the working memory, and generalization of proposed method requires further investigations [21]. In contrast, a crossover interaction was observed between working memory and intervening TD. Individuals with low working memory scores benefited more when TD was easy vs. more difficult, but individuals with high working memory scores demonstrated the opposite effect [32]. In addition, working memory has been shown to reach mature performance only in the transition phase between late adolescence and early adulthood [33]. Based on this, and the fact that information behind a late provided extrinsic feedback was kept in the working memory to improve error detection, it is still contentious as to whether children are able to appropriately combine intrinsic and extrinsic feedback [20].

Furthermore, it is worth noting that the effects on learning of practice and augmented feedback (AF) variables are much more complex than initially believed [34]. Although previous research has shown the relevance of the learning methods based on reduced BF frequency and TD, little is known about how children learn motor skills despite these well-known age-related performance discrepancies [14]. It should be acknowledged that reduced FB frequency and TD are traditionally investigated separately.

To the best of our knowledge, studies simultaneously investigating the manipulation of both strategies (manipulation of TD and reduced FB frequency) during a novel fine motor coordination learning and retentions task are lacking. Therefore, the aim of this study was to determine (i) whether TD strategies (i.e., gradual manipulation of level difficulty), combined with reduced FB, influenced learning performance of a novel fine motor coordination task (dart throwing) and (ii) to explore relationships between accuracy and consistency variables in a dart throwing task, and executive function, working memory, and perceived difficulty. It was hypothesized that differences in performance variables would be observed between combined TD and reduced FB frequency groups regarding acquisition and retentions tests, in relation to cognitive performances and associated with perceptions.

2.1. Participants

Thirty-six right-handed children (age = 10.72 ± 0.89 years, body height = 149.61±8.94 cm and body mass = 41.33 ± 10.49 kg; mean ± SD) volunteered to participate in this study. The different groups were fixed with the constraint that participants were approximately matched to pre-test performance (i.e., throwing nine darts to strike as close as possible to the bullseye), from the regular distance (i.e.: 2.37 m) [8,35] (Ong et al., 2015, Elghoul et al., 2018) and following two experimental stress conditions (with and without time-pressure) (Elghoul et al., 2018). They were assigned to either a 33% feedback group (33% RFB; n =13), a 50% feedback group (50% RFB; n = 11) or a 100% feedback group (100% FB; n =12). In the acquisition phase, participants in the 100% condition received visual FB after every trial. However, the FB frequency in the 50% condition was reduced to one visual FB every two trials (54 trials out of 108 practice trials). For the last ones, the FB frequency in the 33% condition was reduced to one visual FB every three trials (36 trials out of 108 practice trials). The level difficulty was manipulated by increasing the distance from the dartboard every three blocks (2 m; 2.37 m and 3.56 m) [8,36]. Participants declared no experience in dart throwing. The protocol was explained in full and informed consent was obtained before participation. All procedures were conducted according to the declaration of Helsinki.

2.2. Procedures

Subjects performed the dart throwing task across two experimental sessions. There was a pre-test followed by an acquisition phase and immediate post-test during the first session, then, delayed retention tests one and two weeks after, respectively. Test sessions were performed at the same time of day; on testing days a 10 min standard warm-up, including running and static stretching exercises [37], was followed by three dart throws. During the test session, two conditions were investigated. In the first, free condition (FC), subjects threw a trial of nine darts and were instructed always to aim for the bullseye. In the second, time pressure condition (TPC), participants were instructed to complete the set of throwing as quickly and accurately as possible. The dartboard was fixed on a wall so that its center was at eye level for each subject [37]. No instructions were given to participants. Individuals' posture and throwing techniques were maintained the same in the test conditions. For the non-visual feedback trials, an opaque curtain, 2m wide, were placed in front of each participant following throws without feedback [38]. In this condition, as soon as a participant released the dart, the experimenter, who stood one meter away from the line of throw, raised the opaque curtain to occlude the view of the impact of the dart and prevent knowledge of the result during the throwing task [31]. The pre-test consisted of nine trials. During the acquisition phase, participants were asked to complete a set of nine blocks of 12 trials of dart throwing. The acquisition phase was followed by an immediate post-test, which was the same as the pre-test. The delayed retention test 1, consisting of nine trials, was administered one week later [8,35]. In addition, as during the primary retention test, participants in the delayed retention 2 had to complete a set of nine trials, performed two weeks post acquisition.

2.3. Task and Apparatus:

A digital camera (SONY Corporation, HDR PJ 270E, Tokyo, Japan) was installed behind and above the participant to record the position of each throw for subsequent analysis of x (horizontal) and y (vertical) coordinates to the origin of the dartboard. The same posture and throwing techniques were maintained across different conditions [35].

For the progressive level of difficulty manipulation, we modified the difficulty level by increasing the distance to the dartboard. Three distances were maintained in this experimental condition: short (2m), regular (2.37m) and long (3.56m) [8,36]. The dartboard was fixed on a wall so that its center was at eye level for each subject [8]. No instructions were given to participants. Individual posture and throwing techniques were maintained the same in the test conditions. For the non-visual feedback trials, an opaque curtain with 2m large was placed one meter in front of each participant following throws without feedback [38]. In this condition, as soon as a participant released the dart, the experimenter, standing one meter away from the line of throw, raised the opaque curtain to occlude the view of the impact of the dart and prevent knowledge of the result during the throwing task [31].

2.4. Measures

Perceived difficulty: this scale is composed of 15 points, numbered 1-15, and is anchored at the two extremities by verbal labels – "Extremely easy" and "Extremely difficult" [39].

2.4.1. Trail making test

This is a test exploring mental flexibility EF (aptitude to move quickly from one task to another) [40]. In Part A, circles were numbered 1–25 and presented randomly on a sheet of paper; subjects were required to draw lines to connect the numbers in ascending order. In Part B, the circle included both numbers (1–15) and letters (A–L); as in Part A, the child was required to draw lines to connect the circles in an ascending pattern, but with the added task of alternating between the numbers and letters (i.e. 1-A-2-B-3-C, etc.). The child was also instructed to connect the circles as quickly as possible without lifting the pen or pencil from the paper. The duration of the test was 3 min for each part. The trail-making test (TMT) measures visual conceptual and visuo-motor tracking. TMT part A purportedly measures attention, visual search, and motor function, whereas TMT part B is seen as a measure of EF, speed of attention, visual search, and motor function [41,42,43]. Outcome measures for both tasks included time to completion and number of errors [43]. Results for both TMT part A and B are reported as the number of seconds required to complete the task [44], errors committed and corrected. Higher scores reveal greater impairment.

2.4.2. Corsi block tapping test

The Corsi Block Tapping Test assesses short-term and working memory using a nonverbal analogue of the Digit Span procedure originally proposed by Hebb [45]. It may be seen as a spatial equivalent of the word and digit span tests that are sometimes used to measure aspects of memory. The test consists of nine uniformly small white wooden blocks, which are distributed over a rectangular board. Numbers from 1 to 9 are printed on the sides of the blocks that face the examiner. The examiner taps the blocks in a pattern that is then copied by the subject. Five sequences are tapped for each series. A correct performance is scored when the subject is able to correctly copy three of the five sequences. When a correct response is given, the next sequence is given until a series of eight blocks is given or until the subject is unable to copy three of the five sequences. For a correct response to be scored, the subject must tap only one block at a time and must tap directly on the top of the block, not to the side. The pattern of taps is repeated for every third sequence; however, the intervening taps are not repeated. Subjects tend to improve on the repeated stimuli, but not necessarily on the non-repeated sequences [46].

2.5. Score calculations:

A measure of outcome accuracy was evaluated based on mean radial error (MRE), which was defined as the absolute distance between the dart position and the center of the target. Mean RE was calculated as $RE^2 = (x^2 + y^2)$ for each block of trials.

We also calculated consistency based on bivariate variable error (BVE) with the following equation [47]:

$$\mathrm{BVE} = \sqrt{\frac{1}{k}\sum_{i=1}^{k}(X_i - X_c)^2 + (Y_i - Y_c)^2}$$

k = number of trials
Xc = mean constant error on the X axis within a test or block
Yc = mean constant error on the Y axis within a test or block

2.6. Data Analysis:

All results are expressed as mean (± SD). As data were normally distributed, the calculated and measured variables were analyzed using a mixed two-way analysis of variance (ANOVA) with repeated measurements: 3 Groups (RFB 33% vs. RFB 50% vs. FB100%) × 4

Times (pre-test, post-test, delayed retention1 and retention 2). Mean radial error (MRE) and bivariate variable error (BVE) were averaged across practice difficulty and feedback frequencies for each test session. When appropriate, a Bonferroni Post-Hoc analysis was performed. Correlation coefficients were used to assess the relationships between variables [48]. We also calculated the effect size, as partial η_p^2, where the thresholds for describing the effect sizes as small, moderate, and large were considered as 0.01 (small), 0.06 (medium), and 0.14 (large), respectively [49]. The level of statistical significance was set, a priori, at $p<0.05$.

3. Results

3.1. Performance measures

3.1.1. Mean Radial Error

Outcome accuracy for FC is shown in Figure 1. Results revealed no significant effect of FB frequency ($F_{(2; 33)} = 1.321$; $p = 0.28$; $\eta_p^2 = 0.074$). During the familiarization, acquisition and retention phases, results reveal a significant main effect for motor learning on mean radial error (MRE) ($F_{(3; 6)} = 3.506$; $p = 0.018$; $\eta_p^2 = 0.096$). In addition, there were no significant interaction between learning and FB frequency ($F_{(6; 99)} = 0.889$; $p = 0.505$; $\eta_p^2 = 0.051$). The post-hoc analysis revealed that the score of the MRE was better in retention 2 than during pre-test. Furthermore, participants with progressive difficulty and 100% FB demonstrated significantly greater accuracy improvement (i.e., decreasing MRE) over all phases (retention 2 compared to retention 1, post-test and pre-test) ($p < 0.05$; Figure 1). Moreover, Post-hoc analysis of RFB 50% group showed also a linear trend in MRE improvement in retention 2, but only when compared to post-test and pre-test ($p < 0.05$; Figure 1).

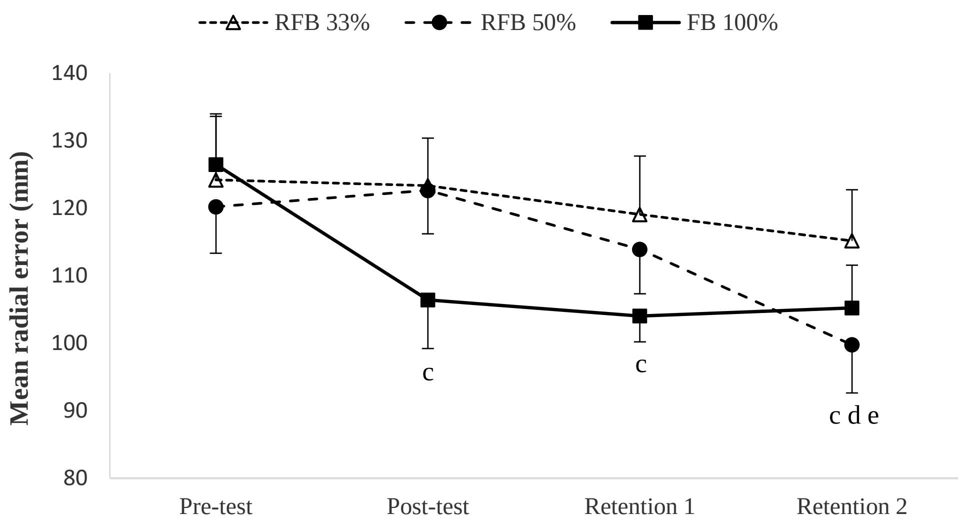

Figure 1. Accuracy as measured through mean radial error under free condition in the dart throwing task. RFB 33%: reduced visual FB condition to one visual FB by three trials; RFB 50%: reduced visual FB condition to one visual FB by two trials; FB 100%: condition received visual FB after every trial. c: Significant difference in RFB 100% compared to Pre-test at $p < 0.05$; d: Significant difference in RFB 50% compared to Pre-test at $p < 0.05$; e: Significant difference in RFB 50% compared to Post-test at $p < 0.05$.

Outcome accuracy for TPC is shown in Figure 2. Results reveal a significant main effect for learning on accuracy in time pressure condition during the familiarization, acquisition, and retention phases ($F_{(3; 6)} = 14.96$; $p = 0.001$; $\eta_p^2 = 0.312$). The post-hoc analysis revealed that the score of the MRE for TPC was better in retention 2 than pre-test, post-test and retention 1 ($p < 0.001$; Figure 2). Moreover, analysis showed no significant effect of FB frequency ($F_{(2; 33)} = 0.344$; $p = 0.711$; $\eta_p^2 = 0.02$) and no significant interaction between learning and FB frequency ($F_{(6; 99)} = 0.364$; $p = 0.9$; $\eta_p^2 = 0.021$).

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Further analysis showed that accuracy under TPC in 33% and 50% conditions were better than in 100% condition. Motor learning when based on progressive difficulty combined to reduced FB in both 33% RFB and 50% RFB conditions display significantly greater accuracy improvement (i.e., decreasing MRE) over all phases (retention 2, retention 1 and post-test compared to pre-test) ($p < 0.001$; Figure 2).

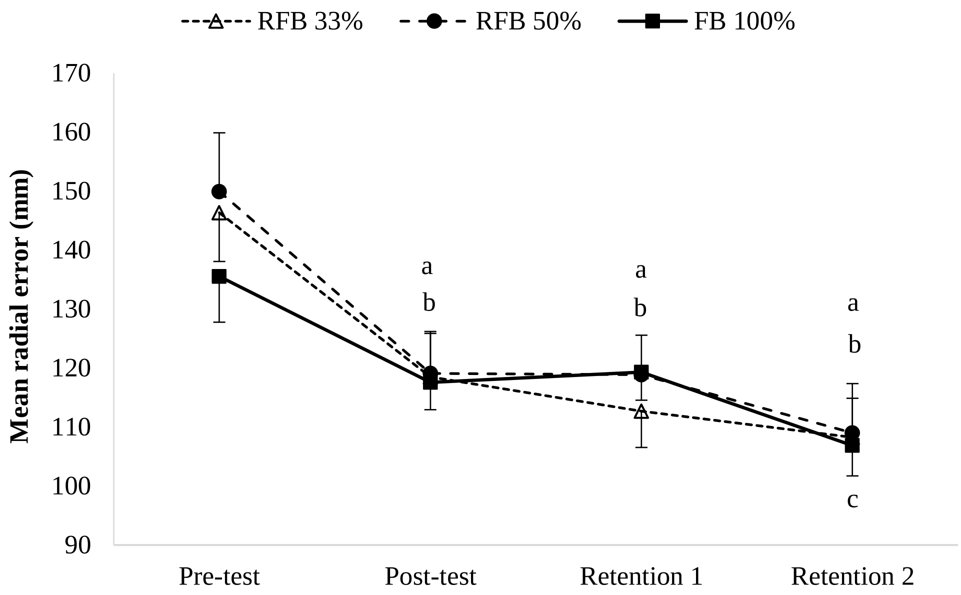

Figure 2. Accuracy as measured through mean radial error under time pressure condition in the dart throwing task. RFB 33%: reduced visual feedback condition to one visual feedback by three trials (36 trials out of 108 practice trials); RFB 50%: reduced visual FB condition to one visual feedback by two trials (54 trials out of 108 practice trials); FB 100%: condition received visual feedback after every trial. a: Significant difference in RFB 33% group compared to Pre-test at $p < 0.05$; b: Significant difference in RFB 50% group compared to Pre-test at $p < 0.05$; c: Significant difference in FB 100% group compared to Pre-test at $p < 0.05$.

3.1.2. Bivariate Variable Error

There were no significant effects of FB frequency ($F_{(2; 33)} = 2.034$; $p = 0.147$; $\eta_p^2 = 0.109$), learning ($F_{(3 ; 6)} = 0.172$; $p = 0.915$; $\eta_p^2 = 0.005$) and no significant interaction between learning × FB frequency ($F_{(6 ; 99)} = 0.803$; $p = 0.57$; $\eta_p^2 = 0.046$) under the free condition.

Under the time pressure condition, ANOVA revealed no significant effect of FB frequency on consistency (BVE) ($F_{(2; 33)} = 0.002$; $p = 0.997$; $\eta_p^2 = 0.000$) and a significant effect of learning ($F_{(3; 6)} = 4.743$; $p = 0.003$; $\eta_p^2 = 0.125$). The post-hoc analysis revealed that the score of the BVE under TPC was better in retention 2 than pre-test ($p < 0.01$; Figure 3). There was no significant interaction (learning × FB frequency) ($F_{(6; 99)} = 0.061$; $p = 0.999$; $\eta_p^2 = 0.003$). Further analysis showed that improvement in BVE under TPC was comparable for all groups (33% RFB, 50% RFB and 100% FB) when comparing retention 2 to pre-test ($p < 0.05$; Figure 3).

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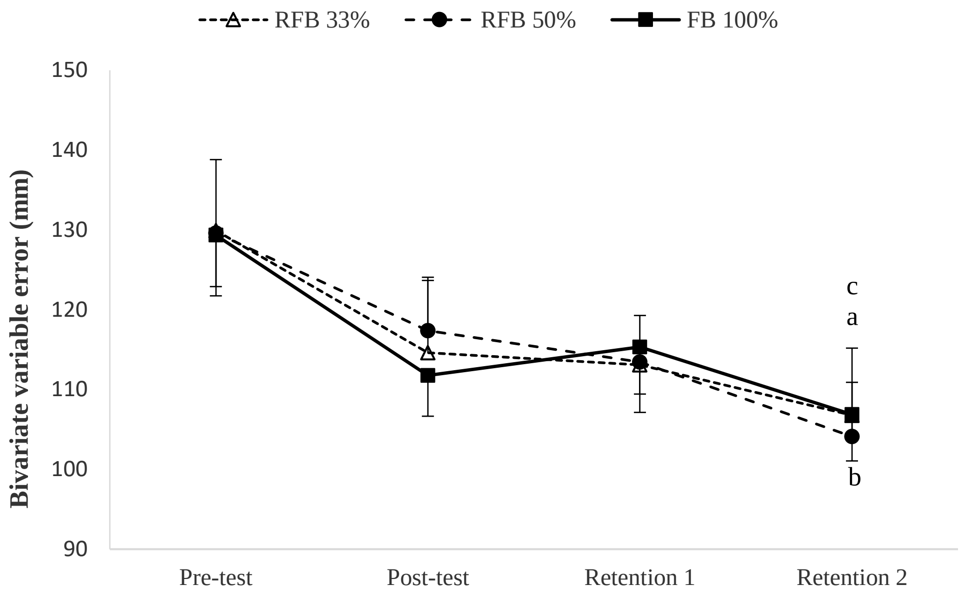

Figure 3: Consistency as measured through mean radial error under time pressure condition in the dart throwing task. RFB 33%: reduced visual FB condition to one visual FB by three trials; RFB 50%: reduced visual FB condition to one visual FB by two trials; FB 100%: condition received visual FB after every trial. a: Significant difference in RFB 33% compared to Pre-test at $p < 0.05$; b: Significant difference in RFB 50% compared to Pre-test at $p < 0.05$; c: Significant difference in FB group 100% compared to Pre-test at $p < 0.05$.

3.2. Relationship between the used strategies (combined progressive difficulty and reduced FB frequency) and executive function, working memory and perceived difficulty

Table 1 presents the correlations for the studied variables in 33% RFB frequency. There was a significant positive correlation between average time in TMT part B and both average time in TMT part A and committed errors in TMT part B ($r = 0.82$, $p < 0.01$; $r = 0.78$, $p < 0.01$, respectively). Results revealed a significant negative correlation between executive function (average time in TMT part B) and working memory (Corsi Forward) ($r = -0.66$; $p < 0.05$). In addition, a significant negative correlation was found between Corsi Backward and both average time in TMT-B and committed errors in TMT part B ($r = -0.57$, $p < 0.05$; $r = -0.58$, $p < 0.05$ respectively) (Table 1). There was a significant positive correlation between Corsi Backward and Corsi Forward ($r = 0.72$, $p < 0.01$). Moreover, PD was positively correlated to executive function (average time in TMT part B and committed errors in TMT part B) ($r = 0.67$, $p < 0.05$; $r = 0.65$, $p < 0.05$; respectively) and negatively correlated to working memory measured variables in free conditions tasks ($r = -0.66$, $p < 0.05$). Under time pressure condition, perceived difficulty was correlated only to perceived difficulty in free condition ($r = 0.72$, $p < 0.01$) (Table 1). Finally, there was no significant difference between variables in fine coordination task (throwing task) and both cognitive and perceived measured variables. A strong positive correlation was found between accuracy (MRE) and consistency (BVE) measures only under the same condition (free and time pressure condition throws) ($r = 0.94$, $p < 0.001$; $r = 0.7$, $p < 0.01$) (respectively) (Table 1).

Table 1. Correlations between cognitive performances measures: executive function (TMT parts A and B) and working memory (Corsi Forward and Backward), dart throwing performance:

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accuracy (MRE) and consistency (BVE) measures and perceived difficulty score (PD) under free (FC) and time pressure (TPC) conditions in 33% reduced feedback condition.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Time TMT A	–													
2. CME TMT A	0	–												
3. CRE TMT A	0	0	–											
4. Time TMT B	.82**	0	0	–										
5. CME TMT B	.52	0	0	.78**	–									
6. CRE TMT B	-0.35	0	0	-.05	0.3	–								
7. Corsi Forward	-.66*	0	0	-.5	-.26	.66*	–							
8. Corsi Backward	-.54	0	0	-.57*	-.58*	.33	.72**	–						
9. PD FC	.54	0	0	.67*	.65*	-.27	.15	-.66*	–					
10. PD TPC	.29	0	0	.48	.49	-.22	-.03	-.44	.64*	–				
11. MRE FC	-.1	0	0	-.14	-.12	-.31	-.18	-.18	-.16	-.05	–			
12. BVE FC	-.08	0	0	-.09	-.01	-.21	-.05	-.18	-.11	.09	.94***	–		
13. MRE TPC	-.13	0	0	.08	.15	-.03	.14	.1	-.02	.22	.25	.43	–	
14. BVE TPC	0	0	0	.24	.52	.3	.18	.09	.29	.31	-.18	0	.7**	–

* Significant correlation at $p < .05$; ** $p < .01$; *** $p < .001$. Time TMT A indicates average time in TMT test part A; CME TMT A: Committed error in TMT test part A; CRE TMT A: Corrected errors in TMT test part A; Time TMT B: average time in TMT test part B; CME TMT B: Committed error in TMT test part B; CRE TMT B: Corrected errors in TMT test part B; PD FC: Perceived difficulty under free condition; PD TPC: Perceived difficulty under time pressure condition; MRE FC: Mean radial error under free condition; BVE FC: Bivariate variable error under free condition; MRE TPC: Mean radial error under free condition; BVE TPC: Bivariate variable error under free condition.

Table 2 presents the correlations for the studied variables in 50% reduced FB frequency. Compared to the results of correlation in 33% reduced FB frequency, the condition of 50% reduced FB present less significant correlation. First, there is no significant correlation between cognitive, working memory variables and measured performance in fine coordination task. However, perceived difficulty under both free and time pressure conditions was positively correlated to executive function (average time in TMT part B) ($r = .89$, $p < 0.001$; $r = .63$, $p < 0.05$) (respectively) (Table 2). Finally, a significant positive correlation was found between consistency under free condition (BVE FC) and accuracy (MRE FC) under the same condition ($r = .84$, $p < 0.01$) (Table 2).

Table 2. Correlations between cognitive performances measures: executive function (TMT parts A and B) and working memory (Corsi Forward and Backward), dart throwing performance: accuracy (MRE) and consistency (BVE) measures and perceived difficulty score (PD) under free (FC) and time pressure (TPC) conditions in 50% reduced feedback condition.

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Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Time TMT A	–													
2. CME TMT A	0	–												
3. CRE TMT A	0	0	–											
4. Time TMT B	.49	0	0	–										
5. CME TMT B	.27	0	0	.36	–									
6. CRE TMT B	-.15	0	0	-.02	-.24	–								
7. Corsi Forward	-.44	0	0	-.45	-.6	.59	–							
8. Corsi Backward	-.6	0	0	-.48	-.09	-.35	.26	–						
9. PD FC	.52	0	0	.89***	.4	.04	-.09	.07	–					
10. PD TPC	-.07	0	0	.63*	.54	-.11	-.15	.28	.71*	–				
11. MRE FC	.35	0	0	-.09	.02	-.15	-.2	-.51	-.03	-.32	–			
12. BVE FC	.48	0	0	-.23	-.01	-.44	-.26	-.24	-.18	-.48	.84**	–		
13. MRE TPC	-.02	0	0	.28	-.33	.22	-.12	-.08	.01	-.14	-.47	-.47	–	
14. BVE TPC	-.35	0	0	.01	-.15	.26	0	-.28	.11	.2	-.11	-.46	.26	–

* Significant correlation at $p < .05$; ** $p < .01$; *** $p < .001$. Time TMT A indicates average time in TMT test part A; CME TMT A: Committed error in TMT test part A; CRE TMT A: Corrected errors in TMT test part A; Time TMT B: average time in TMT test part B; CME TMT B: Committed error in TMT test part B; CRE TMT B: Corrected errors in TMT test part B; PD FC: Perceived difficulty under free condition; PD TPC: Perceived difficulty under time pressure condition; MRE FC: Mean radial error under free condition; BVE FC: Bivariate variable error under free condition; MRE TPC: Mean radial error under free condition; BVE TPC: Bivariate variable error under free condition.

As shown in Table 3, results suggest that processing time in TMT part B (average time) and TMT part A (average time) were positively related ($r = 0.71$, $p < 0.01$). Concerning the working memory test, the less (Corsi forward) and more complex (Corsi Backward) pattern of taps were positively correlated to executive function (TMT part B corrected errors) ($r = 0.74$, $p < 0.01$; $r = 0.65$; $p < 0.05$; respectively) (Table 3). Furthermore, a significant negative correlation was found between Corsi Backward and consistency measures for the difficult throw condition (MRE TPC) ($r = -0.63$, $p < 0.05$). Consistency performance in free condition throws (BVE FC) was negatively correlated to both PD under free and time pressure conditions ($r = -0.8$, $p < 0.01$; $r = 0.76$, $p < 0.01$; respectively) (Table 3). In addition, accuracy (MRE) and consistency (BVE) measures under the same condition (FC or TPC) were positively correlated ($r = 0.63$, $p < 0.05$; $r = 0.62$, $p < 0.05$; respectively); however there was a significant negative correlation between the same variables under different throw conditions (free condition vs. time pressure condition) ($r = 0.62$, $p < 0.05$) (Table 3). Finally, performance measures under time pressure for both accuracy and consistency (MRE TPC and BVE TPC) were negatively related to TMT part A committed errors ($r = -0.65$, $p < 0.05$; $r = -0.76$, $p < 0.01$; respectively).

Table 3. Correlations between cognitive performances measures: executive function (TMT parts A and B) and working memory (Corsi Forward and Backward), dart throwing performance: accuracy (MRE) and consistency (BVE) measures and perceived difficulty score (PD) under free (FC) and time pressure (TPC) conditions in 100% feedback condition.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Time TMT A	–													
2. CME TMT A	-.2	–												

3. CRE TMT A	0	0	–											
4. Time TMT B	.71**	-.43	0	–										
5. CME TMT B	-.15	.32	0	.23	–									
6. CRE TMT B	-.07	-.09	0	.09	-.1	–								
7. Corsi Forward	-.37	.21	0	-.2	.2	.74**	–							
8. Corsi Backward	-.3	.5	0	-.21	.38	.65*	.9***	–						
9. PD FC	.1	-.15	0	.11	-.32	-.06	-.37	.43	–					
10. PD TPC	.54	-.34	0	.51	-.22	.1	-.53	.23	.68*	–				
11. MRE FC	-.43	-.21	0	-.41	.04	-.1	-.01	-.13	-.5	-.54	–			
12. BVE FC	-.19	.12	0	-.31	.19	.24	.54	.45	-.8**	-.76**	.63*	–		
13. MRE TPC	.33	-.65*	0	.56	-.28	0	-.56	-.63*	.48	.72**	-.12	-.65*	–	
14. BVE TPC	.2	-.76**	0	.41	-.11	.18	-.27	-.43	-.16	.26	.5	.11	.62*	–

* Significant correlation at $p < .05$; ** $p < .01$; *** $p < .001$. Time TMT A indicates average time in TMT test part A; CME TMT A: Committed error in TMT test part A; CRE TMT A: Corrected errors in TMT test part A; Time TMT B: average time in TMT test part B; CME TMT B: Committed error in TMT test part B; CRE TMT B: Corrected errors in TMT test part B; PD FC: Perceived difficulty under free condition; PD TPC: Perceived difficulty under time pressure condition; MRE FC: Mean radial error under free condition; BVE FC: Bivariate variable error under free condition; MRE TPC: Mean radial error under free condition; BVE TPC: Bivariate variable error under free condition.

4. Discussion

The aim of the present study was to (i) examine whether strategies (i.e., gradual manipulation of level difficulty combined to reduced FB frequencies) used in learning a novel fine motor coordination task (darts throwing) affect performance, and (ii) to explore relationships between accuracy and consistency variables in dart throwing task, executive function, storage in working memory, and PD among 11–12-year-old boys.

In this study, the strategy based on progressive difficulty manipulation combined with reduced FB frequency benefited accuracy performance under FC for both, the 100% FB and the 50% FB group, compared to the 33% FB group. In addition, the 100% FB group showed better accuracy performance in the post-test and the delayed retention test 1 compared to the 50% FB group. Whereas, in the 50% reduced FB group, this occurred only at retention 2 compared to pre-test and post-test. In addition, the learning performance of the 50% reduced FB group seems to be more durable compared to the 100% FB group. While some studies support the guidance hypothesis that augmented FB lead to a better retention performance [50,51], others offer conflicting evidence, suggesting that a reduced frequency of FB may benefit retention [15,52]. The findings from the current study were in line with those that support guidance hypothesis showing that more FB led to a better retention performance [30]. Moreover, it has been demonstrated that practice may be less effective for the children in the reduced FB practice condition compared to those who practiced with 100% feedback [14]. We suggest that the progressive level of difficulty combined with visual FB could be a plausible explanation that more feedback led to a better performance in retention test. Moreover, it was suggested from previous studies that there may be an interaction between task complexity and feedback frequency [26, 52]. Our current findings are concordant with those of Sidaway et al. [53] who revealed that, in children, the effect of FB may be mediated by the difficulty of the motor skill being learned.

Furthermore, we have shown that reduced FB frequency benefits accuracy under TPC for both the 33% FB and the 50% FB group, compared to the 100% FB group. It has been suggested that there exists a possible interaction between task complexity and FB frequency [26,52]. Fujii et al. [30] reported that a reaching task was considered as relatively complex; however, was not controlled as a study variable. To our knowledge, only a limited number of studies have employed augmented FB when considering the difficulty of the learned task. However, in a recent study, Elghoul et al. [8] demonstrated that progressive difficulty manipulation leads to durable throwing accuracy and consistency performance. In addition, previous research suggests that adding difficulty to the instructional process can increase learning [54,55]. It is worth noting that studies involving reduced feedback frequencies tend to be more focused on the nature of the task (simple vs. complex), rather than the association between the percentage of reduced FB frequencies and the TD, which could conceivably provide a more appropriate, challenging, environment and a more manageable cognitive load.

In the present study, a change in MRE performance under time pressure condition across the learning phases was reported. The 100% group demonstrated a decrease in BVE and MRE variables at post-test, retention 1 and retention 2, but the changes did not reach significance (Figure 2 and 3). On the contrary, the 50% reduced FB and the 33% reduced FB group under time pressure condition appeared to enhance learning. The combination of reduced FB frequencies and progressive difficulty manipulation may positively influence accuracy performance in the retention test. Regarding performance under time pressure condition, MRE and BVE (accuracy and consistency) displayed significantly improved linear performance, when compared to retention 2, retention 1, and post-test to pre-test. Previous work has demonstrated that reduced feedback practice conditions may yield increases in information-processing demands during practice, which are advantageous to the relatively permanent motor learning effects observed in delayed retention tests [14,56]. In addition, it has been posited that visual sighting of the path of a projected object may not be a critical factor in skill learning [57]. Moreover, reducing KR would allow participants to focus more intently on the movement-produced FB and strategies for error detection [56]. It seems that adding a progressive level of difficulty to the reduced FB conditions during the learning process can limit deteriorated performance in the acquisition phase, thus potentially explaining the enhancement in accuracy for the reduced FB groups in the post-test. It seems that adding a progressive level of difficulty to the learning process allows the children to take advantage of the additional FB, limiting the effect of excess information on the capacity for information processing, and reducing the dependence to this additional external FB.

Concerning the relationships between dart throwing performance with combined progressive difficulty and reduced FB frequency, as well as executive function, working memory, and PD. Findings suggest that reduced FB 50% combined with progressive TD strategy may benefit learning processes by decreasing cognitive demands imposed on the learners and could provide a more controlled degree of learning efficiency trade-off under various experimental conditions. The results of the current study show that conditions of throwing in the group with visual feedback (100%) and with the reduced FB frequency group (33%) could contribute an additional cognitive load to the cognitive processes of participants. Of particular interest are the correlations found between measured variables. These results were supported, in the case of the visual feedback group, by the significant positive correlation between measured cognitive variables (Time TMT part A and Time TMT part B) and between EF (CRE TMT part B) and working memory (Corsi Forward and Backward). Moreover, a significant correlation was found between the measured throwing performances (both MRE and BVE under TPC) and EF (CME part A)), and between working memory (Corsi Backward) and throwing performances (MRE under TPC). These results were supported by a previous study [26], showing that frequent visual feedback typically promotes strong feedback dependency.

In the case of the reduced feedback frequency group (33%), the hypothesis of an additional cognitive load was also supported by the observed correlations between cognitive components of the learner. There was a positive correlation between measured cognitive variables (Time TMT part A and Time TMT part B) and (Time TMT part B and CME TMT part B). In addition, significant correlations were found between EF (Time TMT part B and CME TMT part B) and working memory (Corsi Forward). Regarding the working memory (Corsi Backward), there was a negative significant correlation with EF (Time TMT and CME TMT part B). Based on the correlation found between PD under free condition (PD, FC) and both EF (Time TMT and CME TMT part B) and working memory

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(Corsi Backward)), it is likely that the deterioration in the cognitive performances may be associated with an increase in the PD level. One explanation for this may be the effect on the learning processes by reducing feedback frequency, which increases the demands imposed on the learner and requires the learner to develop their own internal error detection and correction mechanisms [26].

Learning via reduced FB (FB 50%) might provide a more appropriate environment with manageable cognitive load; particularly given the subject population (novice young learners). However, reduced feedback practice conditions can increase information-processing demands during practice [14] and recent findings suggest that only consistent performance was accompanied by a significant change in PD scores when learning a novel psychomotor task [8].

A prior study has reported that the implicit process may be independent of working memory [21]. This was supported in the current study by the lack of relationship between measured cognitive variables after the reduced FB 50% condition, when comparing to both 33% reduced FB and 100% FB conditions. Studies using reduced feedback strategy have suggested that skills may be acquired through an implicit process, which is independent of the working memory [58,59]. Previous studies have argued that, by suppressing working memory's involvement in motor learning, an implicit motor learning takes place [58]. Furthermore, the skill that is learned implicitly in comparison with explicit practice learning tends to be much less exposed to failure and loss under stress [60,61]. In this regard, implicit motor learning encourages implicit processes to support the performance by avoiding the serial transition of explicit declarative knowledge from the onset of learning [28].

Concerning the contradiction based on the benefits enhanced by the reducing feedback frequency in comparison to the augmented feedback on the learning process [26]. Guadagnoli et al. [25] previously highlighted the relationship between the task complexity and task-related experience interaction. Our results are consistent with the predictions of the Challenge Point Framework [10], which suggests that task demands, learner characteristics, and practice conditions interact to influence the level of challenge posed to the learner during practice. Based on the Challenge Point Framework, there is a point of optimal challenge that allows a learner-appropriate level of cognitive effort, maximizing benefits for learning. When the level of the challenge exceeds the optimal challenge point, the level of effort may be beyond the information-processing capability of the learner, interfering with learning benefits. The results of the current study suggest that when learning a novel-throwing task, children can benefit more from combined TD and reduced feedback frequency. Therefore, these considerations allow the individual a more appropriate level of cognitive effort and optimal information-processing capability, thereby maximizing benefits for learning.

In the present study, it is important to point out that the interaction between TD and feedback strategies, even in a novel fine motor coordination task learning, should be considered. Despite its novelty, the present study suffers from some limitations that should acknowledged. First, the small sample size (n= 36 participants) could hinder the generalizability of these results (e.g., different ability levels combined with TD and visual or reduced FB strategies). Second, we only incorporated novice learners in this study; relationships between learner and task characteristics and specific fields should be assessed to measure the finer intricacies of improved performance. Third, further research evaluating the persistence of practice strategies over time and under psychologically stressful conditions is warranted. Finally, these results pertain only to young novice learners; future studies assessing the relationship between cognitive variables and performances in learning a psychomotor task in competitive and elite athletes are needed.

5. Conclusions

While the FB interventions were not confirmed as a significant factor in practice, the association between TD and visual feedback was more beneficial than non-visual feedback in the acquisition of a target task. The reduced FB frequency (both 33 % and 50%

strategies groups) was more efficient and may benefit retention performance in learning a novel psychomotor task. Moreover, regarding the relationship between cognitive variables and performances in learning a novel psychomotor task, the association between the percentage of reduced FB frequency and the task difficulty (50% FB), could provide a more appropriate, challenging, environment and manageable cognitive load. Consequently, physical education teachers and practitioners are encouraged to consider TD, FB practices, and the learner's idiosyncratic characteristics, to facilitate a better effective learning process of novel fine motor coordination tasks.

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