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Effects of Variable Practice on Kinematics and Accuracy of Throwing in Boys with Developmental Coordination Disorder

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Abstract

Many children with Developmental Coordination Disorder (DCD) cannot throw, which often prevents them from taking part in age-appropriate activities. The present research examined the degree to which variable practice, embedded in the Motor Schema Theory (Schmidt, 1975), would positively affect movement effectiveness, and coinciding accuracy, as well and parametrization of spatial and temporal aspects of control. Nine boys diagnosed with DCD (M = 10.7 years, SD = 1.0) participated in a pre-test, ten 30 minute training sessions, post-test, and a transfer test. Only pre- and post-tests involved kinematic data collection and measurement of accuracy. The variable practice involved throwing a tennis ball from a distance of 5 meters at 3 different targets (40 cm vs 35 cm vs 25 cm), positioned in three different locations. The transfer test was presented in a new environment with novel conditions. Results reveled improvement in movement effectiveness, at the group level, however when individual data was examined not all participants benefited to the same degree, especially when the transfer test was considered. All participants improved in regards to their accuracy. The changes in the outcome coincided with changes in spatial parametrization at the elbow, but not the shoulder. Also, higher velocity of the ball and angular velocity at the elbow were evident. From the clinical standpoint, the present study highlighted the importance of introducing context relevant variability in the learning program, however the decline in performance in the transfer test indicates that more research is warranted to understand the lasting effects on motor schema.

Keywords: variable practice, parametrization, DCD, spatial / temporal control, accuracy

1. Introduction

Overhand throwing, and the coinciding motion, is incorporated in a variety of sport activities such as football, baseball, the overhead clear in badminton, and volleyball serve and it is the predominantly used action in a sport such as handball (Butterfield & Loovis, 1993). Thus, the development of throwing is essential to meaningful involvement in many activities, for both boys and girls (Gromeier, Koester, & Schack, 2017). Developmentally, by the age of 7 or 8 boys start to exhibit adult-like performance as evident from behavioral descriptors of the emerging actions (Payne & Isaacs, 2002), as well as corresponding spatial and temporal kinematic parameters of control (Yan, Pen, & Thomas, 2000). In regards to the developmental process of throwing, the type of throwing technique utilized by children showed a progression from a 'static' and 'rigid' throwing technique to a more 'dynamic' and 'sequentially-linked' technique where the trunk, shoulder and the elbow joints are actively involved in the action. These changes coincided with higher velocities of the ball and improved accuracy and distance, where relevant (Yan et al., 2000). Although developmentally throwing improves with age, in a pedagogical context, different types of learning approaches have been used to enhance these skills even among the typically developing children. Different types of instruction such as critical cues, a biomechanical approach, and traditional approaches based on modelling have been implemented with varying degrees of success (Adams, 2001; Fronske, Blakemore, & Abendroth-Smith, 1997).

Little research has been devoted to improvement of these skills in children who are atypically functioning, more specifically those diagnosed with Developmental Coordination Disorder (DCD). This is a deficit that affects approximately 10 to 15 percent of school-age children (Henderson & Sugden, 2007), and affects boys more than girls (Kasdesjo & Gillberg, 1998). The focal point of screening and diagnosis is the fact that children with DCD perform actions that are qualitatively different, are more variable, and lack effectiveness when compared to the actions exhibited by typically developing, age-matched children. These motor issues often prevent them from taking part in organized sports or even playground age-appropriate activities. Being excluded from such settings, often due to bulling, may lead to psychosocial problems such as low self-worth, self-esteem and high anxiety (Piek, Barret, Allen, Jones, & Louise, 2010). In line with predictions of self-determination theory, children with DCD may exhibit lower perceptions of competence, locus of control or sense of belonging which in turn negatively affect their intrinsic motivation to take part in physical activities, further exacerbating their movement problems (Ryan & Deci, 2017). Although, from the motor perspective, children with DCD represent a heterogeneous population in regards to the nature of the movement problems exhibited, anecdotal evidence and clinical reports confirm that many of them struggle to learn how to perform an overhand throw (Wilmut & Barnett, 2019). In a recent and the only comprehensive study thus far, Schott and Getchell (2021) showed that children with DCD between 7 and 11 years of age exhibited different movement patterns when compared to typically developing children of comparable ages, when asked to throw as "accurately and as hard" as they could at target from various distances. Also, these different coordination tendencies coincided with substantially lower success rate in terms of the outcome measures. Despite the prevalence of throwing problems in this populations, there has been no research which explicitly examines the effectiveness of theoretically sound learning approaches to address these problems.

Over the last few decades one of the most important corner stones in the field of motor learning has been the variability of practice hypothesis (VPH) (Boyce, Coker, & Bunker, 2006), an extension of Schema theory put forward by R. Schmidt (1975). The key constructs associated with this conceptual framework are the notion of generalized motor program (GMP), and the schema, which is a "rule" that conceptually scales the sensory outcomes produced during performances and the magnitude of spatial (e.g., displacement) and temporal (e.g., velocity) parameters required for the successful completion of the task (Sherwood & Lee, 2003). In the context of motor learning, variable practice enhances the development of the schema. This approach is conceptually (Schmidt & Wrisberg, 2010), pedagogically (Boyce et al., 2006), and clinically sound as "natural variability" represents an inherent component of most voluntary actions. There is a vast amount of literature supporting the effectiveness of variable type of practice across different populations and skills such as baseball hitting (e.g., Hall, Domingues, & Cavados, 1994), striking in soccer (e.g., Zetou et al., 2014), forehand in tennis strokes (Douvis, 2005), and basketball shooting (e.g., Mammert, 2006). There is also evidence that this type of approach can have a positive effect on typically developing children (e.g., Wulf & Schmidt, 1993), children with movement problems such as Down syndrome (e.g., Noghondar et al., 2021), and children with DCD (Przysucha, Klarner, & Zerpa, 2021). Also, there is much research in the adapted field, but less specifically in the context of DCD population, which showed that task specific interventions, based on instructions that are focused directly at the targeted task across ecologically valid constraints, could be an effective clinical approach (e.g., Mandich, Polatajko, Macnab, & Miller, 2001; Yuo, Barnet, & Sit, 2018). Given that from the clinical standpoint variable practice constitutes a task-specific intervention, the purpose of this study was to examine if variable practice could enhance effectiveness and accuracy of throwing exhibited by children with DCD, and capture the coinciding changes in spatial and temporal kinematic parameters.

2. Method

2.1 Participants

Recruitment involved purposive sampling through local clinical programs. Nine boys diagnosed with DCD (M = 10.7 years, SD = 1.0) were recruited. In order for a child to be included in the study he had to meet all diagnostic criteria of DCD (DSM-V; APA, 2013). The motor problems had to impact areas such as academic achievement or activities of daily living, which was inferred from the Developmental Coordination Disorder Questionnaire (DCDQ; Wilson & Crawford, 2007). The participants could not exhibit any known medical condition that may contribute to the movement difficulties, which was inferred via consent forms from the parents. Finally, the child had to have coordination abilities that were significantly lower when compared to their age-matched peers, as evident from the Total Test Score (TTS), and the percentile scores from Movement Assessment Battery for Children – Second Edition (MABC-2), for age-band 3 (Henderson et al., 2007). Children had to score below 57 (M = 50.2, SD = 4.1), in terms of total score, which placed them between 5th and 10th percentile. Also, in terms of throwing skills the child had to score 40% or below, on the throwing item from MABC-2, where he was asked to perform an overhand throw at a target from 2.2 meters with a tennis size ball.

2.2 Procedures

All procedures were approved from a local research ethics committee with guidelines that are in line with the Declaration of Helsinki. At the pre-test and post-test formal testing was implemented, including kinematic analysis. The child was asked to throw at a target 50 cm in diameter, placed on the black tarp, from the distance of 5 m. The target height was adjusted to each participant's standing eye level. Participants were not blinded from knowledge of the results and verbal encouragement was provided; phrases included ('nice', 'well done' and 'good job'). Each child was allowed 3 practice trials, and subsequently completed 10 formal trials. In order to infer the number of hits, as well as the accuracy of the throws, the balls were chalked so that after each trial the researcher was able to measure the distance between the center of the ball and the center of the target (see Figure 1). For the purpose of the kinematic analysis, reflective markers were placed on relevant bony landmarks at the hip (greater trochanter), shoulder (acromion), elbow (lateral epicondyle), and wrist (styloid process) of the throwing arm. As the propulsion phase of the action was of interest, participants were allowed to implement their own preferred throwing strategy by either throwing from the standing position or taking one step towards the target. The 3D kinematic analysis was carried out using two high-speed Basler cameras set up according to recommendations for optimal camera positioning (Allard, Stokes, & Blanchi, 1995), with a sampling frequency of 200 Hz, and filtered using a fourth-order low pass digital filter with a cut-off frequency of 12 Hz (Yan et al., 2000). Data were then subsequently analyzed using the Vicon Peak Motus 8 system.

In terms of the intervention, participants were asked to attend 10 separate, 30 minute, sessions involving variable practice. These sessions did not involve kinematic data collection, or measurement of accuracy. During the sessions, the participants were asked to throw a tennis ball, from a distance of 5 meters, at 3 different sized targets (40 cm vs, 35 cm vs 25) cm), positioned in three different locations (Figure 1). Each participant was asked to carry out the same sequence of throws, attempting 5 throws at the target straight in front of him positioned at the head level, then 5 attempts at the target to his right positioned above the head, and 5 throws at the target furthest to the right, positioned at chest high. After 15 throws, the locations of the targets were varied for variable practice clockwise. In total 45 throws were completed per session. A transfer test was carried out in a different environment in order to assure the novelty of the task. Although the size of the target remained the same at 50 cm, this time the participant was asked to throw from the distance of 6 meters, which was adjusted to the chest height of each participant (Figure 1). Again, 10 throws were attempted.

Figure 1. Experimental set up for the pre- and post-test (left), the training tasks (middle), and transfer test (right)

2.3 Measures and Data Reduction

For the kinematic analysis, the propulsive phase of the throw was analyzed where the beginning of the movement was defined as the start of forward and continuous motion of the wrist marker in the direction of the target. The end of the trial was defined as the moment when the ball was released, as inferred from the instance when the wrist marker shifted from acceleration to deceleration. Four kinematic variables were derived from the data in order to examine the potential changes due to variable training. Temporal aspect of control was inferred from the wrist velocity at the point of release, which coincides with peak ball velocity. Angular velocity of the elbow at the instance of ball release was also captured. In the spatial domain, in order to reconstruct the qualitative nature of the action, shoulder and angular displacement at the moment of ball release were derived. The kinematic profiles were derived from the reflective passive markers which were attached to the greater trochanter (hip marker), the acromion (shoulder marker), lateral epicondyle (elbow marker), and the styloid process of the ulna (hand marker), of the participant's throwing arm. For the purpose of inferring the angular displacement and velocity, shoulder displacement was defined as the angular changes between the hip, shoulder and elbow markers, whereas the displacement and velocity of the elbow were derived from the positional data defined between the shoulder, elbow and wrist markers. The peak velocity of the ball was inferred from the linear velocity of the wrist marker.

Movement effectiveness was inferred from the percentage of successful throws out of 10 attempts. In regards to accuracy, mean absolute constant error (AE) was calculate (AE = Σ (xi-T)/k, where Xi was the observed score, T was the target, and K was the number of trials considered (k = 10)). The observed score represented the distance from the center of the ball in-print to the center of the target (cm), regardless of the direction / location of the attempt (e.g., above or below).

2.4 Research Design & Analysis

A repeated measure design was implemented, followed by repeated measures analysis of variance (ANOVA), with Time as the within factor (pre- vs post vs transfer test). If significant, this analysis was followed by a series of dependent samples t-tests as pre-planned comparisons on the measure of effectiveness. As the accuracy as well as the kinematic measures were obtained only during the pre- and a post-test therefore a series of dependent samples t-testes were implemented. All the analyses were carried out at alpha = .05, using SPSS® Statistics software.

3. Results

3.1 Movement Effectiveness

In terms of the number of target hits results revealed a significant effect of time (F(9)=22.80, *p*<.001). The planned comparisons further showed a significant difference between the pre- and post-test (t(8)=7.35, *p*<.001), post- and transfer test (t(8)=3.01, *p*< .01), as well as between pre- and transfer tests (t(8)=3.45*, p*<.004). The analysis of potential changes in the accuracy of the emerging actions revealed a statistically significant difference as on average less absolute error was evident at the post session (M=57.02cm, SD=11.2) as compared to the pre-test (M=78.8cm, SD=14.7) (t(8)=10.62, *p*<.001). As evident from the individual analysis (Table 1), not all children improved their performance in terms of the number of hits, however all of them improved their accuracy with variable practice training. Also, when the transfer test data was examined, it was evident that the level of effectiveness evident at the post-test did not generalize to the transfer test.

3.2 Temporal Parameters

The analysis of release velocity, as a proxy for the temporal parameters, showed a statistically significant increase from pre- (M=11.06m/s, SD=1.93) to post test (M=14.5m/s, SD=1.48) (t(8)=4.74, *p*<.001). Also, the analysis of angular velocity of the elbow, at the time of ball release, revealed a significant change between the pre- (M=429.77deg/sec, SD=33.20) and the post test (M=531.1deg/sec, SD=28.64) (t(8)=7.58, *p*<.001).

3.3 Spatial Parameters

The analysis of spatial aspects of control revealed no statistically significant differences between angular displacement of the shoulder, at the time of ball release, between the pre- (M=80.44deg, SD=9.22) and the post-test (M=83.7deg, SD=7.32) (t(8)=1.65, *p*=.07). However, this was not the case for the angular displacement of the elbow as on average participants exhibited statistically larger elbow extension at the post test (M=112.4deg, SD=12.3) as compared to the pre-test (M=82.33deg, SD=9.57) (t(8)=7.82, *p*<.001).

Table 1. Individual and group (Mean, SD) data for number of hits (%), and absolute accuracy (AE) (cm)

Participants	Pre-Test		Post-Test		Transfer-Test
	Hits	AE	Hits	AE	Hits
1	30	74.2	70	46.3	70
2	30	78.4	70	52.7	40
3	40	59.2	80	39.2	60
4	10	91.2	30	71.6	20
5	20	76.5	70	54.3	60
6	10	102.4	40	62.3	30
7	10	98.6	30	67.6	20
8	20	92.1	60	72.1	60
9	30	56.7	70	47.2	70
Mean	22.2	88.8	60.2	57.02	50.3
SD	10.9	14.7	16.3	11.2	19.5

4. Discussion

4.1 Movement Effectiveness and Accuracy

It was hypothesized that variable practice would have a meaningful effect on movement effectiveness, which in practical and clinical terms represents the most important index of movement status and its functionality. As evident from the group data, this hypothesis was confirmed as the results showed that in fact, children achieved a higher percentage of target hits at the post test (M = 60%) as compared to the pre-test (M = 20%). Also, there was a significant difference between the pre- and transfer test, once again confirming the positive outcomes of the variable practice. However, it should also be pointed out that when the post and transfer tests were examined the significant difference showed that when participants were presented with a similar, but not the same task, the participants decreased their proficiency. Stated differently, the participants improved their performance over the acquisition period, however in regards to their ability to "transfer" their skills to a similar task, their performance declined.

Another variable which allowed inferences to be made about the nature of the emerging outcome was the absolute error. As evident from the data, similar to movement effectiveness, children with DCD improved their accuracy as a result of variable practice, when the pre- and post-test were examined. In addition, when the individual data were examined (Table 1), it is evident that accuracy was enhanced across all the participants, thus confirming the inferential analysis. In the context of the task set up, and how absolute error was operationalized, it is evident that although the changes in movement effectiveness were not pronounced for all of the participants, even when they missed the target they were closer to the desired location. The data showed that the changes in the absolute error, even for the least skilled individuals (4, 6, 7) was approximately 20 to 30 cm on average. To put it in the context of task constraints, considering that the diameter of the target was 40 cm in length, the decrease in the location of the attempts was close to the radius of the target, which from the clinical perspective has to be considered as meaningful. Thus, although some of the participants were still missing the target on the majority of the attempts the resulting outcomes can be characterized as "near misses", as compared to the initial attempts that could be characterized as "full misses", where the degree of error was substantial.

Despite the prevalence of this issue in the DCD population, a very limited amount of research has been carried out on throwing, compared to the volumes of research devoted to performance of other skills such as balance or ball catching. In a recent, and comprehensive study, Schoot and Getchell (2021) reported that when performing a comparable task, to the one implemented in the current study, children with DCD were successful on 10-30% of attempts, as compared to their typically developing peers. This degree of movement effectiveness is in line with the performance evident in the present sample, where children with DCD likely represent the bottom 10% of the "normal" population. Thus, developmentally they appear to be substantially below what is considered an average performance. To our knowledge, there is no other studies involving children with or without DCD which reported on the degree of movement effectiveness in the context of the task constraints imposed here.

In regards to the accuracy, Kawamura and colleagues (2016) reported that developmentally the degree of the radial error decreased in 9 to 10 year old children by almost half. Also, no differences were evident when this performance was compared with 12 year old children, suggesting that accuracy plateaus around this time. Interestingly, in their study, the degree of accuracy remained constant across conditions, for both groups, regardless if the tasks constraints emphasized force or accuracy. In terms of the effects of variable practice on throwing accuracy, Matsouka and colleagues (2010) showed that children with intellectual disability enhanced their accuracy from pre- to post as a result of varying the distance from which the children had to hit a target fixed 5meters away. Also, their scores on the transfer test, which was a basketball hoop, confirmed that the initial improvements in performance "transferred" to a novel task. Unfortunately, this was not the case in the present study. However, a very similar pattern of results emerged in the most recent study by Noghondar and colleagues (2021), where the researchers asked children with Downs Syndrome to throw a ball at a target 1meter in diameter, once again by manipulating the distance during the variable practice. The magnitude of absolute error decreased systematically from the pre (M11cm) to post test (M=8.3 cm), and the retention test (M= 8cm). However, the magnitude of error for the control group, who was involved in a constant type of practice, remained the same (M= 11 - 13 cm). Thus, based on the current results, and the existing, even if limited literature, it appears that children with DCD exhibited a decrease in the emerging error that is comparable to that exhibited by other atypically developing children. Collectively the present and past research showed a robust finding that manipulating different task constraints (e.g., location; distance) can have a positive impact on refining the GMP responsible for throwing actions.

4.2 Spatial Control

Given the nature of the task, the majority of motor behaviour literature either explicitly or implicitly examined the nature of spatial adaptations of the shoulder and elbow joints. Kinematically, often such actions have been analyzed at the instance of ball-release. In terms of the shoulder adaptations, the current data showed that on average the shoulder remained flexed at approximately 90degrees, at the time of ball release, through the testing. Hence, no differences due to practice were evident. From the qualitative standpoint, this type of alignment indicates that the ball was released well in front of the trunk, which is consistent with mature, 'sequentially-linked' throws (Lorson, Stodden, Landergorfer, & Goodway, 2013). This is also in line with data reported by Fleising, Escamilla and Andrews (1996) who noted that skilled adult throwers exhibited this kind of alignment, at approximately 90degrees, when throwing for power. Developmentally, mixed results emerged as some studies reported developmental changes related to the position of the shoulder at ball release (Stodden et al., 2006), while others showed that such alignment remained invariant from about 6 years of age on (Yan et al., 2000). Palmer and colleagues (2021) as well as Breidenbach (2000) showed a similar scenario reporting no developmental changes in the shoulder range of motion when children between 6 to 14 years of age were compared. Thus, it appears that the tendency to release the ball in front of the trunk, which is achieved biomechanically by extending the shoulder to 90 degrees, or beyond, at the time of ball release, represents an invariant component of the action which most of children tend to exhibit from even a relatively early age. In the context of children with DCD, this indicates that possibly the issues they face may be embedded in the control, rather than coordination domain of organization.

The analysis of the elbow showed a different scenario. The nature of spatial adaptations exhibited at the elbow were differentiated between the pre- and post-test performance. From the qualitative standpoint, the fact that children were realising the ball past 100 degrees of extension, on average, indicated that the ball was released at the end of the follow-through. This type of tendency often coincides with achieving a maximum velocity at the instance of ball release (Yan et al., 2000). These findings were consistent within the developmental literature showing that with age children tend to increase the range of motion at the elbow from 80 to 110degrees between the age of 4 and 6, respectively (Yan et al., 2000) and reaching is increased from approximately 90 degrees at 7 years old (Breidenbach, 2000) to about 115degrees 10 years old (Larsen et al., 2013). The reason behind this substantial extension change could be attributed to the task constraints, as well as it could be related to the actual biomechanics of throwing. In the former case, the fact that the ball was in the hand closer towards the end of the throwing motion may indicate the desire to maintain the directional precision, as the child has control over the ball until the end of the available range of motion. Also, the presence of this large amount of extension, at the time of ball release, could be attributed to the fact that when “sequentially-linked” throws are performed, the limb is moving fast, thus it takes longer to decelerate and stop the movement until the elbow goes through the majority of its range of motion. Thus, it is likely that in order to optimize energy transfer and achieve a high distal segment velocity, and resulting ball-release velocity, the tendency to extend the elbow is warranted. At present, there is no motor learning research which examined kinematically the nature of these adaptations in children with DCD.

4.3 Temporal Control

Velocity represents one of the essential control parameters in the context of Schema Theory, GMP, as well as variable practice. In the present study, the issue of temporal adaptations were examined via two variables. In terms of the angular velocity of the elbow, at the instance of ball release, the data showed that variable practice coincided with increased angular velocity of the joint. The amount of developmental literature devoted to angular velocity of joints during throwing is limited. Nevertheless, research studies examining the dynamics of throwing actions across sports such as baseball, football or softball confirmed that elbow joint torques, and the resulting velocities, are critical to the development of the skill (e.g., Fleising et al., 1999). In terms of the developmental studies, Yan and colleagues (2000) showed that differences between younger and older children in throwing also coincided with changes in angular velocity of the elbow. These data showed that although peak velocity of the elbow was achieved earlier during the propulsion phase of the movement, the angular velocity at the elbow in 6year-olds was twice as high as compared to younger children. Also, the velocity of the elbow was substantially larger as compared to the velocity of the shoulder, suggesting that biomechanically the control of the elbow joint may be more essential. A similar scenario was evident in the study involving children with Downs Syndrome exposed to variable practice throwing at targets at different locations. Once again, angular velocity of the elbow was one of the parameters that was modulated in order to adapt the GMP to changes in the task demands (Noghondar et al., 2021). Further research is warranted in this context.

In the context of discrete motor skill such as throwing, the potential changes in the velocity of the ball at the instance of release represents one of the most indicative control parameters associated with development and learning of this skill in children and adolescents (e.g., Halverson, Roberton, & Langendorfer, 1982). The changes in parametrization of the ball speed evident here are in line with the developmental trajectory reported by Roberton and colleagues (1979), and Roberton and Konchak (2001). All these studies showed that between 6 and 13 years of age there is a linear increment in the ball velocity suggesting that this temporal variable represents a strong predictor of changes in the overall skill level of the participant. The same pattern was evident in a study comparing throwing actions of adolescence and adults (Larson et al., 2013), showing that achievement of more advanced skill level coincides with changes in ball velocity. Indirectly, the changes in ball speed are indicative of age and/or skill related adaptations to force production implemented in the overarm throw (Roberton & Konczak, 2001). This appears to be the case regardless if the goal of the throw is accuracy, or if the performer is instructed to throw as "hard" as he/she can. For example, in a study by Kawamura and colleagues (2016) the data showed that although developmentally there were substantial changes in ball speed when 7-8 and 9-10 year olds were compared, these changes were consistent regardless if the task demanded accuracy or power. This observation suggests that parametrization of ball speed (e.g. velocity of the wrist) is essential and required regardless of the different task constraints. In the present study, the explicit goal of the task was to be accurate, yet the changes in ball speed were evident despite the fact that the distance was not manipulated in order to evoke more force.

5. Conclusion and Clinical Implications

Development of the GMP is essential to the ability to perform discrete actions pertaining to the same family of movement, across many different task demands. From the motor learning perspective, variable practice essentially makes the GMP more generalizable (Czyż, Zvonař, & Pretorius, 2019). From the practical/clinical standpoint, and in line with a well-known specificity of practice hypothesis it is recommended that skills that are variable in nature are practiced in conditions that are also variable. In the adapted field, this approach is also known as task-specific instruction, which is focused directly at the targeted task under ecologically valid tasks demands (Mandich et al., 2001).

The outcome data, more specifically the individual profiles, revealed a "person x treatment" interaction effect, which is a common occurrence when atypically functioning individuals are engaged in training, as evident for example from research examining the impact of variable practice on ball catching (Przysucha et al., 2021). Thus, the variable practice implemented was effective for many, but not all children, in regards to movement effectiveness. Also, the fact that at the transfer test, the performance deteriorated suggests that "generalizability" of the respective motor program is still less than optimal. It is important to note, however, that all of participants improved their overall accuracy, indicating that even if a child did not record more hits, the errors associated with his performance where more in the desired locations. These positive changes were accompanied by spatial adaptations to the elbow and temporal parametrization via changes to angular velocity of the elbow, and overall increase in ball velocity at the instance of release. However, despite these positive changes, even the children who did improve were still not performing at the developmental level consistent with their typically developing peers, as evident from the developmental data (Schott & Getchell, 2021). Thus further enhancement of the underlying schema is required (Noghondar et al., 2021). One potential way of enhancing the effectiveness of the parametrization may be simply by prolonging the duration of the program. Also, since the degree of contextual interference implemented represents an important moderator in the learning process (Boyce et al., 2006), possible manipulations of other task-specific constraints, such as distance, may also lead to better outcomes. This manipulation would constraint the participant to adapt the absolute force of the throw, which is another important parameter of the GMP. Also, the role of augmented feedback, provided after the completion of the task, cannot be underestimated in this process. This kind of feedback usually involves information about the outcome or the quality of the movement, with the latter likely being more relevant in clinical settings (Wulf, Shea, & Lewthwaite, 2010). Augmented feedback may help to develop a reference of correctness that allows for better detection of errors. This approach may enhance the performer's abilities to plan and execute the movement, and generalize it to a novel context, which is the ultimate goal of variable practice.

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