Thesis Title: The effect of variable type of practice on one handed catching in children with developmental disorders

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Abstract

Children with developmental disorders, such as DCD, struggle with interceptive tasks like ball catching. These problems may be due to less than optimal abilities to coordinate and control actions at intra- and inter-limb levels of organization. Although the kinematic characteristics exhibited by these children while catching are well documented, little has been done to enhance their skills to accomplish this seemingly simple task. One possible avenue to explore is the utilization of variable type of practice (Schmidt, 1975), which has been widely implemented as an intervention approach across many populations and skills (Van Rossum, 1990). From the conceptual standpoint, performance of a particular skill under varying task demands leads to improvements in parameterization of spatial and temporal aspects of organization, thus affording more flexible and adaptable movement patterns. It is plausible that this type of practice may positively affect the movement organization of children with developmental difficulties, however this issue has not been investigated thus far. Therefore, the purpose of this study was to examine the effects of variable type of practice on coordination and control of one-handed catching in children with symptoms of DCD and their typically functioning peers.

Three boys and one girl (mean age = 10.5 years, SD = 1.29 years) with symptoms of DCD, and four typically functioning boys (mean age = 9 years, SD = 0 years) were recruited. Both groups participated in 12 variable practice sessions over a 6-week period. Three-dimensional kinematic analysis occurred at pre-, mid-, and post-intervention. Following a one-week delay, retention and transfer tests were administered to assess permanency and generalizability of the acquired patterns, respectively. The nature (mean and variability) of intra-limb coordination was inferred from intra-class correlations, which captured the degree of association between angular displacement of shoulder-elbow and elbow-wrist joint pairs. The qualitative nature of the emerging

movement pattern was examined using angle-angle plots. The nature of spatial control was inferred from the angular displacement (degrees) of the hip, shoulder, elbow, and wrist, while temporal aspects of control were inferred from peak wrist velocity (m/s) and relative time to peak wrist velocity (proportion of total movement time).

Movement Effectiveness. As inferred from the percentage of balls caught, the typical group (M = 75%, SD = 37.86%) caught significantly more balls than the atypical group (M= 0%) at pre-intervention. There were no significant differences between the groups at mid-, post-intervention, retention, or transfer. Also, the atypical children exhibited no significant changes across pre- (M = 0%), mid- (M = 40%, SD = 16.33%), post-intervention (M = 40%, SD = 43.20%), retention (M = 30%, SD = 47.61), and transfer (M = 45%, SD = 44.35%). However, individual analysis indicated that one of the children from the atypical group made considerable improvements from 0% at pre-intervention to 100% at retention and at transfer. The typical group demonstrated no significant changes across pre- (M = 75%, SD = 37.86%), mid- (M = 75%, SD = 25.17%), post-intervention (M = 70%, SD = 20%), retention (M = 80%, SD = 16.33%), and transfer (M = 95%, SD = 10%). However, individual analysis of the typical children demonstrated that participant 5 improved from 20% at pre-intervention to 80% at retention and 100% at transfer. Thus, as evident, the individual data supported the inferential analyses.

Coordination. In terms of between-group differences, mean ICC values revealed significantly less coupling at the shoulder-elbow for the atypical group at mid-, and post-intervention, as well as retention/transfer. However, the angle-angle plots failed to support those differences, as both groups exhibited a qualitatively similar movement pattern, with a tendency to flex the elbow, followed by flexion of the shoulder to catch the ball. When elbow-wrist relations were examined, significant differences in mean ICC values emerged only at retention, where the atypical group showed weaker coupling. However, the corresponding angle-angle plots suggested that differences were present at all testing sessions. The atypical children tended to flex and extend the wrist throughout the movement, whereas the typical children gradually extended the wrist until contact with the ball. In terms of intra-individual stability, significant differences at the shoulder-elbow were evident at mid-intervention and transfer, where the typical group was more stable across trials. No significant differences were found between groups in terms of stability of elbow-wrist relations.

In terms of within-group differences, the atypical group did not demonstrate any significant changes in mean ICC values at either of the joint pairs. The same was true for the typically functioning group. Thus, as the intervention progressed, the children did not alter their overall movement patterns at the intra-limb level of coordination. This was also confirmed via qualitative analysis of the angle-angle plots. The analysis of intra-individual stability across testing sessions revealed that the atypical group exhibited no significant changes at either joint pair. However, this was only partially confirmed by individual (angle-angle) profiles which showed that participants 2 and 4 became more stable in their coordination of both joint pairs. Lastly, the typical group exhibited no change in intra-individual variability across testing sessions. However, once again the qualitative analysis of the corresponding angle-angle plots showed that this was not true for all children, as participants 5 and 7 were more stable while coordinating the shoulder-elbow joint pair following the intervention.

Spatial Control. There were no significant between-group differences for mean angular displacement of the hip, shoulder, or elbow. However, displacement of the wrist was significantly different between groups at retention, where the atypical group ($M = 48.58°$, $SD = 21.12°$) exhibited a larger range of motion compared to the typical group ($M = 19.56°$, $SD = 6.47°$). Also, between group differences in intra-individual variability were evident only at mid-intervention, where the atypical group demonstrated less stability at the elbow (M = 8.29°, SD = 3.57°), when compared to the typical group (M = 5.69°, SD = 1.39°). From a practical standpoint, although statistically significant, such difference should not be considered as clinically meaningful.

In terms of within-group differences, the atypical group exhibited no changes in mean angular displacement of the hip, shoulder, or wrist. However, significant difference was found at the elbow between pre-intervention (M = 42.01°, SD = 14.79°) and the transfer test (M = 61.49°, SD = 20.96°). The typically functioning group did not exhibit any significant changes in mean angular displacement at any of the measured joints. As for differences in intra-individual variability across sessions, the atypically functioning group exhibited no significant changes at the hip, shoulder, or elbow joints. The atypical group did show significantly less variability in angular displacement of the wrist between the post-intervention session (M = 6.49°, SD = 4.26°) and the transfer test (M = 4.24°, SD = 1.86°). However, once again such differences are not substantial and should not be considered as meaningful. No changes in intra-individual variability were found for the typically functioning group across the sessions.

Temporal Control. There were no between-group differences found for mean peak wrist velocity or relative time to peak wrist velocity. When intra-individual variability of peak wrist velocity was examined, significant difference was found at post-intervention, where the atypical group was less stable across trials (M = 0.29 m/s, SD = 0.25 m/s) as compared to the typical group (M = 0.09 m/s, SD = 0.03 m/s). Additionally, there were no differences between groups in intra-individual variability of relative time to peak wrist velocity.

In terms of within-group differences, no significant changes occurred for peak wrist velocity from pre-intervention to retention. Both, the atypical and typical groups did however demonstrate a decrease in peak wrist velocity from retention to transfer. Additionally, no changes were found across testing sessions for intra-individual variability of peak wrist velocity within either group. No change in relative time to peak wrist velocity was evident from pre-intervention to retention, and from retention to transfer for either group. In terms of intra-individual variability of relative time to peak wrist velocity, no changes were found within the atypical group. As for the typical group, the results indicated a significant change in intra-individual variability of relative time to peak wrist velocity from pre- (M = 0.06, SD = 0.02) to mid-intervention (M = 0.03, SD = 0.01).

Discussion and Conclusion. The purpose of the study was to examine the effect of variable type of practice on coordination and control of the one-handed catch in children suspected of having DCD. It was expected that improvements in movement effectiveness would coincide with no substantial changes to coordination, but adaptations in movement control, in both spatial and temporal domains.

Functionally, the results suggested that the task was too difficult for the atypical group as a whole to demonstrate meaningful improvements, and therefore changes in catching ability could not be captured by the performance variable. On the other hand, the task was likely too simple for the typical children, as they were perfect or near perfect at the beginning of the study. Thus, the sampling method originally implemented may have affected the nature of the emerging inferences. In terms of coordination, as expected, no changes occurred for either group in the degree of coupling and its stability, although in the latter case the angle-angle plots suggested that at least some participants in the atypical group exhibited lower variability as a result of the intervention. This is likely indicative of these individuals still acquiring the general movement pattern, thus being in the early stages of the motor learning continuum (Newell, 1985). When differences in spatial and temporal control variables were examined from pre-intervention to retention, neither group made improvements in this aspect of motor organization. At transfer, the ICC values and angle-angle plots demonstrated that both groups generalized the movement patterns to the constraints of the novel task. This indicated that the same GMP was used and that the schema was parameterizing the spatial-temporal aspects to accomplish the new task. Both groups exhibited meaningful adaptations in temporal control to the novel velocity and trajectory, but contrary to what was expected, not in the spatial domain (Mazyn et al., 2006). These changes emerged at the statistical level, however functionally, these adaptations did not coincide with improvements in the number of balls caught, particularly for the atypical children. This fact may indicate that although some learning has taken place within the atypical group, due to the nature of the task, even more refined adaptations needed to occur to place the hand in the right place at the right time to intercept the ball.

The study also examined the differences in movement coordination and control between the groups. Qualitative examination of the movement patterns confirmed that children with DCD exhibited different coordinative tendencies, particularly at the distal joints, as compared to their typically functioning peers when performing one-handed catching actions (Asmussen, Przysucha, & Dounskaia, 2014; Mazyn, Montagne, & Savelsbergh, 2006; Przysucha, 2011). The results however failed to support the differences in spatial and temporal control found in previous research (Przysucha & Maraj, 2014; Sekaran et al., 2012). Given that the differences emerged in coordination and movement effectiveness, this result warrants caution from the conceptual standpoint (Newell, 1985). It is plausible that the differences in movement control may not have emerged due to the fact that the variables chosen were non-essential to capture the emerging internal motor processes. Ball catching actions are composed of two types of sub-movements. Those that afford the hand(s) to get in the correct and timely position in space, and those that require fine-tuning of the hands/fingers to secure the ball once contacted. Since the differences emerged at the level of coordination, but not control, it is plausible that the substantial differences between the groups in terms of balls caught may be attributed to the spatial and temporal differences during the fine-tuning of the distal joints of the hand. However, since the size or time of hand aperture or closure was not measured here, this remains a speculation, even if one that was supported by previous literature (Deconinck, De Clercq, Savelsbergh, Van Coster, Oostra, Dewitte, & Lenoir, 2006).

Overall, 6-weeks of variable type of practice did not result in meaningful improvements in movement effectiveness for 3 of the 4 atypical children, or in the expected adaptations in the spatial and temporal domains. Thus, these findings suggested that this type of learning experience might not be effective within this population. It is possible that manipulating the degree of contextaul interference (e.g., less variability) may result in more positive effects. In regards to the typically functioing group, the possible effects on their coordination and control were difficult to delineate due to them exhibiting optimal coordination and control at baseline.

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Table of Contents

List of Figures 14

List of Tables 15

Key Definitions 17

Review of the Literature 19

Schmidt's Schema Theory 19

Newell's Model of Motor Learning 21

Variability of Practice Hypothesis 22

Variability of Practice Hypothesis: Research Designs and Studies Across Different Skills 23

The Effect of Contextual Interference on Retention and Transfer 25

Variability of Practice in Children 27

Developmental Coordination Disorder 28

Intra-Limb Coordination and Control in Goal Directed Arm Actions 30

One-Handed Catching 31

Two- and One-Handed Catching in Children with DCD 33

Coordination 34

Spatial Control 37

Temporal Control 39

Implementing Motor Skill Intervention Techniques in Children with DCD 40

Research Problem 42

Purpose 43

Hypotheses 43

Method 44

Participants and Recruitment Process 44

Inclusion/Exclusion Criteria 44

Procedure 46

Pre-Intervention 46

Intervention 48

Post-Test/Retention/Transfer 48

Experimental Design/ Dependent Variables 49

Analyses 50

Hypothesis a) 51

Hypothesis b) 51

Hypothesis c) 51

Hypothesis d) 51

Results 51

Movement Effectiveness 51

Intra-Limb Coordination 52

Shoulder-Elbow 52

Elbow-Wrist 58

Spatial Control 62

Hip Displacement 62

Shoulder Displacement 63

Elbow Displacement 65

Wrist Displacement 66

Temporal Control 68

Peak Wrist Velocity 68

Relative Time to Peak Wrist Velocity 70

Discussion 71

Movement Effectiveness 71

Intra-Limb Coordination 76

Shoulder-Elbow Relations 76

Elbow-Wrist Relations 79

Summary of Intra-Limb Coordination 81

Spatial Control 81

Between Group Differences 81

Within Group Differences 82

Summary of Spatial Control 84

Temporal Control 85

Between Group Differences 85

Within Group Differences 87

Summary of Temporal Control 92

Conclusion 93

Limitations and Future Research 96

References 97

Appendix A: Formal Recruitment Letter 107

Appendix B: Consent Form 109

Appendix C: Assent Form 111

Appendix D: Developmental Coordination Disorder Questionnaire (DCDQ) 113

List of Figures

Figure 1: Elbow-shoulder angle-angle plots for a typical child and a child with DCD. 35

Figure 2: Shoulder-elbow angle-angle plots for the atypical group across 5 trials for each testing session. 56

Figure 3: Shoulder-elbow angle-angle plots for the typical group across 5 trials for each testing session. 57

Figure 4: Elbow-wrist angle-angle plots for the atypical group across 5 trials for each testing session. 60

Figure 5: Elbow-wrist angle-angle plots for the typical group across 5 trials for each testing session. 62

Figure 6: Movement effectiveness (% of balls caught) of atypically functioning children, across testing sessions. 73

Figure 7: Movement effectiveness (% of balls caught) of typically functioning children, across testing sessions. 75

Figure 8: Velocity profile (m/s) of the wrist for one participant under changing temporal constraints. 89

Figure 9: Velocity profiles (m/s) of the wrist of the same atypical child (participant 2) for one attempt at retention and transfer. 90

Figure 10: Velocity profiles (m/s) of the wrist of the same atypical child (participant 3) for one attempt at retention and transfer. 91

Figure 11: Velocity profiles (m/s) of the wrist of the same typical child (participant 6) for one attempt at retention and transfer. 92

List of Tables

Table 1: Mean and Standard Deviation of ICC Values for Angular Displacement of the Shoulder and Elbow for Both Groups Across Testing Sessions 53

Table 2: Mean and Standard Deviation for Intra-Individual Variability of ICC Values for Angular Displacement of the Shoulder and Elbow for Both Groups Across Testing Sessions 54

Table 3: Mean and Standard Deviation of ICC Values for Angular Displacement of the Elbow and Wrist for Both Groups Across Testing Sessions 58

Table 4: Mean and Standard Deviation for Intra-Individual Variability of ICC Values for Angular Displacement of the Elbow and Wrist for Both Groups Across Testing Sessions 59

Table 5: Angular Displacement (degrees) of the Hip for Both Groups Across Testing Sessions 62

Table 6: Intra-Individual Variability of Angular Displacement (degrees) of the Hip for Both Groups Across Testing Sessions 63

Table 7: Angular Displacement (degrees) of the Shoulder for Both Groups Across Testing Sessions 64

Table 8: Intra-Individual Variability of Angular Displacement (degrees) of the Shoulder for Both Groups Across Testing Sessions 64

Table 9: Angular Displacement (degrees) of the Elbow for both groups Across Testing Sessions 65

Table 10: Intra-Individual Variability of Angular Displacement (degrees) of the Elbow for Both Groups Across Testing Sessions 66

Table 11: Angular Displacement (degrees) of the Wrist for Both Groups Across Testing Sessions 67

Table 12: Intra-Individual Variability of Angular Displacement (degrees) of the Wrist for Both Groups Across Testing Sessions 68

Table 13: Peak Wrist Velocity (m/s) for Both Groups Across Testing Sessions 69

Table 14: Intra-Individual Variability of Peak Wrist Velocity (m/s) for Both Groups Across Testing Sessions 69

Table 15: Relative Time to Peak Wrist Velocity (proportion of movement time) for Both Groups Across Testing Sessions 70

Table 16: Intra-Individual Variability of Relative Time to Peak Wrist Velocity (proportion of movement time) for Both Groups Across Testing Sessions 71

Key Definitions

Closed-Loop Control: Control system that relies on afferent feedback to compare the emerging movement to a pre-established memory state. The control system involves error detection and correction mechanisms. This type of control applies to slow movements requiring adjustments to the environment (Adams, 1971).

Coordination: The degree and stability of spatial and temporal relationships between components of the motor system (Newell, 1986).

Generalizability: The flexibility and adaptability of the motor system to different contexts. This results from a well-developed schema that can parameterize the generalized motor program under changing task demands (Schmidt, 1975).

Generalized Motor Program: An internal structure that contains the essential details of an entire class of movements (Schmidt, 1975).

Intra-Individual Stability: Degree of consistency between trials for one person (Sparrow, 1992).

Invariant Features: Components of a movement that do not change across variations of the skill. Even when surface parameters are changed from one movement to the next, these features remain constant (e.g. relative timing) (Schmidt, 1975).

Motor Learning: Permanent changes in interval structures leading to improvements in performance of a motor skill as a result of practice. It also coincides with improved ability to adapt a motor program to novel variations of the skill and an improved ability to execute a motor task consistently (Schmidt & Wrisberg, 2004).

Movement Control: Ability to adapt to changing task demands while preserving functionality and spatio-temporal structure of the action (Przysucha, 2011).

Open-Loop Control: Control system that does not incorporate a feedback mechanism. The movement is initiated and runs its course without the use of feedback to make corrections. Applies to fast ballistic movements (McMorris, 2004).

Parameterization: The process by which the schema specifies the surface parameters based on current task demands. This process allows for consistent production of a movement under constant task constraints, as well as the production of different variations of a skill without changing the movement pattern when task demands do change (Schmidt & Wrisberg, 2004).

Retention Test: Type of test that is used to assess the permanency in skill performance (Schmidt & Wrisberg, 2004).

Surface Parameters: The components of movement that are modified by the schema. These components are easily changed to adapt a general pattern of movement to a specific goal with specific demands. Modifying these parameters of the movement does not change the overall qualitative nature of the movement (Schmidt, 1975).

Transfer Test: Type of test that is used to assess the ability to generalize the practiced skill to new contexts. It allows for inferences to be made regarding the degree of flexibility of the motor system (Schmidt & Wrisberg, 2004).

Variability of Practice Hypothesis: VPH posits that practicing a skill under changing task constraints will lead to better generalizability due to improved parameterization of the motor Schema (Schmidt, 1975).

Review of the Literature

Schmidt's Schema Theory

Prior to executing a movement, sensory information is gathered by the central nervous system (CNS) and used to select the proper movement commands that will best accomplish a given task. The concept of central representation of movement, which is stored in long-term memory, is derived from the centralist view of motor control. This representation has been coined as a motor program, and defined as "a set of muscle commands that allow movement to be performed without any peripheral feedback" (McMorris, 2004, p. 144; Lashley, 1917; Russell, 1976).

From the conceptual standpoint, the classical definition of a motor program presented a number of shortcomings. The motor program theory, as articulated in earlier works by Henry and Rogers (1960) as well as Keele (1968), could not explain how people make even subtle alterations to the on-going performance of an action in response to changing context (McMorris, 2004; Schmidt, 1976). It also raised the issue of storage within the CNS (MacNeilage, 1970). If a motor program is needed for every possible movement, it is not plausible that the CNS could effectively store and access them when needed. Finally, the motor program theory could not adequately explain how novel movements or skills were produced when no prior representation existed for the particular movement (McMorris, 2004; Schmidt, 1976).

The more contemporary concept of the generalized motor program (GMP), as presented by Schmidt (1975), directly addressed these issues. The notion of GMP implies that movement is organized and programmed generally, meaning one GMP can be executed to produce a number of same/similar movement patterns. The GMP achieves its flexibility through the manipulation of surface parameters, which are easily varied components that when altered do not change the qualitative nature of the emerging action (Schmidt, 1975). The surface parameters can be adapted under different task demands, and as long as the spatial and temporal relations do not change drastically, the same GMP can be used to achieve the task goal. When they do change substantially, resulting in a qualitatively different movement pattern, it is assumed that a new GMP was implemented (Schmidt, 1975). This process of adapting the spatial and temporal parameters of an existing motor program to a novel task or to changing task demands is known as parameterization (Schmidt & Wrisberg, 2004). Thus, a skilled performer can efficiently parameterize the GMP to complete a number of related actions without changing the overall movement pattern.

According to Schmidt's schema theory (1975), the schema is what allows for the process of parameterization to occur. The schema resides within the GMP for a particular skill and functions as a means of "storage", "management", and "representation of previous movement experience" (Van Rossum, 1990). There are four important components of a movement that are stored together in the schema; the initial conditions, response specifications, the sensory consequences of the response, and the response outcome of that movement (Schmidt, 1975). The schema uses all of this stored information together to specify the surface parameters of the GMP. The *initial conditions* refer to information available prior to the response phase of the movement, such as proprioceptive, visual, and auditory cues. *Response specifications* refer to the values of the surface parameters used to accomplish the task (i.e. wrist velocity). The *sensory consequences of the response* refer to information collected throughout the movement regarding body positioning and the environment. Finally, the *response outcome* refers to the actual result of the movement in relation to the intended goal (i.e. whether the ball was successfully caught) (Schmidt, 1975).

In the context of catching, which is of primary focus here, the schema would first collect the information about the velocity and trajectory of the incoming ball. Next, the schema would make the necessary adaptations to the surface parameters and execute the GMP to intercept the ball. As the movement proceeds based on the specifications provided by the schema, sensory information about the emerging action is to be fed back to the expected feedback states (Schmidt, 1975). If there is a discrepancy between the expected and the actual feedback, the error would be sent to the schema so that the necessary adjustments can be made to correct it in the future (Schmidt, 1975). Finally, the ball would be successfully intercepted or missed. In either event, the schema would establish a relationship between the initial conditions, response specifications, sensory consequences, and the actual outcome, which will be used to improve parameterization. For example, well-developed schema would reliably execute the GMP under stable task demands (i.e. same wrist velocity for unchanging ball velocity), and adapt the action by adjusting temporal (i.e. velocity of the hand) and spatial (i.e. hand path) variables when the speed of the approaching ball or its trajectory are changing. This is often referred to as the ability to "control" the emerging actions. The ability to efficiently parameterize the related spatial and temporal variables develops over time, and it can be enhanced through practice.

Newell's Model of Motor Learning

The process of motor learning is associated with permanent improvements in performance due to changes to various internal structures resulting from practice. According to Newell (1985), the process of motor learning begins with the acquisition of the basic coordinative movement pattern, where the performer learns to couple joints, limbs or body segments to generate effective, efficient, and consistent movement patterns. This initial stage of learning is characterized by considerable instability across attempts and a low level of movement effectiveness. Once stable coordination patterns are acquired, the performer moves to the second stage where he/she learns how to best *control* the new movement pattern (Newell, 1985; Schmidt & Wrisberg, 2004). At this stage, an individual is expected to learn how to adapt the already learned patterns to different environmental demands, either by changing the action or by maintaining the qualitative nature of the movement and adjusting the spatial and/or temporal parameters (i.e. parameterization). Efficient parameterization of "surface variables" allows for a nearly infinite number of variations of a skill to be produced (Schmidt & Wrisberg, 2004). As the performer is able to learn how to coordinate and subsequently control the emerging actions, across different levels of organization (e.g., intra-limb; inter-limb), he/she also tends to master parameterization of spatial variables before acquiring the ability to control the temporal aspects of the action (Marteniuk & Romanow, 1983).

Variability of Practice Hypothesis

Schema development is greatly influenced by the type of practice an individual is exposed to while learning a skill. Schmidt's schema theory hypothesizes that implementing a significant degree of variability into practice sessions promotes improvements in parameterization and therefore transfer to similar variations of a task (Schmidt, 1975). This prediction is known as the variability of practice hypothesis (VPH).

Variable practice may be accomplished by presenting a learner with a variety of task constraints that force him/her to adapt the GMP, such as different ball speeds and trajectories in the case of one-catching. A number of different constraints can be manipulated as long as they do not force the performer to switch to a different movement pattern, hence a new GMP. By incorporating variable practice, the schema is required to specify a variety of surface parameters, thereby updating the schema rules and making the GMP more generalizable to similar task demands (Boyce & Coker, 2006; Schmidt, 1975). This is beneficial to future performance of the skill, as it does not require the person to retrieve new a GMP, which is time consuming and requires a fair amount of cognitive processing (e.g., attention).

The implementation of this type of practice is ecologically valid and is in line with the specificity of learning hypothesis, which states that the best way to learn a skill is to practice the movement under conditions that replicate the real world task (Henry, 1968). Hence, it can be conceptually assumed that the performance of real-world skills that require an ongoing adaptation to the environment and task demands would benefit from variable type of practice. Ball catching represents one of such tasks.

Variability of Practice Hypothesis: Research Designs and Studies Across Different Skills

From the research design standpoint, the effect of variable practice on learning is inferred primarily through the use of retention and transfer tests. The retention test is administered following a delay, and mimics the characteristics of the post-intervention testing session so that permanency of learning can be assessed. The delay will allow for the temporary changes in performance to dissipate, and for the permanent changes to be evaluated (Schmidt & Wrisberg, 2004). Transfer tests incorporate novel variations of the practiced skill, which can include either extrapolation tasks, where the learner must perform a variation outside the practiced range (e.g., faster or slower ball speed for catching), or a task requiring the general application of the skill (e.g., larger or smaller balls in catching) (Van Rossum, 1990). The use of a transfer test is important when inferring improvements in parameterization.

It has been postulated that the variability of practice hypothesis is most suitable when applied to discrete, open motor skills that are of short duration (ballistic) (Schmidt, 1975). The feature that distinguishes an open skill from a closed skill is the environment in which it is performed. Closed skills are generally self-paced and are performed in a predictable environment where the relevant factors of the movement are maintained constant, thus decreasing the potential variability in the corresponding actions (e.g., throwing darts at a stationary target) (Brady, 1995).

On the other hand, open skills are those which occur in less predictable environments. Their performance is often affected by numerous external factors (e.g., speed or trajectories in ball catching) and require flexibility of the motor system as the task may be slightly or substantially different from one attempt to the next (Brady, 1995). From a motor learning perspective, the acquisition of open skills is much more difficult especially for younger or less skilled individuals.

A study, involving two experiments, by Barto (1996) demonstrated the effectiveness of variable type of practice on an open skill compared to a closed skill. In experiment 1, participants were instructed to hit a moving dart board (open skill). In experiment 2, a closed variation was used which involved hitting a stationary dart board. In both experiments, the participants were divided into two groups. One group underwent variable type of practice, while the other group was subject to constant practice conditions. The findings of the first experiment (open skill) demonstrated that the variable practice group was able to throw the dart with greater accuracy and consistency on retention and transfer than the blocked practice group. Conversely, the findings of the second experiment (closed skill) demonstrated that constant practice was more beneficial to performance than variable practice. Thus, variable practice was more beneficial than constant practice in learning an open variation of a skill, but not in the context of a closed variation. Conceptually these findings are in line with Schmidt's schema theory (Schmidt, 1975). Performance of a skill that requires adaptations to changing environments would benefit from improved parameterization of the GMP, whereas improved generalizability would be of little relevance when a skill does not require adaptions.

The variability of practice hypothesis has also been tested in the context of various open, interceptive (ballistic) ball skills. Hall, Domingues, and Cavados (1994) explored the effects of variable type of practice on batting ability of college level baseball players. The players were divided into three groups. The first group underwent variable practice, the second was subject to blocked practice, and the third group served as a control which received no batting practice sessions. Following the 12 acquisition sessions, administered twice a week over a 6-week period, all three groups completed retention and transfer tests. The findings demonstrated that the variable practice group had superior performance in terms of number of “solid contacts” on both retention and transfer tests when compared to the blocked practice and control groups. In yet another study examining open ballistic skills, Mammert (2006) investigated the effects variable and constant practice on free-throw shooting in basketball. A constant practice group took 160 shots from the free-throw line, while a variable practice group took 160 shots from various locations around the free-throw line. Pre- and post-tests were administered to examine shooting accuracy, as well as a retention/transfer test administered one year later. The transfer task involved shooting from various distances and with varying ball sizes. The results showed improvements from pre- to post-test in both groups, however the variable group showed significantly better accuracy with the novel ball sizes and locations. The results from this study confirmed that variable practice is beneficial in producing long-term learning effects when compared to constant practice, in particular when open skills are considered. Collectively, the results from these investigations support the usefulness of variable type of practice while learning skills that have an inherent degree of variability in the actions used to accomplish them, as well as in the context in which they are unfolding.

The Effect of Contextual Interference on Retention and Transfer

The degree of variability in the learning setting is referred to as contextual interference (CI). Contextual interference can be achieved in a variety of ways, primarily by manipulating the spatial (i.e. trajectory of ball while catching) and temporal constraints (i.e. ball velocity while catching) of the task being learned (Shea & Morgan, 1979). Increasing the number of variations and manipulating the order of presentation of the various task demands are both ways of increasing contextual interference within a practice session and improving learning (Hall & Magill, 1995). The literature suggests that practice under a variable sequence of constraints (high contextual interference) jeopardizes initial performance of the skill, but eventually results in significantly better retention and transfer when compared to practice under a blocked sequence (low contextual interference) (Shea & Morgan, 1979; Sherwood & Lee, 2003).

The degree of variability within a practice session can differ from random variable to blocked variable. However, the degree to which either approach can be effective does depend on the proficiency level of the participants (Van Rossum, 1990). In the context of adult subjects, current research suggests that maximizing variability (random presentation; high CI) is most effective at improving retention and transfer of the learned skill (Van Rossum, 1990). On the other hand, when novice learners are involved, maximizing contextual interference does not appear to be as effective. A study conducted by Pigott and Shapiro (1984) compared the effect of different variable practice structures on learning in novice children. Three groups completed 24 practice sessions of a beanbag-throwing task with four differently weighted bags. The groups were exposed to the same total number of practice trials with each weight. One group received randomized presentation of the weighted beanbags (high CI), another group practiced the weights in blocks of three trials (medium CI), and a third group practiced the weights in blocks of 6 trials (low CI). The results showed that the group that was presented the differently weighted beanbags in blocks of three trials (medium CI) demonstrated superior performance on the retention and transfer tests. Therefore, it can be inferred that the medium CI group made superior improvements in generalizability of their GMP. This result suggests that when working with individuals who are novice or possess lower skill level, implementing a moderate level of contextual interference may be most beneficial to their learning. Thus conceptually, VPH is more applicable to children, or in general, performers who have the "grasp" of the general movement pattern but may not be able to transfer it from one context to the next, even if seemingly similar (Boyce & Coker, 2006).

Variability of Practice in Children

The current literature has shown that variable type of practice is most beneficial when introduced after the individual has developed a rudimentary motor program (Boyce, Coker, & Bunker, 2006). This is in line with Newell's (1985) description of the first stage of motor learning, where the individual learns to coordinate the movement but has yet to refine his/her ability to control it (Schmidt, 1975). An adult or skilled performer who is further along the learning continuum, and who already possesses a well-developed schema, would not show significant improvements with practice, especially in fundamental skills such as throwing or catching (Schmidt, 1975). In fact, evidence supporting the use of variable practice with children (ages ranging from 3 to 12) is promising (Van Rossum, 1990; Yan, Thomas, & Thomas, 1998).

Studies involving children have shown that the use of variable practice resulted in improved performance on retention as well as transfer tests, thus making the acquired skills more permanent (superior retention) and more generalizable (superior transfer) (Carson & Wiegrand, 1979; Eidson & Stadulis, 1991; Moxley, 1979). Support for superior retention in children was offered by Carson and Wiegrand (1979) who employed bean-bag throwing task with a stationary target. The children were divided into a variable practice group, a constant practice group, and a control group. Variability was introduced to the throwing task by manipulating the weight of the bean bags. At post-test, both experimental groups demonstrated superior performance (successful target hits) than their baseline measures and the control group. However, following a 2-week delay, only the variable practice group maintained the elevated level of performance. Thus, variable type of practice was more effective at eliciting long-term improvements in the children's performance than the other conditions. Support for superior transfer across tasks can be found in a study conducted by Moxley (1979). The experiment involved throwing a shuttlecock at a target from four different locations. The participants were divided into variable practice, blocked practice, and control groups. At transfer, children practicing under a variable sequence of throwing locations demonstrated superior performance (i.e. successful targets hit) from novel locations than the blocked practice and control groups. Thus, the children who experienced variable type of practice were better able to generalize what they had learned to new variations of the skill. The findings of these studies suggest that variable practice is an effective strategy that results in superior learning in children (Van Rossum, 1990).

As evident, the variability of practice hypothesis has empirical merit, however, the studies discussed so far involved a typically functioning population performing a self-paced task. Research into the usefulness of this learning approach with children who are atypically functioning is limited, particularly while performing tasks under external time demands. This is likely due to the fact that generally the coaches, instructors, or clinicians assume these children learn best when the environment is stable in nature and the tasks are relatively closed. Intuitively, this may be true, unfortunately, from an ecological validity stand point, this is not the context in which these children are expected to engage in physical activities while playing "catch" with their peers.

Developmental Coordination Disorder

Over the last few decades there has been an increased awareness of children experiencing difficulties performing even seemingly simple motor skills, while not exhibiting any known physical or intellectual disabilities (Henderson & Henderson, 2003). One of such disorders that has been given attention is Developmental Coordination Disorder (DCD). This is a chronic and permanent disorder that affects approximately 5% to 6% of elementary school aged children, and is characterized by the failure to acquire both fine and gross motor skills (Kirby & Sugden, 2007; Zwicker, Harris, & Klassen, 2012).

The American Psychiatric Association (APA) and the World Health Organization (WHO) have provided criteria for diagnosis of DCD. The APA states that there must be "impairment in the development of motor coordination, which can be manifested in delays in milestones such as standing and walking; poor performance in sports activities; and untidy handwriting" (American Psychiatric Association, 2000; Kirby & Sugden, 2007, p.182). The WHO diagnosis requires that on a test of motor impairment, a child with DCD would score two standard deviations below the mean, in addition to experiencing difficulties with activities of daily living and interference with academic achievement (World Health Organization, 1992). Both the APA and WHO state that in order to be considered as having DCD, the associated impairments cannot be due to intellectual impairment (IQ < 70), and the problems in in coordination cannot be caused by a comorbid neurological problem such as cerebral palsy (Dewey & Wilson, 2001; Kirby & Sugden, 2007).

Broadly speaking, it is agreed that children with DCD have "dysfluent" movement patterns (Lafuze, 1951; Larkin & Hoare, 1992; McKinlay, 1988, Missiuna, 1994; Wall, Reid, & Paton, 1990). Practically, these children struggle with coordination, meaning that they have difficulty with planned intentional movements requiring spatial and temporal organization. Hence, they perform actions with qualitatively different movement patterns than their aged matched peers. In addition to problems in coordination, children with DCD may experience difficulties with flexibility or movement control, as evident by a limited ability to adapt to different environments (Henderson & Henderson, 2003). In relation to their movement capabilities, this is a heterogeneous group, where some children are not able to perform even rudimentary tasks, whereas other can coordinate their actions but only if the task/environmental demands are stable. Thus, conceptually it is possible that these children struggle to develop the ability to adequately parameterize the GMP to environmental demands, limiting generalizability (Schmidt, 1975).

Intra-Limb Coordination and Control in Goal Directed Arm Actions

Intra-limb organization (coordination and/or control) is essential when generating goal-directed actions. The strategy employed by the central nervous system to effectively plan goal-directed actions can be explained in multiple ways. The actions may be planned at the level of muscle, joint angle, or endpoint coordinates (Shumway-Cook & Woollacott, 2007). The coordinate strategy, at the muscular level, involves the CNS organizing the activation and sequencing of groups of muscles to accomplish the task. In terms of joint-angle coordinates, the CNS must complete an inverse kinematics calculation to establish the necessary angles at each involved joint to generate the desired trajectory of the end effector (Soechting, 1989). Finally, the endpoint coordinate strategy involves planning the movement in terms of extrinsic coordinates in space (Shumway-Cook & Woollacott, 2007). Using this strategy, the CNS organizes the movement based on the desired final position of the effector. It is currently unclear whether the central nervous system programs actions with exclusively one (joint coordinate or endpoint coordinate), or a combination of the two strategies, however due to the notion of motor equivalence it is unlikely that the actions are programmed at the level of the muscles (Bernstein, 1967).

From the methodological perspective, intra-limb coordination can be examined both quantitatively and qualitatively. In terms of the former, numerous studies used intra-class correlation coefficient (ICC) to examine the coordination issues in a variety of tasks such as javelin throwing (Amblard, Assaiante, Lekhel, & Marchland, 1994), volley ball serves (Temprado, Della-Grast, Farrell & Laurent, 1997), two-handed (Przysucha & Maraj, 2013), and one-handed catching

(Asmussen, Przysucha, & Zerpa, 2014; Mazyn, Montagne, Savelsbergh, & Lenoir, 2006). This type of analysis allows for making inferences about the emerging coordination tendencies. Specifically, the ICC values will demonstrate whether the participants tend to couple or decouple the relevant joints while performing the task. In addition to this type of measure, the nature of the emerging relations can also be examined via angle-angle plots. These can be constructed by plotting the angular position of one joint against the angular position of another joint within that limb at the same instance in time (e.g. shoulder vs. elbow). The potential changes in the qualitative nature of the movement, or its stability, can be observed by comparing angle-angle plots at different testing times (Sparrow, 1992).

In terms of movement control, two approaches can be implemented. Examination of the joint-angle coordinates withstands from the inverse kinematic approach, and the changes in the angular displacement of the individual joints can be inferred (Shumway-Cook & Wollacott, 2007). In addition, the path and velocity of the end-effector can be analyzed, providing insight into movement organization issues associated with spatial and temporal control of trajectory formation of the hand, for example. Although often inter-related, both aspects represent entities that may be controlled independently. For example, research has shown that while learning a new skill, control of the spatial aspects of movement is acquired first, prior to the mastering of the temporal organization (Mazyn et al., 2007). Thus in the context of manual goal-directed actions, the performer would focus on generating a straight path to the target first, while adapting the velocity of the end-effector later on during the learning process (Laurent et al., 1994).

One-Handed Catching

One-handed catching involves the organization of the shoulder, elbow, wrist, and fingers in order to place the hand in the correct location at the correct time. Although seemingly simple, this process demands effective spatial organizations between the respective joints and temporal adaptations of the end effector (i.e. the wrist).

Developmentally, tasks such as one-hand catching should be performed in an adult-like fashion around nine years of age (Savelsbergh & van Santvoord, 1996). The early stages of one-handed catching are characterized by a "trapping" strategy, where the ball is stopped between the arm and the trunk. As the child matures in their catching ability, he/she adopts a strategy where the ball is contacted away from the body with the elbow flexed and the olecranon process pointed downward. Mature catching will also present with the ability to catch the ball in the presence of environmental changes such as varying ball velocity and trajectory (Savelsbergh, Davids, van der Kamp, Bennett, 2003), as well as different task demands (e.g., catching balls of different sizes) (Strohmeyer, William, & Shaub-George, 1991).

To observe the type of adaptations that occur in the presence of changing environmental demands, Laurent, Montagne, and Savelsbergh (1994) conducted a study where adults performed one-handed catches under five different temporal conditions (i.e. ball speeds ranging from 5.7 to 9m/s). Table tennis balls were delivered via a ball-projection machine, and three-dimensional kinematic analysis was used to observe changes in control. The most notable spatial adaptations in response to increasing ball velocities were ball-hand contact closer to the body and an increase in the straightness of trajectory of the catching hand (Laurent et al., 1994). Significant temporal adaptation was evident by a decrease in total movement time. Of particular interest is the fact that regardless of the time constraints imposed on the participant, the acceleration phase (time to peak velocity) remained constant. Conceptually, this indicates that regardless of ball speed, the pre-programmed ballistic phase of the movement remained the same, and the catcher was parameterizing other spatio-temporal aspects of the action, likely related to more subtle changes to hand velocity and position as it approaches the intended target (e.g., the ball).

From the motor learning perspective, research has shown that a performer can learn to make the necessary spatial and temporal adaptations to catch proficiently. These adaptations are typically accompanied by gradual improvements in movement effectiveness (number of balls caught), across same or changing task demands. Mazyn, Lenoir, Montague, and Savelsbergh (2007) examined changes in temporal and spatial kinematic variables during a 2-week one-handed catching intervention involving novice adults. Although they did not implement variable practice explicitly, they did manipulate ball speed and examined the corresponding changes in kinematic variables over time. Adaptations in spatial control were evident at post-intervention, where the performers increased the forward displacement of the wrist, thereby catching the ball farther from the body. Changes in temporal control were also found at post-intervention, including increased movement time, higher peak velocity of the catching wrist, and increased consistency of latency time when compared to the pre-intervention. In line with the motor learning model, it appears that the participants first learned to adjust the spatial characteristics of the movement, and only began adapting the temporal aspects later in the learning process.

In summary, while the previously mentioned studies pertained to the learning processes and adaptations demonstrated in typically functioning adults, it is expected that a similar learning pattern maybe observed in children performing/learning one-handed catch under changing task constraints.

Two- and One-Handed Catching in Children with DCD

Previous research examining intra-limb organization of children with DCD has analyzed the degree (spatio-temporal relations) as well as the stability (intra-individual variability) in the context of goal directed actions such as one-handed catching (Asmussen et al., 2014a), and two-handed catching (Astill & Utley, 2006; Przysucha & Maraj, 2014; Utley, Steenbergen, & Astill, 2007). The following section discusses the trends that emerged from these investigations.

Coordination. Execution of a one- or two-handed catch requires that the performer to coordinate the many degrees of freedom associated with the movement (Berstein, 1967; Utley, Steenbergen, & Astill, 2007). The presence of multiple mechanical degrees of freedom at each joint creates a difficult problem for the CNS because they allow for a nearly infinite number of ways to accomplish a task. This is known as the degrees of freedom problem (Bernstein 1967). Thus, in catching, there are many degrees of freedom that must be coordinated at the shoulder, elbow, and wrist. Specifically, there are three in the shoulder, one in the elbow, and three in the wrist (Berstein, 1967). To reduce the number of degrees of freedom that must be managed, novice individuals may freeze the articulating joints or they may adopt rigid couplings between joints (Sekaran, Reid, Chin, Ndiaye, & Licari, 2012). This is a behavior that has been exhibited in previous studies by children with DCD to cope with the redundant degrees of freedom in both one-handed and two-handed catching (e.g., Utley et al., 2007).

In the context of one-handed catching, Asmussen and colleagues (2014) demonstrated that children with DCD had difficulties coordinating the joints of a single limb to accomplish the task. The results showed that the typically functioning children decoupled the shoulder-elbow and tightly coupled the elbow-wrist, while the children with DCD decoupled both joints pairs (shoulder-elbow and elbow-wrist). Thus, it appears that the children with DCD organized the movement in a similar manner at the proximal joints (shoulder-elbow) but not at the distal joints (elbow-wrist). Although similar between groups, coordination of the shoulder-elbow by the children with DCD was significantly less stable when compared to their peers. Functionally, this indicates that although the patterns were similar, children with DCD were still changing their organization from trial to trial. As shown in Figure 1, a child with DCD demonstrated an inconsistent movement pattern across trials, whereas a typically functioning child was very stable. Given the variability observed, and the fact that children with DCD were less effective (32% caught) as compared to their peers (85% caught), the coordination of the former group was deemed as less than optimal.

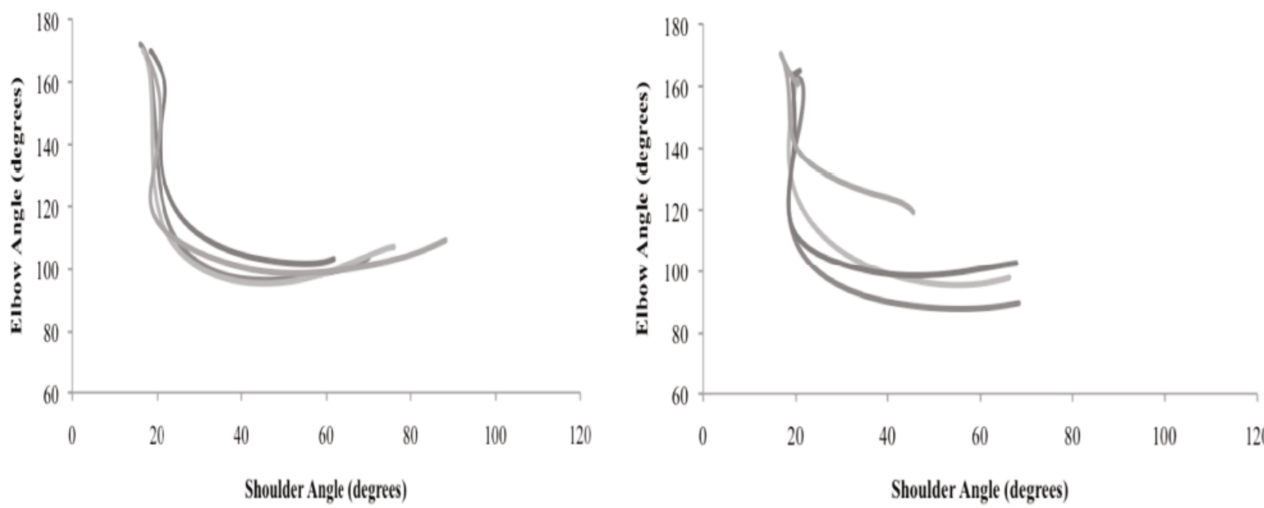


Figure 1. Elbow-shoulder angle-angle plots for a typical child (left diagram) and a child with DCD (Asmussen et al., 2014b).

Although different from one-handed catching, many studies examining two handed-actions provided useful insight into differences in coordination of the upper limbs between children with DCD and their typically functioning peers. One of such studies was conducted by Utley, Steenbergen, and Astill (2007), who found significant differences between the two groups in their coordinative strategies of the two handed catch. The results showed that the children with DCD solved the degrees of freedom problem by rigidly fixing the elbow throughout the movement, whereas the typically functioning children coupled and decoupled their joints in a less rigid fashion. These findings were consistent with earlier research by Astill and Utley (2006) who also showed that children with DCD exhibit a tendency to "freeze" the elbow. It is assumed that the coordinative strategy exhibited by the typically functioning children is the more functional and adult-like strategy to perform the catching task, as they caught significantly more balls.

A more recent study by Przysucha and Maraj (2014) further examined intra-limb coordination in a group of children with and without DCD. In the context of shoulder-elbow relations, the typically functioning group exhibited a high degree of coupling between the joints, indicating that both the shoulder and elbow were actively involved throughout the movement (Przysucha & Maraj, 2014). Functionally, a high correlation indicates that the angular displacement of the shoulder coincided with proportional displacement at the elbow. Additionally, the tight coupling was stable across trials and similar across individuals. The children with DCD on the other hand, exhibited less coupling, which indicates that angular displacement is not proportional between joints. The movement patterns of the children with DCD began with flexion at the elbow, while the shoulder remained fixed. The shoulder only began to flex once the elbow approached its maximally flexed position for that trial. Additionally, the children with DCD demonstrated less stable coordination strategies at the shoulder-elbow joint pair across trials. The DCD group was also heterogeneous, meaning that the difficulties in coordination were more pronounced in certain participants. As for elbow-wrist relations, the typically functioning children had a significantly greater correlation coefficient than the atypical children. Functionally speaking, the differences were apparent at the wrist, where angular displacement of the typically functioning children's wrists were restricted to a fraction of the angular displacement of the elbow. On the other hand, the children with DCD flexed and extended the wrist throughout the movement (Przysucha & Maraj, 2014). Interestingly, there were no differences between groups in terms of the variability of elbow-wrist coordination across trials, indicating that although different, the actions generated by children with DCD were stable at the elbow-wrist joint pair.

Furthermore, the previously mentioned study by Przysucha and Maraj (2014) also examined intra-limb coordination in the context of changing task demands (i.e. varying ball speeds). The researchers found that as the velocity of the ball increased, the children with DCD exhibited significantly lower mean correlation values at the shoulder-elbow, resulting in a further segmented movement. This tendency to decouple the joints in the presence of faster ball speeds was not seen in a group of typically functioning individuals in earlier research by Mazyn and colleagues (2006).

Collectively, the research showed that children with DCD do not coordinate interceptive tasks in the same way as their typically developing peers. Typically developing children couple and decouple the components of the limb in a functional, adult-like manner, whereas the atypical children demonstrate a tendency to decouple the relevant joints (Przysucha & Maraj, 2014). At both joint pairs examined (shoulder-elbow and elbow-wrist), the differences between groups can be attributed to the coordination of the more distal joints. This indicates that coordination of distal joints, when performing both uni-manual and bi-manual ball catching, is an issue in children with DCD.

Spatial Control. To examine spatial control of catching in children with DCD, the primary variable used is angular displacement of the relevant joints (Utley et al., 2007; Sekaran et al., 2012). Sekaran and colleagues (2012) examined spatial control of the two-handed catch at the inter- and intra-limb level in a group of children with DCD compared to a typically functioning control group. The results showed that the children with DCD demonstrated "increased thorax extension, increased flexion and internal rotation of the shoulder, decreased shoulder abduction, decreased elbow flexion, and increased wrist flexion and ulna deviation" (Sekaran et al., 2012, p.

28). The finding of increased trunk extension in children with DCD was consistent with earlier work by Przysucha and Maraj (2010). The extension at the trunk may represent an avoidance reaction or, alternatively, may be a compensatory mechanism to shift the hands upwards closer to the point of reception (Sekaran et al., 2012). The increased flexion, increased internal rotation, and decreased shoulder abduction are likely the result of compensation for the decreased magnitude of displacement at the elbow, a finding that is consistent with earlier research (Sekaran et al., 2012; Utley, Steenbergen, & Astill, 2007; Van Waelvelde, De Weerdt, De Cock, & Smits Engelsman, 2004). When examining the overall movement pattern, Sekaran and colleagues (2012) also found that differences existed in terms of when the joints initiated their angular displacement. In the typically functioning children, the shoulder and wrist underwent a relatively small range of motion at a later stage in the movement. This was not the case for children with DCD, who initiated the shoulder and wrist actions earlier, and moved them through larger ranges of motion (Sekaran et al., 2012). Thus, Sekaran and colleagues (2012) concluded that it is possible that initial error in spatial control of the elbow resulted in the need for significant compensation by other joints to successfully intercept the incoming ball.

In terms of variability of spatial control, the most significant differences between atypically and typically functioning individuals is control of the elbow (Sekaran et al., 2012). In the aforementioned study by Sekaran and colleagues (2012), spatial variability of the elbow was considerably larger across trials in the group of children with DCD as compared to typically functioning children (Sekaran et al., 2012). The presence of greater spatial variability of angular displacement was not limited to the elbow however, as the researchers found significant differences at the trunk, shoulder, and wrist. A more recent study by Asmussen, Przysucha, and Dounskaia (2014) also found that children with DCD showed high variability in angular displacement of the elbow and shoulder when compared to the typically functioning group. The significant variability of spatial control is likely a contributing factor to the low success rate while catching (Asmussen et al., 2014a).

Temporal Control. Through qualitative observation, Larkin and Hoare (1991) found that children with DCD have difficulties with predicting the flight of the ball. These difficulties could be seen as a manifestation of problems in planning the temporal aspects of movement control (Deconinck, De Clercq, Savelsbergh, Van Coster, Oostra, Dewitte, & Lenoir, 2006). For example, as the trajectory of the ball changes and the velocity increases, children with DCD begin to demonstrate decreased movement effectiveness (fewer balls caught) (Lefebvre & Reid, 1998). Previous research has suggested that children DCD are disadvantaged in their ability to uptake and process visual information, and thus experience difficulties appropriately responding to changing temporal constraints (Bairslow & Laszlo, 1989; Henderson, Rose, & Henderson, 1992). However, the recent study by Deconinck and colleagues (2006), appears to reject the notion forwarded by Bairslow and Laszlo (1989) and Henderson and colleagues (1992). The study involved the manipulation of ball velocity, and examined the temporal adaptations made by children with DCD as compared to typically functioning peers. The children with DCD did not show significantly slower reaction times, indicating that their speed of information processing was not disadvantaged. The differences between groups were limited to maximum hand velocity and peak closing velocity of the hand, which was not adapted by children with DCD when presented with faster ball speeds. The typically functioning group however did make the necessary adaptations. Thus, the issues with temporal control are not likely the result of poor information processing, but rather a result of a failure to appropriately parameterize the GMP. Support for this notion was put forward by Przysucha and Maraj (2014). Through the manipulation of ball speeds, the researchers revealed that typically functioning children were able to appropriately increase the velocity of their wrist in response to the increase in ball speed, whereas children with DCD did not. While making contact with the ball closer to the body, they were not making the necessary changes in wrist velocity. Again, these findings suggested that the inability to adapt the temporal parameters of the GMP in response to changing velocity of the ball may be problematic for children with DCD.

Overall, the differences between the typically and atypically functioning children are evident across measures of coordination as well as measures of spatial/temporal control in one- and two-handed catching (Asmussen et al., 2014a; Przysucha, 2014; Utley et al., 2007; Sekaran et al., 2012). Now that these differences have been identified, from a clinical perspective it is important to address these issues. It is plausible that implementation of variable practice may be beneficial for these children, as parameterization of the movement pattern appears to be a constraint in their ability to place their hand in the correct space at the correct time to catch the ball (Asmussen et al., 2014a; Przysucha, 2014; Utley et al., 2007; Sekaran et al., 2012).

Implementing Motor Skill Intervention Techniques in Children with DCD

Although research demonstrates that children with DCD are atypical in their development of coordination and control, limited research exists in how these children learn, or how they adapt as a result of motor experience. Further research is needed to gain a greater understanding of how to specify intervention for these children (Kirby & Sugden, 2007).

There are primarily two different approaches that the existing research has implemented; process-oriented and task-specific interventions (Kirby & Sugden, 2007). Both of these techniques "remedy some underlying process deficit with intervention targeted at a neural structure, such as the cerebellum, or sensory processes, such as vision or proprioception" (Sugden, 2007, p. 468). The process-oriented approach to intervention is a method commonly used when the primary goal is to enhance and remedy sensory input processing, where the task itself is not targeted. For example, the intervention may aim to enhance kinesthetic functioning in order to improve the performance on multiple motor skills (Kirby & Sugden, 2007). On the other hand, the goal of task-specific intervention is to improve performance of a skill by using a range of methods concentrating on the desired task (Kirby & Sugden, 2007). At the core of task specific intervention is the assumption that motor learning is achieved most optimally when the instruction is focused directly at the targeted task (Mandich, Polatajko, Macnab, & Miller, 2001). Therefore, teaching a fundamental movement skill using variable type of practice could constitute a task-specific intervention.

The current literature suggests that task-specific approaches to intervention can be confidently implemented with both typically and atypically functioning children, and results in positive changes in performance of both fine and gross motor skills (Smiths-Engelsman, Blank, Van Der Kaay, Mosterd-Van Der Meijs, Van Der Brand, Polatajko, & Wilson, 2012). The current research demonstrates that this form of intervention results in superior learning than other forms that primarily focus on addressing sensory-integration (i.e. process oriented) (Green, Chambers, & Sugden, 2008; Sangster, Beninger, Polatajko, & Mandich, 2005). A meta-analysis carried out by Smits-Engelsman and colleagues (2013) summarized the relevant literature on intervention in children with DCD. The results demonstrated a robust, strong treatment effect as a result of task-specific approaches across many fine- and gross-motor skills in children with DCD. For example, a study by Jongmans and colleagues (2003) demonstrated that children with motor difficulties improved handwriting skills over a 3-month task-specific intervention, while a control group showed no improvements (Jongmans, Linthorst-Bakker, Westenberg, & Smiths-Engelsman 2003). Further support comes from a study by Niemeijer and colleagues (2007), who implemented an intervention for various fundamental movement skills. Improvements in motor performance were assessed using pre- and post-intervention scores on the Movement Assessment Battery for Children-2 (MABC-2). Participants were limited to those who scored below the 15th percentile at pre-intervention and were assigned to an experimental and control group. At the completion of the 9-week intervention, only the experimental group exhibited changes in motor performance, and improved most on the tasks of the MABC-2 that were practiced during the intervention. Although there is support for the use of task-specific interventions in both fine and gross motor skills, limited research exists in the context of children with DCD and one-handed catching, despite it being an important fundamental motor skill (Smits-Engelsman et al., 2013).

In conclusion, catching is a skill that is considerably impaired in children with DCD, yet limited research exists examining the effect of intervention on catching performance within this population. The current research demonstrates that a task-specific approach to intervention grounded in a theoretical framework of motor learning and skill acquisition is the most effective way of improving learning outcomes. Therefore, it is plausible that implementing a task-specific intervention, based on Schmidt's schema theory (1975) and the variability of practice hypothesis, may improve performance of one-handed catching in children with DCD.

Research Problem

In summary, children with DCD exhibit a low level of proficiency in ball catching, in particular when trying to adapt their catching actions to different task constraints. In the absence of motor skill intervention, children with DCD may never outgrow their movement difficulties, and current research into task-specific intervention techniques has proved to be promising at addressing these issues. Variable type of practice can enhance the flexibility as it improves parameterization and stability of temporal and spatial aspects of movement organization.

Purpose

The purpose of the study was to investigate the effect that variable type of practice has on movement coordination and control of one-handed catching in a group of children with symptoms of developmental coordination disorder and ball skill problems, as compared to a group of typically functioning children.

Hypotheses

It was hypothesized that:

a) Movement effectiveness would improve, as evident by an increased percentage of balls caught for both groups.

b) Shoulder-elbow and elbow-wrist angle-angle plots and ICC values would not reveal changes in the nature and stability of movement coordination across the intervention, and particularly when transfer test was administered.

c) In terms of spatial movement control, it was expected that both groups would have a greater amplitude of angular displacement at the joints of the upper arm. Less angular displacement was expected at the hip, which is a characteristic of less avoidance reaction. Additionally, lower intra-individual variability was expected across all joints following the intervention as compared to pre-intervention. At transfer, both groups were expected to adapt spatial control variables to the novel task demands.

d) In terms of temporal movement control variables, it was hypothesized that both groups would achieve a higher peak wrist velocity, and a smaller value for relative time to peak wrist velocity. These changes would be accompanied by lower intra-individual variability across trials for peak wrist velocity and relative time to peak wrist velocity. At transfer, both groups were expected to adapt temporal control features to the novel task demands.

Method

Participants and Recruitment Process

Using a purposive sampling method, 3 boys and 1 girl (Mean age = 10.5 years, SD = 1.3 years) with symptoms of DCD were recruited. Four boys (Mean age = 9 years, SD = 0 years) were recruited to be included in the typically functioning group. The atypically functioning children were recruited through the Motor Development Clinic at Lakehead University. Parents of children who have previously attended the clinic were contacted and asked if they would be interested in participating in the study. The typically functioning children were recruited though the Lakehead Express soccer program. A meeting was arranged with individuals who had expressed interest in the study, at which the researcher provided an overview of all aspects of the study with the parent and child present. The parents were then provided with the formal recruitment letter (Appendix A). After the initial information session, if the parents were willing to enroll their child in the study, they were given the official consent form (Appendix B), assent form for the child to complete (Appendix C), and the Developmental Coordination Disorder Questionnaire (DCDQ) (Appendix D).

Inclusion/ Exclusion Criteria

In order for a child to be included in the atypically functioning group, he/she had to meet the criteria of DCD, as outlined in the Diagnostic and Statistical Manual of Mental Disorder, 4th edition (DSM-IV; APA, 2000). The DSM-IV outlines four basic criteria for diagnosing a child as having DCD. The first criterion is that the child must exhibit coordination abilities significantly lower than their age-matched peers, which was assessed using the Total Impairment Score (TIS) on the Movement Assessment Battery for Children-Second Edition (Henderson, Sugden, & Barnett, 2007). A child had to score below the 15th percentile on the TIS to meet the criteria for participation in the study, and below 5th percentile for the ball skills portion. The Movement Assessment Battery for Children Second Edition (MABC-2), is a standardized test used to identify and describe movement impairments in children ages 3 to 16 (Brown & Lalor, 2009). The test consists of a checklist component and a movement assessment component. The checklist is a simple way of assessing a child's movement proficiency and can be used as a screening tool. The movement test contains eight tasks for each of three age ranges; 3-6 years, 7-10 years, and 11-16 years of age. The results gathered from these tasks provide an objective measure of motor performance to be used in assessment of the child. A validation study performed by Schoemaker, Niemeijer, Flapper, and Smits-Engelsman (2012) showed construct and concurrent validity for the MABC-2 by comparing the checklist and movement test components against the Development Coordination Disorder Questionnaire '07 (DCDQ). The results showed that the MABC-2 is correlated with results on the DCDQ, and that the checklist component is a better predictor of motor impairment than the DCDQ.

The second criterion requires that the problems associated with coordination impact other areas of life, such as academic achievement or activities of daily living. The DCDQ, which was completed by the parents of the child, was used to determine if this criterion was met. Any score below the 57th percentile on the DCDQ indicated that there was interference with academic achievement and/or activities of daily living. The third criterion requires that the children not exhibit any known medical condition that may contribute to the movement difficulties. The consent form (Appendix B) was used for assessment of this criterion. The fourth criterion outlined by the DSM-IV required that the child have an Intelligence Quotient (IQ) of at least 85 in order to rule out sever cognitive impairments, which was also assessed by means of the consent form. Although the explicit diagnosis of DCD was not provided, as only a medical doctor can do so, children meeting the aforementioned criteria were considered as having symptoms of DCD as outlined by the DSM-IV.

In order to be included in the typically functioning group, the child must perform at a level that meets or exceeds the performance of their peers, assessed using the MABC-2. They must also achieve a score greater than the cutoff of "suspected DCD" on the DCDQ. Additionally, the child must not have any known medical conditions that interfere with motor performance. Finally, the child must be of typical intelligence when compared to their peers to rule out potential cognitive impairments, as assessed by the consent form.

Procedure

The participants meeting the inclusion criteria were invited to a pre-intervention catching session where their hand span (tip of thumb to tip of little finger) was measured, and baseline performance of the one-handed catch was examined using 3-D kinematic analysis. At this point, the participants and parents were required to complete and submit all necessary documents, including the consent and assent forms. After the pre-intervention session, the participants were involved in 6 weeks of intervention, which consisted of 2 practice sessions per week. A mid-intervention session was completed after the first 3 weeks, and a post-intervention session took place at the completion of the 12 sessions to assess potential changes in coordination and control. Following a one-week delay, the participants returned to complete the retention and transfer tests. All data collection and practice sessions took place at the C.J. Sanders building on the campus of Lakehead University and lasted approximately 30 minutes.

Pre-Intervention

During the pre-intervention testing session, the participants were positioned 5 meters away from the Silent Partner Quest tennis ball machine, which ejected a tennis ball at a constant velocity of 7m/s (Asmussen et al., 2014a). A pilot study revealed that the tennis ball machine was reliable within a standard deviation of 0.24 m/s when the desired velocity was 7m/s. Reflective markers were placed on relevant bony landmarks to allow for analysis of flexion and extension at the hip (greater trochanter), shoulder (acromion), elbow (lateral epicondyle), and wrist (styloid process and the distal end of the 5th metacarpal) of the catching arm (Asmussen et al., 2014a). Participants were given 5 practice trials to familiarize themselves with the task prior to beginning data collection (Asmussen et al., 2014a; Sekaran et al., 2012). The only instruction given was to catch with one hand in any way he/she desired. Five trials were administered in total. Each trial began with the child in a uniform starting position, which entailed facing the tennis ball machine with their hands at their side. Once in the starting position, the researchers provided a three-second countdown to ball release (Asmussen et al., 2014a; Sekaran et al., 2012). In order to keep the trajectory consistent across participants, adjustments were made during the 5 practice trials to ensure the ball arrived at chest height. The number of balls successfully caught was recorded during the testing sessions.

The kinematic data was collected using two high-speed Basler cameras set up according to recommendations for optimal camera positioning, with a sampling frequency of 100 fps and analyzed using Vicon Peak Motus 8 (Allard, Stokes, & Blanchi, 1995). The beginning of a trial was operationalized as the moment the catching wrist achieved 10% of its peak linear velocity. The end of the trial was defined as the moment the ball made contact with/missed the hand (Asmussen et al., 2014a). Trials were automatically digitized using Peak Motus 8. The same protocol was used during the mid- and post-intervention sessions, as well as at retention to assess potential changes in movement coordination and control.

Intervention

Participants from both groups were asked to return to the C.J. Saunders field house for 12 variable practice sessions over 6-weeks. These sessions involved no kinematic data collection. A variable practice schedule was created by randomly generating 12 practice sessions for the 6-week intervention. All participants were exposed to the same variable practice schedule. Each session consisted of 40 practice trials (8 blocks of 5 trials), where 2 blocks of each of four velocities were presented. Using the random number generator in Microsoft Excel, velocity was randomly assigned to the 8 blocks. The velocities presented were 6.7 m/s, 7 m/s, 7.6 m/s, and 8.25 m/s, which were settings, 10, 11, 12, and 13 on the Silent Partner Quest tennis ball machine. Thus, the ball naturally followed a variable trajectory with the changing ball velocities, however the end location was always at chest height of the participant. Manipulating the velocity and trajectory of the ejected balls is conceptually in line with the variability of practice hypothesis (Wrisberg & Mead, 2013). After each attempt, the child was asked to return to the initial position before the subsequent trial took place.

Post-Test/ Retention/ Transfer

The post-intervention testing session was conducted following the 12 practice sessions, and was identical to pre- and mid-intervention. The participants then returned one week later in order to complete the transfer and retention tests. The retention test was identical to the pre-, mid, and post-intervention analysis sessions. The transfer test involved the examiner bouncing a ball to the participant who was positioned 4 meters away. The ball was bounced at a location marked 2 meters away from the participant, and 2 meters away from the examiner. This task was selected to infer whether the child could generalize the movement pattern learned/used to catch a ball approaching at a slower speed with a considerably different trajectory. A pilot study revealed that the examiner was able to bounce the ball relatively consistently at 3.96 m/s (SD = 0.23 m/s). The trajectory was not controlled for as the inherited, natural variability was desired given the scope of the project.

Experimental Design/ Dependent Variables

The research design was a 2 Group (atypical vs. typical) x 4 Session (pre-, vs. mid-, vs. post-intervention, vs. retention/transfer) mixed-experimental design, with session as the repeated measure factor.

The nature of intra-limb coordination for the shoulder-elbow and elbow-wrist joint pairs were inferred through quantitative analysis of intra-class correlations (ICC) (Mazyn et al., 2006), and through qualitative analysis of angle-angle plots. An ICC value approaching 1 is indicative of tight coupling between the measured joints, while a value closer to 0 signifies decoupling of the joint pair. The nature of the emerging action at the shoulder was inferred from the markers located at the greater trochanter, acromion, and olecranon. The elbow angular displacement was assessed using the markers on the acromion, olecranon, and lateral epicondyle. Finally, wrist angular displacement was assessed using the markers on the olecranon, the lateral epicondyle, and the distal end of the 5th metacarpal.

The spatial aspects of movement control were inferred from:

- Hip, shoulder, elbow, and wrist angular displacement (degrees): defined as the difference between the maximum and minimum joint angle achieved between movement onset and ball contact.
- Intra-individual variability of angular displacement of the hip, shoulder, elbow, and wrist (degrees): defined as the standard deviation of angular displacement across trials.

The nature of temporal control was inferred from:

- Peak wrist velocity (m/s): defined as the first peak present in the wrist linear velocity profile (measured in the x-axis). This represents the velocity achieved at the end of the ballistic phase of the movement. A negative value implies the wrist was travelling in the opposite direction of the incoming ball, while a positive value implies the wrist was travelling in the same direction.
- Intra-individual variability of peak wrist velocity (m/s): defined as the standard deviation of peak wrist velocity across trials.
- Relative time to peak wrist velocity (proportion of movement time): defined as a proportion of the total movement time, calculated by dividing time to peak wrist velocity by movement time. This represents the proportion of the movement dedicated to accelerating the wrist to peak velocity (acceleration phase).
- Intra-individual variability of relative time to peak wrist velocity (proportion of movement time): defined as the standard deviation of relative time to peak wrist velocity across trials.

Analyses

The dependent variables were analyzed in terms of their mean values as well as intra-individual variability. At each testing session, participant's mean values were determined by averaging the results of the 5 trials. The groups' overall mean value was then calculated by averaging the mean values for each participant within the group. Intra-individual variability was determined from the standard deviation of the measured dependent variable across the 5 trials of the testing sessions. The groups' intra-individual variability was calculated by averaging the standard deviations of the participants within the group.

Hypothesis a). This hypothesis was tested by implementing two Friedman tests to determine if significant differences in movement effectiveness existed across testing sessions. Mann-Whitney U tests were used to identify differences between groups at each testing session.

Hypothesis b). This hypothesis was tested using a series of Friedman tests to assess changes at the shoulder-elbow and elbow-wrist in terms of mean ICC values and intra-individual variability. A series of Mann-Whitney U tests were then implemented to identify differences between groups at individual testing sessions.

Hypothesis c). This hypothesis was tested by using a series of Friedman tests to determine if significant differences in hip, shoulder, elbow, and wrist angular displacement existed across sessions. Next a series of Friedman tests were used to determine if differences in intra-individual variability existed across sessions. For each joint, a series of Mann-Whitney U tests were also implemented to identify potential differences between groups at individual testing sessions.

Hypothesis d). This hypothesis was tested by implementing a series of Friedman tests to determine if significant differences in peak wrist velocity and relative time to peak wrist velocity existed across testing sessions. Next, a series of Friedman tests were used to assess changes in intra-individual variability of peak wrist velocity and relative time to peak wrist velocity. A series of Mann-Whitney U tests were implemented to test for significant differences between groups for each variable at individual testing sessions.

Results

Movement Effectiveness

The results of the Friedman tests showed no significant changes across sessions for the atypical group in terms of the number of balls caught ($\chi^2(4) = 7.40$, $p = 0.12$). Analysis of the individual participants showed that two of the atypical children increased performance from 0%

to 100%, and 0% to 20%, respectively, while the other two participants did not change. Additionally, no significant changes were evident for the typical group, ($\chi^2(4) = 2.67$, $p = 0.62$). Analysis of individual participants showed that one of the children increased from 20% to 80%, one remained unchanged, and two decreased their performance, from 100% to 80%, and 80% to 60% respectively.

The Mann-Whitney U tests revealed significant difference at pre-intervention, where the typical group (M = 75%, SD = 37%) caught more balls than the atypical group (M = 0%, SD = 0%) ($U = 16$, $z = 2.48$, $p < .02$). No statistically significant differences emerged between the groups at mid- ($U = 14$, $z = 1.79$, $p = .11$), post-intervention ($U = 12.50$, $z = 1.34$, $p = .20$), retention ($U = 12.5$, $z = 1.32$, $p = .20$) or transfer tests ($U = 13.50$, $z = 1.69$, $p = .11$).

Intra-Limb Coordination

Shoulder-Elbow. A series of Friedman tests were implemented to determine if significant differences existed across testing sessions for shoulder-elbow ICC values. For the atypical group, no statistically significant differences were found, ($\chi^2(4) = 1.6$, $p = .81$). The same was true for the typical group ($\chi^2(4) = 8$, $p = 0.09$), although the value approached the significance level of .05.

A series of Mann-Whitney U tests were used to determine if significant differences existed between groups at any of the individual testing sessions. No significant differences were found at pre-intervention ($U = 14$, $z = 1.74$, $p = .11$), or retention ($U = 13$, $z = 1.45$, $p = .20$). The groups were statistically significantly different at mid- ($U = 16$, $z = 2.32$, $p < .02$), post- intervention ($U = 16$, $z = 2.32$, $p < .03$), and at transfer, ($U = 16$, $z = 2.32$, $p < .03$) (Table 1).

Table 1:

Mean and Standard Deviation of ICC Values for Angular Displacement of the Shoulder and Elbow for Both Groups Across Testing Sessions

	Pre-Intervention	Mid-Intervention	Post-Intervention	Retention Test	Transfer Test
Atypical Group Mean	.49	.44	.40	.47	.37
Atypical Group Std. Deviation	.15	.24	.14	.19	.12
Typical Group Mean	.73	.84	.82	.71	.64
Typical Group Std. Deviation	.12	.08	.05	.21	.06

Next, two Friedman tests were implemented to determine if there were significant changes in intra-individual variability of the ICC values. The differences across sessions were not significant for the atypical ($\chi^2(4) = 5$, p = 0.29) or typical group ($\chi^2(4) = 8.2$, p = 0.08), although the latter approached the significance level of .05.

Next, a series of Mann-Whitney U test were implemented to determine if significant differences existed between groups in terms of intra-individual variability of ICC values. The results showed no differences at pre- ($U = 4$, $z = -1.16$, p = .34), post-intervention ($U = 2$, $z = -1.7$, p = .11), or at retention ($U = 11$, $z = .87$, p = .11). Significant differences were found at mid-intervention ($U = .00$, $z = -2.32$, $p < .03$) and at transfer ($U = .00$, $z = -2.32$, $p < .03$).

Table 2:

Mean and Standard Deviation for Intra-Individual Variability of ICC Values for Angular Displacement of the Shoulder and Elbow for Both Groups Across Testing Sessions

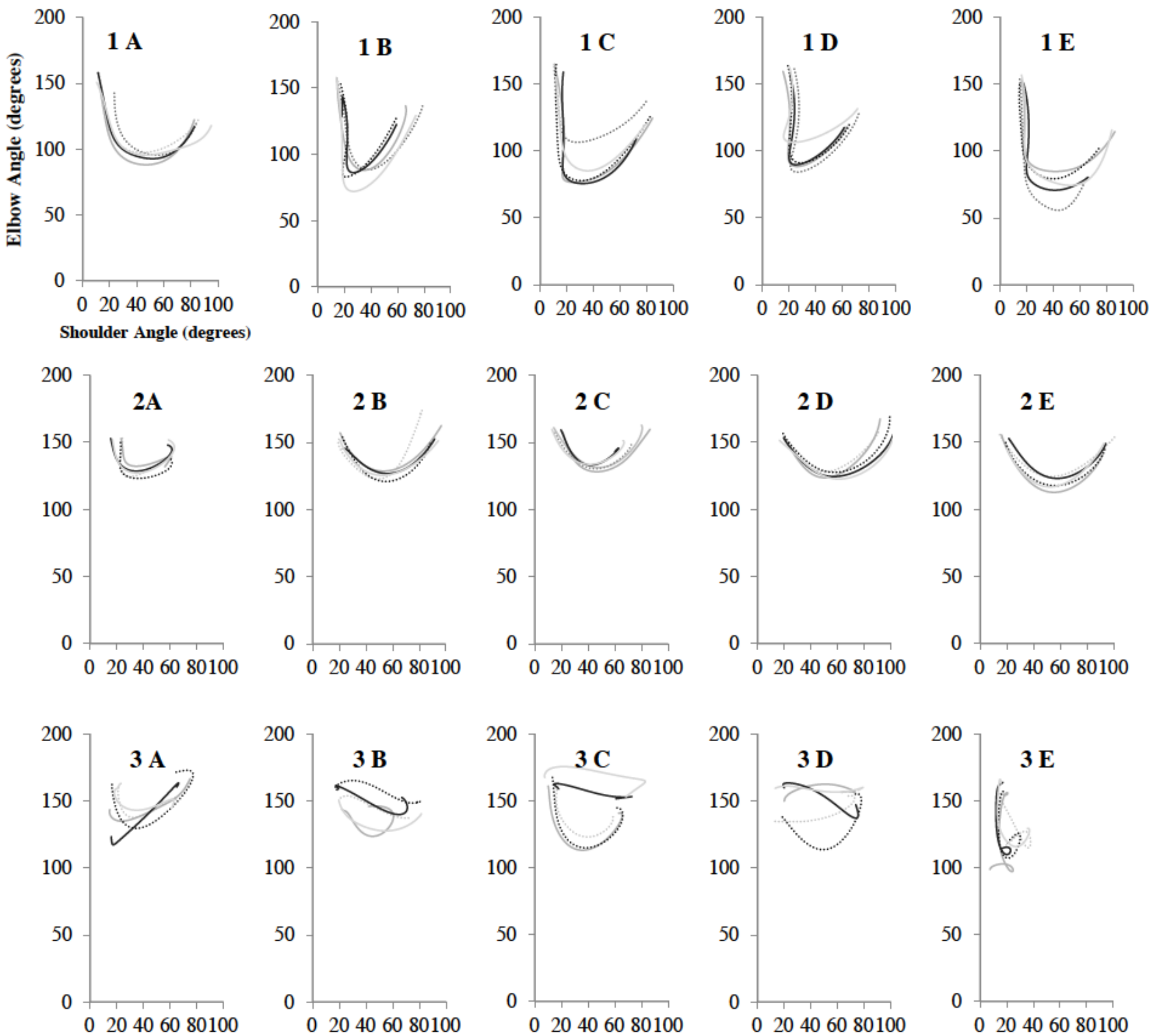
	Pre-Intervention	Mid-Intervention	Post-Intervention	Retention Test	Transfer Test
Atypical Group Mean	.23	.18	.16	.14	.19
Atypical Group Std. Deviation	.14	.09	.08	.08	.07
Typical Group Mean	.09	.05	.08	.18	.07
Typical Group Std. Deviation	.05	.02	.06	.13	.03

Qualitative examination of the atypical group's angle-angle plots (Figure 2) showed that 2 of the 4 children (participants 1 and 4) tended to initiate the movement by flexing the elbow while the shoulder was relatively fixed, and subsequently flexed the shoulder and extended the elbow to intercept the ball. Participant 2 executed a similar movement pattern, however tended to flex both the elbow and shoulder to initiate the movement. As for participant 3, at pre-intervention the child presented with a movement pattern that was qualitatively similar to the other children on some trials, but drastically different on others (see Figure 2). For example, on trial 3 of pre-intervention, the participant began the movement by quickly flexing the elbow only 5° before extending the elbow and flexing the shoulder until ball-hand contact.

Qualitative examination of the shoulder-elbow angle-angle plots (Figure 2) also shows that as the intervention progressed, 3 of the 4 atypical children (participants 1, 2, and 4) did not alter their general movement pattern. At transfer, the children then used the same movement pattern to accomplish the novel task. Beyond the initial testing session, participant 3 demonstrated considerably different movement patterns on nearly all trials.

In terms of intra-individual variability, it can be seen that 3 of the 4 participants

(participants 1, 2, and 4) improved their consistency of execution of the one-handed catch (Figure 2). As evident from the angle-angle plots, they became more stable when pre- and post-intervention profiles were compared. The improved degree of consistency was also evident at retention. Participant 3, however, appears to become less stable in his movement pattern as the intervention progressed, changing the coordinative strategy on nearly all attempts. In summary, participants 1, 2, and 4 exhibited similar and more stable movement patterns, while participant 3 appeared to become less stable as a result of the intervention.



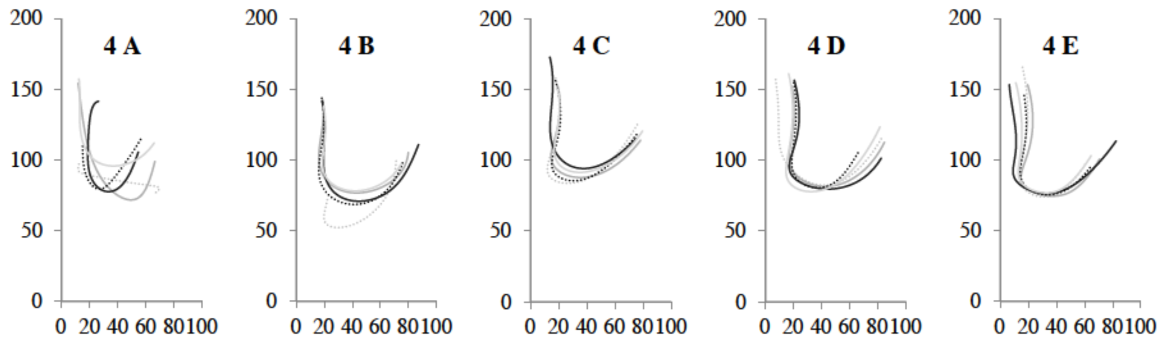


Figure 2: Shoulder-elbow angle-angle plots for the atypical group across 5 trials for each testing session , A = pre-, B = mid, C = post, D = retention, E = transfer.

Examination of the individual angle-angle plots of the typical group showed that the participants began the intervention with a qualitatively similar movement pattern (Figure 3). This movement began with flexion at the elbow and a relatively small amount of flexion at the shoulder. The elbow and shoulder continued to flex, followed by extension of the elbow mid-way through the movement (see Figure 3). Ball-hand contact occurred with the shoulder at its maximally flexed position for that trial. As the intervention progressed, 3 of the 4 participants (6, 7, and 8) did not drastically alter this movement pattern. On the other hand, participant 5 altered the movement from pre-intervention to mid-intervention, where the elbow continued to flex throughout the entire catching attempt. At post-intervention, participant 5 reverted back to the original pattern. At retention, all the children performed the catch with a qualitatively similar movement pattern. At transfer, the children then used the same movement pattern to accomplish the novel task. As for stability in the movement pattern, the typical group exhibited a high degree of consistency across trials at pre-intervention and remained relatively stable as the intervention progressed.

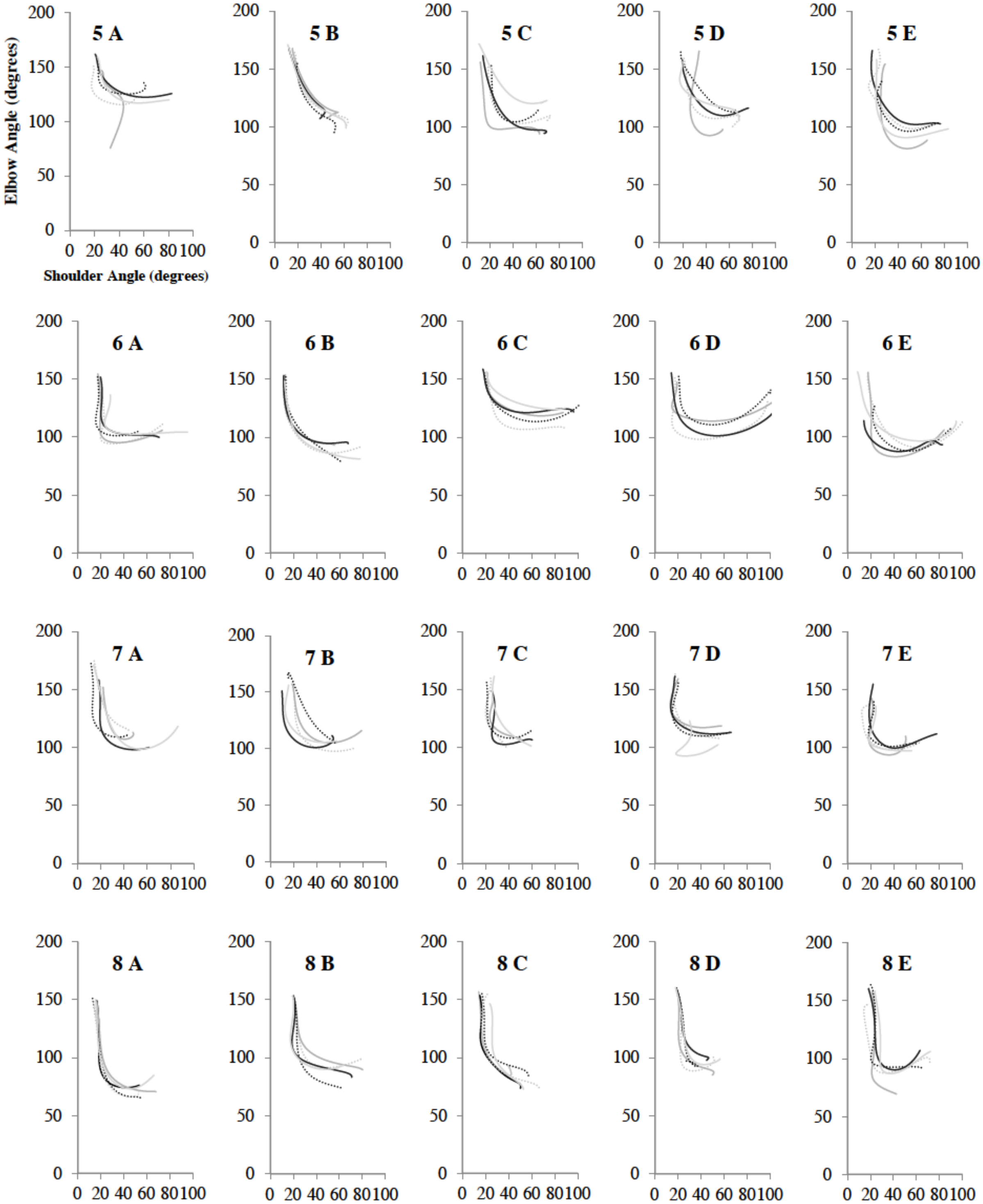


Figure 3: Shoulder-elbow angle-angle plots for the typical group across 5 trials for each testing session, A = pre-, B = mid, C = post, D = retention, E = transfer.

Elbow-Wrist. Two Friedman tests were implemented to determine if significant changes in elbow-wrist correlations occurred across testing sessions. Results for the atypical group revealed no significant changes in correlation values across sessions ($\chi^2(4) = 2.6$, $p = 0.63$) (Table 3). The same was true for the typical group ($\chi^2(4) = 3.4$, $p = 0.49$).

Table 3:

Mean and Standard Deviation of ICC Values for Angular Displacement of the Elbow and Wrist for Both Groups Across Testing Sessions

	Pre-Intervention	Mid-Intervention	Post-Intervention	Retention Test	Transfer Test
Atypical Group Mean	.66	.59	.68	.48	.69
Atypical Group Std. Deviation	.21	.11	.18	.07	.25
Typical Group Mean	.49	.43	.68	.79	.52
Typical Group Std. Deviation	.26	.15	.09	.16	.13

Next a series of Mann-Whitney U tests were implemented to determine if significant differences existed between groups. No significant differences were found at pre- ($U = 4$, $z = -1.62$, $p = .34$), mid- ($U = 2$, $z = -1.74$, $p = .11$), post-intervention ($U = 7$, $z = -0.29$, $p = .88$), or transfer ($U = 4$, $z = -1.16$, $p = .34$). However, significant difference existed between groups at retention ($U = 16$, $z = -2.33$, $p < .02$).

Next, two Friedman tests were implemented to determine if significant changes existed in intra-individual variability of the movement pattern across sessions (Table 4). Neither the atypical, ($\chi^2(4) = 2.8$, $p = 0.59$), or typical group, ($\chi^2(4) = 8.6$, $p = 0.07$), demonstrated significant changes, although the differences exhibited by the latter group did approach the significance level of 0.05.

Table 4:

Mean and Standard Deviation for Intra-Individual Variability of ICC Values for Angular Displacement of the Elbow and Wrist for Both Groups Across Testing Sessions

	Pre-Intervention	Mid-Intervention	Post-Intervention	Retention Test	Transfer Test
Atypical Group Mean	.23	.29	.21	.26	.15
Atypical Group Std. Deviation	.16	.06	.11	.07	.10
Typical Group Mean	.15	.25	.26	.13	.29
Typical Group Std. Deviation	.08	.07	.04	.12	.05

A series of Mann-Whitney U tests were used to determine if significant differences existed between groups for intra-individual variability of ICC values of the elbow-wrist. No significant differences were found between the groups at pre- ($U = 7$, $z = -.29$, $p = .88$), mid- ($U = 3$, $z = -1.45$, $p = .20$), post-intervention ($U = 10$, $z = .58$, $p = .68$), or retention ($U = 2$, $z = -1.74$, $p = .11$). The difference at transfer approached statistical significance ($U = 15$, $z = -2.03$, $p = .06$).

When the atypical group's elbow-wrist angle-angle plots were examined, it was evident that the atypical participants used qualitatively different movement patterns from one another, however all demonstrated a tendency to flex and extend the wrist throughout the attempts (Figure 4). As the intervention progressed, participants 1, 2, and 4 altered their movement pattern across sessions, but remained constant in their stability across trials. As for participant 3, he continued to coordinate the elbow-wrist joint pair differently on nearly all attempts, and therefore did not become more consistent. At transfer, the children exhibited movement patterns qualitatively similar to those used at retention.

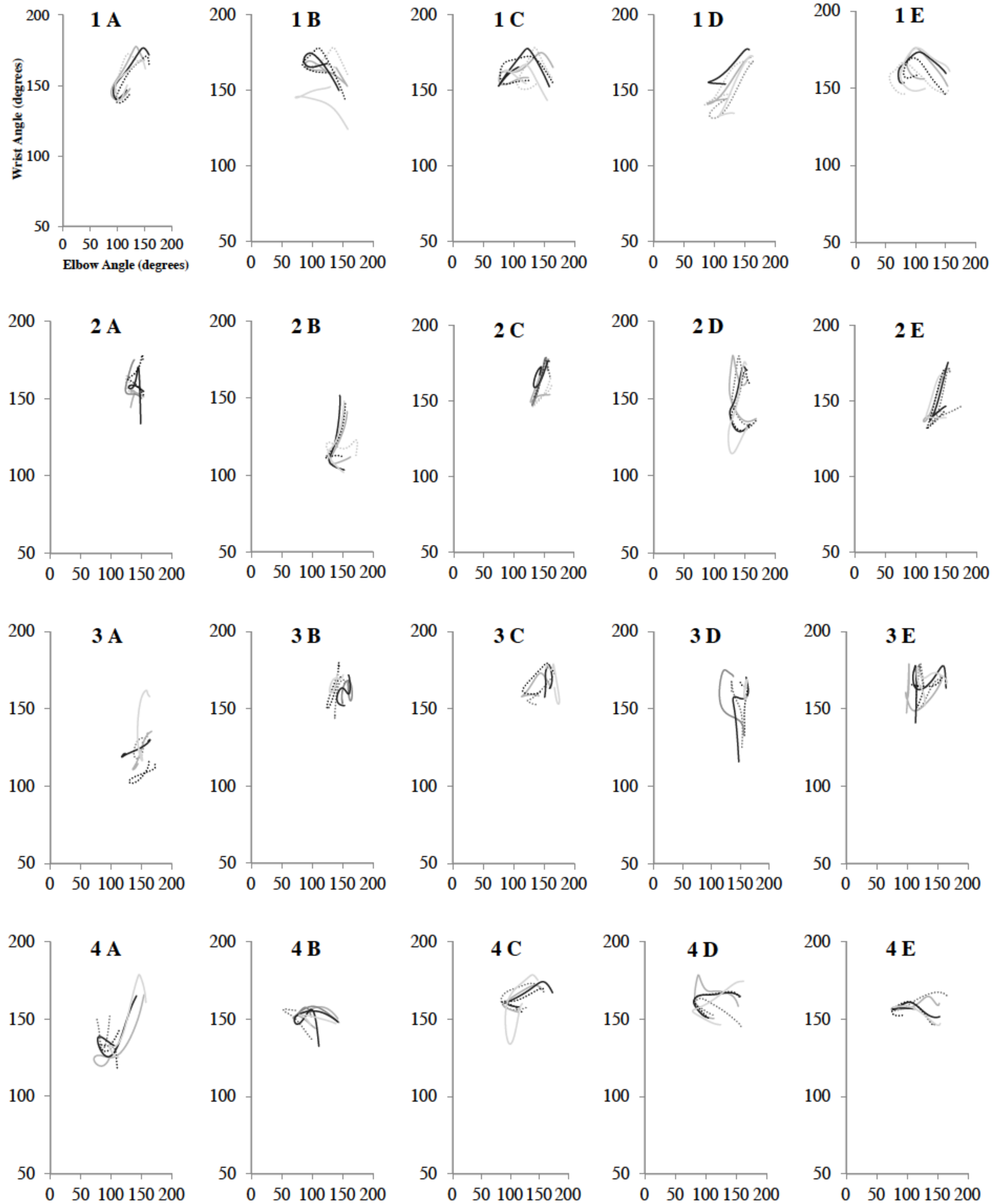
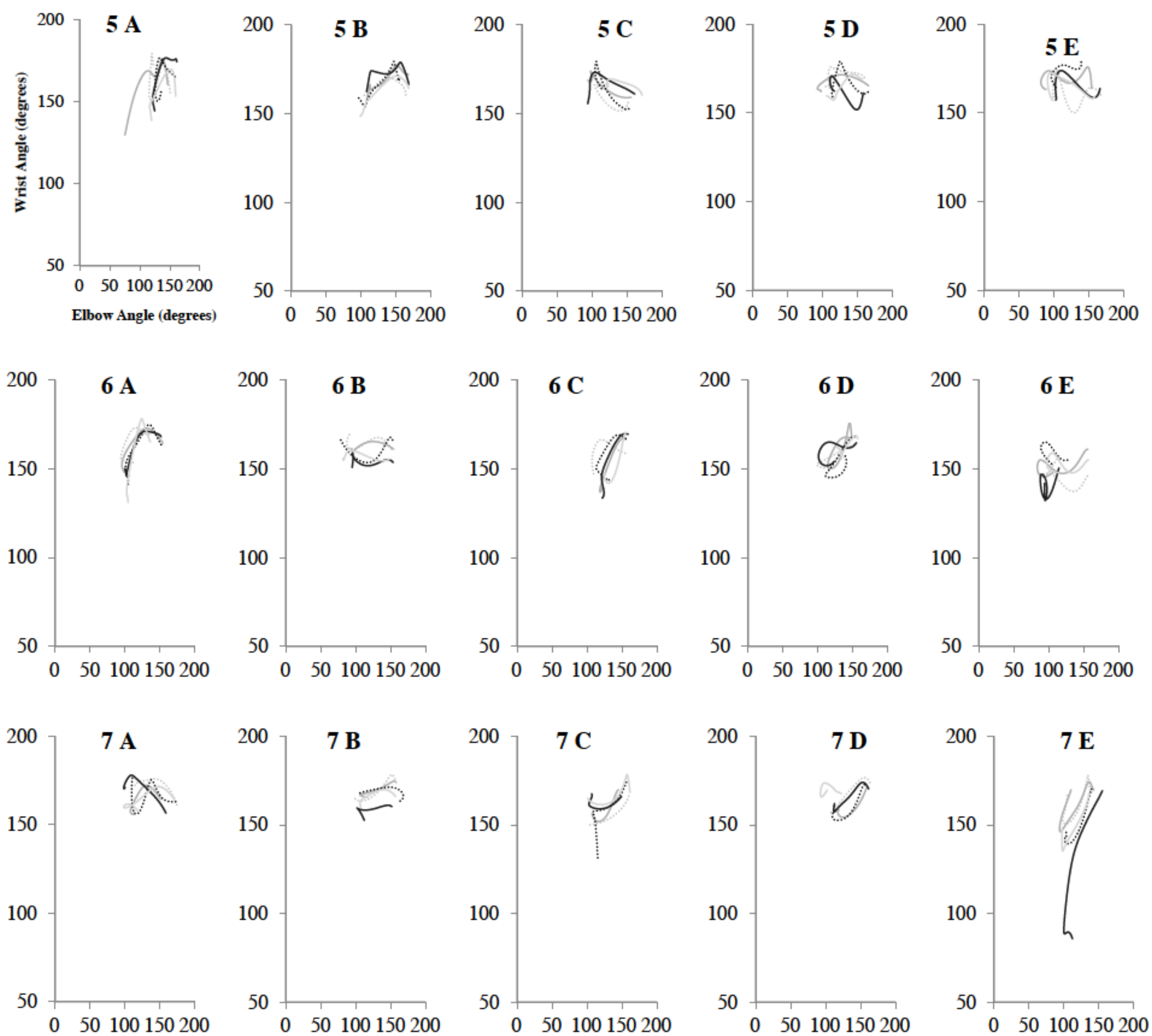


Figure 4: Elbow-wrist angle-angle plots for the atypical group across 5 trials for each testing session, A = pre-, B = mid, C = post, D = retention, E = transfer.

When examining the angle-angle plots of the typically functioning children, it can be seen that they began the intervention with qualitatively similar movement patterns. The children began the action with flexion at the elbow and at the wrist (Figure 5). Mid-way through the response, as the elbow reached maximal flexion for the trial, the wrist then gradually extended until ball-hand contact. In terms of consistency across trials, 2 of the 4 participants (participants 6, and 8) began the intervention with relatively stable movement patterns. As the intervention progressed, the typical children appear to maintain a similar movement pattern and remain constant in their stability across trials. At transfer, no qualitative changes were made to the movement pattern.



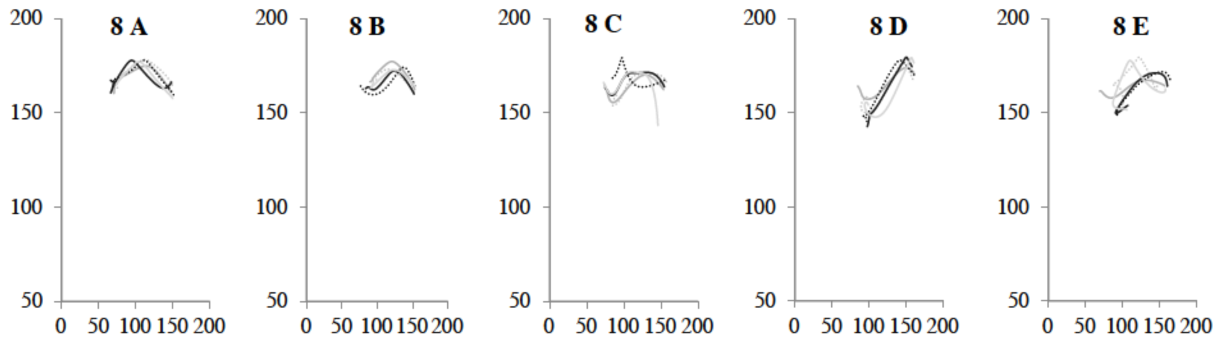


Figure 5: Elbow-wrist angle-angle plots for the typical group across 5 trials for each testing session, A = pre-, B = mid, C = post, D = retention, E = transfer.

Spatial Control

Hip Displacement. Two Friedman tests were implemented to determine if significant differences existed across testing sessions. Differences were not statistically significant for the atypical, ($\chi^2(4) = 5.4$, $p = 0.25$), or the typical group, ($\chi^2(4) = 1.4$, $p = 0.84$).

A series of Mann-Whitney U tests were used to determine if significant differences existed between groups. No significant differences were found at pre- ($U = 9$, $z = .29$, $p = 1.00$), mid- ($U = 5$, $z = -.87$, $p = .49$), post-intervention ($U = 7$, $z = -.29$, $p = .89$), retention ($U = 5$, $z = -.87$, $p = .49$), or transfer ($U = 6$, $z = -.57$, $p = .69$).

Table 5:

Angular Displacement (degrees) of the Hip for Both Groups Across Testing Sessions

	Pre-Intervention	Mid-Intervention	Post-Intervention	Retention Test	Transfer Test
Atypical Group Mean	12.84	16.61	22.97	20.24	14.65
Atypical Group Std. Deviation	9.11	5.42	13.46	15.05	5.23
Typical Group Mean	12.76	13.12	18.66	14.49	12.03
Typical Group Std. Deviation	4.75	7.21	16.41	15.93	4.18

The potential changes in intra-individual variability were examined with two Friedman tests (Table 6). The results showed that the differences across sessions were not statistically significant for the atypical ($\chi^2(4) = 1.60$, p = 0.81), or the typical group ($\chi^2(4) = 2.6$, p = 0.63).

Table 6:

Intra-Individual Variability of Angular Displacement (degrees) of the Hip for Both Groups Across Testing Sessions

	Pre-Intervention	Mid-Intervention	Post-Intervention	Retention Test	Transfer Test
Atypical Group Mean	10.01	10.89	7.64	6.78	6.48
Atypical Group Std. Deviation	10.40	7.84	3.44	4.48	5.55
Typical Group Mean	12.19	12.26	8.03	8.22	6.80
Typical Group Std. Deviation	8.95	12.71	3.45	10.26	3.69

Next, a series of Mann-Whitney U tests were used to determine if significant differences existed between groups in terms of intra-individual variability. No significant differences were found at pre- ($U = 10$, $z = .57$, p = .68), mid- ($U = 8$, $z = 0$, p = 1.00), post-intervention ($U = 8$, $z = 0$, p = 1.00), retention ($U = 7$, $z = -.29$, p = .88), or transfer ($U = 9$, $z = .29$, p = 1.00).

Shoulder Displacement. Two Friedman tests were implemented to determine if significant differences existed across testing sessions (Table 7). The tests revealed that the changes were not statistically significant for the atypical ($\chi^2(4) = 2.64$, p = .66), or the typical group ($\chi^2(4) = 2.4$, p = .66).

Table 7:

Angular Displacement (degrees) of the Shoulder for Both Groups Across Testing Sessions

	Pre-Intervention	Mid-Intervention	Post-Intervention	Retention	Transfer
Atypical Group Mean	52.70	58.76	61.23	62.74	53.42
Atypical Group Std. Deviation	13.79	7.75	5.13	12.20	25.33
Typical Group Mean	45.60	49.32	48.26	52.85	54.35
Typical Group Std. Deviation	6.09	6.80	18.99	25.82	14.42

Next, a series of Mann-Whitney U tests were used to determine if significant differences existed between the groups. No significant differences were found at pre- (U = 6, z = -.58, p = .68), mid- (U = 3, z = -1.44, p = .20), post-intervention (U = 4, z = -1.15, p = .34), retention (U = 4, z = -1.15, p = .34), or transfer (U = 6, z = -.56, p = .68).

The potential changes in intra-individual variability were examined using two Friedman tests (Table 8). The results showed that the differences across testing sessions were not statistically significant for the atypical ($\chi^2(4) = 3.4$, p = .49), or typical group ($\chi^2(4) = 3.4$, p = .49).

Table 8:

Intra-Individual Variability of Angular Displacement (degrees) of the Shoulder for Both Groups Across Testing Sessions

	Pre-Intervention	Mid-Intervention	Post-Intervention	Retention	Transfer
Atypical Group Mean	9.16	8.35	7.53	6.75	9.43
Atypical Group Std. Deviation	.76	2.31	4.46	2.68	2.69
Typical Group Mean	14.11	8.56	8.26	9.08	10.55
Typical Group Std. Deviation	5.73	1.26	.87	2.17	1.93

Next, a series of Mann-Whitney U tests were used to determine if significant differences existed between groups in terms of intra-individual variability. No significant differences were found at pre- (U = 12, z = 1.15, p = .34), mid- (U = 9, z = .29, p = 1.00), post-intervention (U = 7, z = -.29, p = .88), retention (U = 13, z = 1.44, p = .20), or transfer (U = 8, z = .00, p = 1.00).

Elbow Displacement. Two Friedman tests were implemented to determine if significant differences existed across testing sessions (Table 9). Significant differences were found within the atypical group, ($\chi^2(4) = 9.6$, $p < .05$). Further analysis using Friedman pair-wise comparisons revealed significant difference between pre-intervention (M = 42.01°, SD = 14.79°) and transfer (M = 61.49°, SD = 20.96°), ($\chi^2(4) = -3.25$, $p < 0.05$). Significant differences were not found across testing sessions for the typical group, ($\chi^2(4) = 2.20$, p = .69).

Table 9:

Angular Displacement (degrees) of the Elbow for Both Groups Across Testing Sessions

	Pre-Intervention	Mid-Intervention	Post-Intervention	Retention	Transfer
Atypical Group Mean	42.01	46.88	52.02	52.01	61.49
Atypical Group Std. Deviation	14.79	23.77	23.86	26.14	20.97
Typical Group Mean	57.89	62.47	56.08	53.06	58.03
Typical Group Std. Deviation	16.01	5.383	14.89	11.81	12.16

Next, a series of Mann-Whitney U tests were implemented to determine if significant differences existed between groups. No significant differences were found at pre- (U = 12, z = 1.16, p=.34), mid- (U = 10, z = .58, p = .69), post-intervention (U= 9, z = .29, p = 1.00), retention (U = 8, z = .00, p = 1.00) or transfer (U = 7, x = -.29, p = .88).

The potential changes in intra-individual variability were examined with two Friedman tests (Table 10). The results showed that the differences across testing sessions were not statistically significant within the atypical ($\chi^2(4) = 1$, $p = .91$), or the typical group ($\chi^2(4) = 5$, $p = .29$).

Table 10:

Intra-Individual Variability of Angular Displacement (degrees) of the Elbow for Both Groups Across Testing Sessions

	Pre-Intervention	Mid-Intervention	Post-Intervention	Retention	Transfer
Atypical Group Mean	11.71	8.29	10.74	9.65	8.73
Atypical Group Std. Deviation	9.27	3.57	6.31	2.94	2.23
Typical Group Mean	9.78	5.69	7.57	8.87	12.01
Atypical Group Std. Deviation	4.59	1.31	3.29	2.48	4.96

Next, a series of Mann-Whitney U tests were implemented to determine if any significant differences existed between groups in terms of intra-individual variability. The results showed no significant differences at pre- ($U = 2$, $z = -1.73$, $p = .11$), post-intervention ($U = 12$, $z = 1.15$, $p = .34$), retention ($U = 3$, $z = -1.44$, $p = .20$), or transfer ($U = 12$, $z = 1.15$, $p = .34$). However, the difference at mid-intervention between the atypical (M = 8.29°, SD = 3.57°) and the typical group (M = 5.69°, SD = 1.32°) was statistically significant ($U = .00$, $z = -2.31$, $p < .02$).

Wrist Displacement. Two Friedman tests were implemented to determine if significant differences existed across testing sessions (Table 11). The results revealed no statistically significant differences for the atypical, ($\chi^2(4) = 7.4$, $p = .12$) or the typical group ($\chi^2(4) = 4.0$, $p = .41$).

Table 11:

Angular Displacement (degrees) of the Wrist for Both Groups Across Testing Sessions

	Pre-Intervention	Mid-Intervention	Post-Intervention	Retention	Transfer Test
Atypical Group Mean	28.85	24.20	22.37	48.58	24.73
Atypical Group Std. Deviation	7.34	10.10	1.83	21.12	10.23
Typical Group Mean	24.40	12.64	20.75	19.56	23.71
Typical Group Std. Deviation	8.45	4.71	5.28	6.47	11.56

Next, a series of Mann-Whitney U tests were implemented to determine if significant differences existed between groups. No significant differences were found at pre- ($U = 5$, $z = -.87$, p=.49), mid- ($U = 1$, $z = -2.02$, p = .06), post-intervention ($U = 5$, $z = -.87$, p = .49), or transfer ($U = 7$, $z = -.29$, p = .89). However, the difference at retention between the atypical (M = 48.58°, SD = 21.12°) and the typical group (M = 19.56°, SD = 6.47°) was statistically significant, ($U = .00$, $z = -2.31$, $p < .03$).

The potential changes in intra-individual variability were examined with Friedman tests (Table 12). The results showed that significant differences existed across testing sessions for the atypical group ($\chi^2(4) = 9.6$, $p < .05$). Further analysis using Friedman pairwise comparisons revealed that significant differences existed between pre-intervention (M = 10.94°, SD = 3.79°) and transfer (M = 4.24°, SD = 1.86°) ($\chi^2(2) = 3.0$, $p < .05$); between mid-intervention (M = 7.33°, SD = 0.91°) and transfer (M = 4.24°, SD = 1.86°) ($\chi^2(2) = 2.5$, $p < .05$); and between retention (M = 9.08°, SD = 4.35°) and transfer (M = 4.24°, SD = 1.86°) ($\chi^2(2) = 2.25$, $p < .05$). No significant differences existed across testing sessions for the typical group ($\chi^2(4) = 2.6$, p = .63).

Table 12:

Intra-Individual Variability of Angular Displacement (degrees) of the Wrist for Both Groups Across Testing Sessions

	Pre-Intervention	Mid-Intervention	Post-Intervention	Retention	Transfer
Atypical Group Mean	10.94	7.33	6.49	9.08	4.24
Atypical Group Std. Deviation	3.79	.81	4.26	4.35	1.86
Typical Group Mean	6.09	3.59	7.86	5.93	9.88
Typical Group Std. Deviation	3.92	1.58	3.37	1.55	9.62

Next, a series of Mann-Whitney U tests were implemented to determine if any significant differences existed between groups in terms of intra-individual variability. No statistically significant differences existed at pre- (U = 8, z = .00, p = 1.00), mid- (U = 3, z = -1.44, p = .20), post-intervention (U = 11, z = .87, p = .48), retention (U = 8, z = .00, p = 1.00), or transfer (U = 11, z = .87, p = .49).

Temporal Control

Peak Wrist Velocity. Two Friedman tests were implemented to determine if significant differences existed across testing sessions (Table 13). The results revealed no statistically significant differences across sessions within the atypical, ($\chi^2(4) = 7.4$, p = .12), or the typical group ($\chi^2(4) = 2.4$, p = .66). Friedman Pairwise comparisons revealed that the difference in peak wrist velocity between retention and transfer was approaching significance for both the atypical ($\chi^2(2) = 2.15$, p = 0.06), and the typical group ($\chi^2(2) = 2.2$, p = 0.06).

Table 13:

Peak Wrist Velocity (m/s) for Both Groups Across Testing Sessions

	Pre-Intervention	Mid-Intervention	Post-Intervention	Retention	Transfer
Atypical Group Mean	-1.14	-1.29	-1.43	-1.45	-1.09
Atypical Group Std. Deviation	.48	.36	.15	.31	.38
Typical Group Mean	-1.03	-1.04	-1.11	-1.20	-.93
Typical Group Std. Deviation	.29	.15	.20	.22	.20

Next, a series of Mann-Whitney U tests were implemented to determine if significant differences existed between groups. No significant differences were present at pre- (U = 10, z = .58, p = .69), mid- (U = 10, z = .58, p = 69), post-intervention (U = 15, z = 2.02, p = 0.57), retention (U = 11, z = .87, p = .49), or transfer (U = 11, z = .87, p = .49).

Potential changes in intra-individual variability were examined using two Friedman tests (Table 14). The results revealed that the differences were not statistically significant for the atypical ($\chi^2(4) = 1.00$, p = .91), or the typical group ($\chi^2(4) = 6.4$, p = .17).

Table 14:

Intra-Individual Variability of Peak Wrist Velocity (m/s) for Both Groups Across Testing Sessions

	Pre-Intervention	Mid-Intervention	Post-Intervention	Retention	Transfer
Atypical Group Mean	.22	.22	.29	.24	.27
Atypical Group Std. Deviation	.09	.07	.25	.03	.15
Typical Group Mean	.18	.17	.09	.14	.24
Typical Group Std. Deviation	.06	.09	.03	.08	.08

Next, a series of Mann-Whitney U tests were implemented to determine if significant differences existed between groups in terms of intra-individual variability. No statistically significant differences were found at pre- (U = 5, z = -.87, p = .48), mid-intervention (U = 6, z = -.58, p = .69), retention (U = 3, z = -1.14, p = .20), or transfer (U = 8, z = .00, p = 1.00). The difference at post intervention between the atypical (M = 0.29 m/s, SD = 0.25 m/s) and the typical group (M = 0.09 m/s, SD = 0.03 m/s) was statistically significant (U = .00, z = -2.31, $p < .03$).

Relative Time to Peak Wrist Velocity. Two Friedman tests were implemented to test for changes across testing sessions (Table 15). The results revealed no statistically significant differences across sessions within the atypical ($\chi^2(4)$ = .40 p = .98), or the typical group ($\chi^2(4)$ = 9.2, p = .06).

Table 15:

Relative Time to Peak Wrist Velocity (proportion of total movement time) for Both Groups Across Testing Sessions

	Pre-Intervention	Mid-Intervention	Post-Intervention	Retention	Transfer
Atypical Group Mean	.42	.46	.49	.42	.45
Atypical Group Std. Deviation	.05	.08	.13	.04	.04
Typical Group Mean	.48	.44	.43	.42	.47
Typical Group Std. Deviation	.03	.03	.03	.01	.03

Next, a series of Mann-Whitney U tests were implemented to determine if significant differences existed between groups. No significant differences were found at pre- (U = 12, z = 1.16, p = .34), mid- (U = 7, z = -.29, p = .88), post-intervention (U = 8, z = .00, p = 1.00), retention (U = 9, z = .29, p = 1.00), or transfer (U = 10, z = .58, p = .68).

Potential changes in intra-individual variability were examined using two Friedman tests (Table 16). The results revealed that the differences between sessions were not statistically significant within the atypical group, ($\chi^2(4) = 4$, p = .41). Significant differences were found within the typical group, ($\chi^2(4) = 13$, p < .01). After conducting Friedman pairwise comparisons, it was determined that significant difference existed between pre-intervention (M = 0.06, SD = 0.02) and mid-intervention (M = 0.03, SD = 0.01) ($\chi^2(2) = 3.25$, p < .05).

Table 16:

Intra-Individual Variability of Relative Time to Peak Wrist Velocity (proportion of movement time) for Both Groups Across Testing Sessions

	Pre-Intervention	Mid-Intervention	Post-Intervention	Retention	Transfer
Atypical Group Mean	.06	.06	.10	.03	.05
Atypical Group Std. Deviation	.01	.06	.14	.01	.02
Typical Group Mean	.06	.03	.03	.04	.05
Typical Group Std. Deviation	.02	.01	.02	.01	.02

Mann-Whitney U tests were implemented to determine if significant differences existed between groups in terms of intra-individual variability. The difference between groups were not significant at pre- (U = 10, z =.58, p = .68), mid- (U = 6, z = -.58, p = .68), post-intervention (U = 5, z = -,87, p = .48), retention (U = 7, z = -.29, p = .88), or transfer (U = 8, z = .00, p = 1.00).

Discussion

Movement Effectiveness

As expected, when between-group comparisons were made, the results revealed that the typical children caught significantly more balls than the atypical children prior to the intervention. This finding is in-line with earlier research which implemented a one- or two-handed task under similar conditions (Asmussen et al., 2014a; Asmussen et al., 2014b; Astill & Utley, 2006; Przysucha & Maraj, 2014; Utley et al., 2007). Thus, the present study supports the notion that by 10-11 years of age, typically functioning children have developed the ability to catch one-handed (Savelsbergh & van Santvoord, 1989). Although the children in both groups were nearly identical in age, the results confirmed that developmentally, those suspected of having DCD are not able to generate effective one-handed catching actions (Asmussen et al., 2014b).

Overall, task-specific intervention approaches have been shown to produce positive improvements in motor performance in children with DCD (Smits-Engelsman et al., 2012). More specifically, in the context of variable type of practice, such effects have been seen in different populations across different fundamental movement skills (Van Rossum, 1990). Thus, it was hypothesized that the children in both groups would demonstrate improvements in movement effectiveness, as inferred by an increasing number of balls caught across sessions. The results did not confirm this hypothesis, as no significant changes were found for either group. However, when examining the results individually, it appears that a person by treatment effect has emerged within the respective groups.

The atypical group began the intervention with a mean movement effectiveness of 0%, indicating that none of the children were able to catch on any of the attempts presented to them. As the intervention progressed, it can be seen that participant 1 improved his catching ability, as inferred from an increase in movement effectiveness from 0% at pre-intervention to 100% at retention and transfer (Figure 6). Participant 2 showed improvements from 0% at pre-intervention to 20% at retention, and 60% at transfer. Participant 4 also improved considerably from 0% movement effectiveness at pre-intervention to 100% at post-intervention. However, these improvements did not persist to retention and transfer, where movement effectiveness was 0% and

20% respectively. Finally, participant 3 showed no improvements. He began the intervention with a 0% movement effectiveness, and completed the intervention with 0% at both retention and transfer. Thus as evident, the participants responded to the intervention in different ways.

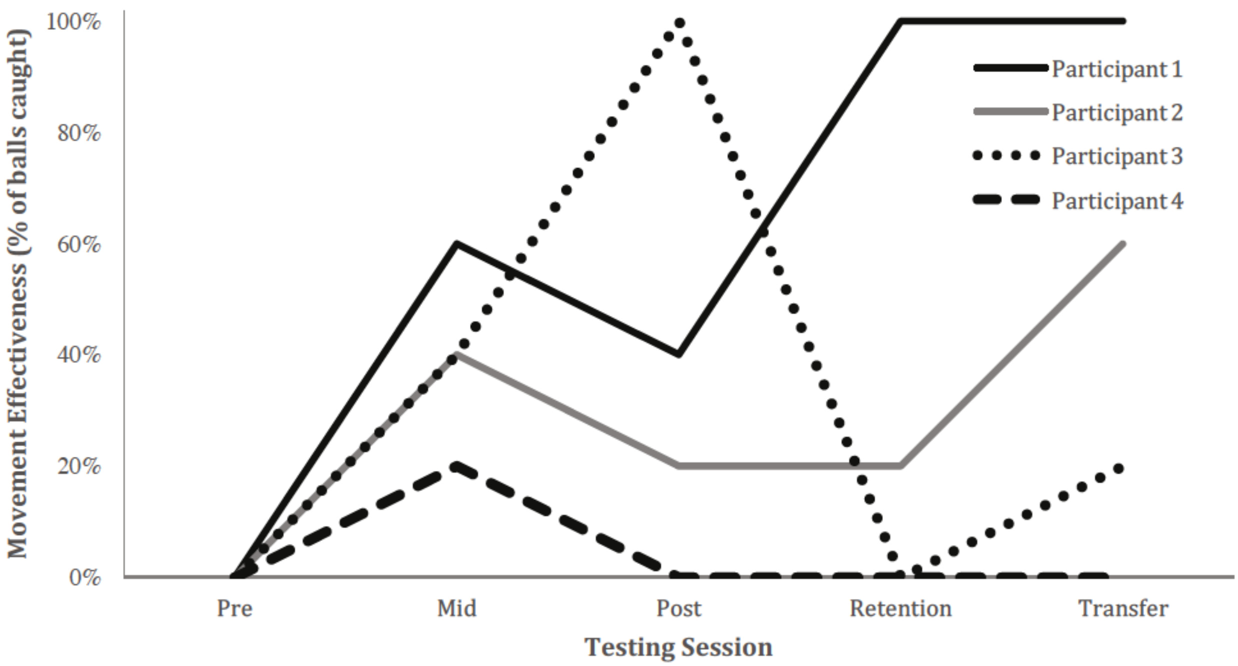


Figure 6: Movement effectiveness (% of balls caught) of atypically functioning children, across testing sessions.

The fact that the intervention did not affect the entire group equally is not uncommon, especially when considering the heterogeneity of atypically developing individuals. One plausible explanation for the person by treatment effect is that the response to variable type of practice may be dependent on individual factors such as motivation level (Hall, 1988), previous experience (Del Rey, Wughalter, & Whitehurst 1982), or degree of motor impairment. Motivation level was not measured in the current study and it is difficult to control for from the experimental standpoint. Earlier research has shown that children with DCD experience lower self-esteem and increased stress when performing new motor tasks, which hinders performance and therefore the ability to learn the skill is jeopardized (Hall, 1988; Rasmussen & Gillberg, 2000). Thus, it is plausible that less demanding approaches (e.g., constant practice) may be more beneficial for at least some of the participants. While some studies have found that experienced performers benefit the most from variable type of practice (Conell, 1984; Del Rey et al., 1982), they have also shown that this approach may elicit improvements in novice performers, even if those changes are less pronounced (e.g., Goode, 1986; Whitehurst, 1981). Consequently, it is not likely that certain individual's inexperience with the task would explain the lack of improvements. Instead, it is much more likely that the person by treatment effect emerged due to differences in the degree of motor impairment. Even though the sample was limited to children scoring below the 15th percentile on the MABC-2 test, there was nonetheless differences in total impairment score and score on various tasks. It is possible that certain participants were more severely impaired than others in their ball skills ability, and thus could not demonstrate improvements in movement effectiveness due to an inability to perform the task.

It was expected that improvements would also occur within the typical group (Del Rey et al., 1982; Van Rossum, 1990). Of the 4 participants, only participant 5 demonstrated a notable improvement in his movement effectiveness as a result of the intervention (see Figure 7). Participant 5 improved from 20% effectiveness at pre-intervention to 80% at retention and 100% at transfer. Participant 6 showed a marginal decrease in performance from pre-intervention (80%) to retention (60%) but was able to catch 100% of the balls delivered at transfer. Participant 7 also showed a slight decrease in catching performance from pre-intervention (100%) to retention (80%), however caught 100% of the balls on the transfer test. Finally, participant 8 showed no change in performance from pre-intervention (100%) to retention (100%), but was less effective on the novel transfer task (80%). Thus, the most likely explanation for these results is the fact that children exhibited high movement effectiveness at the beginning of the study (M = 75%, SD = 37.85%).

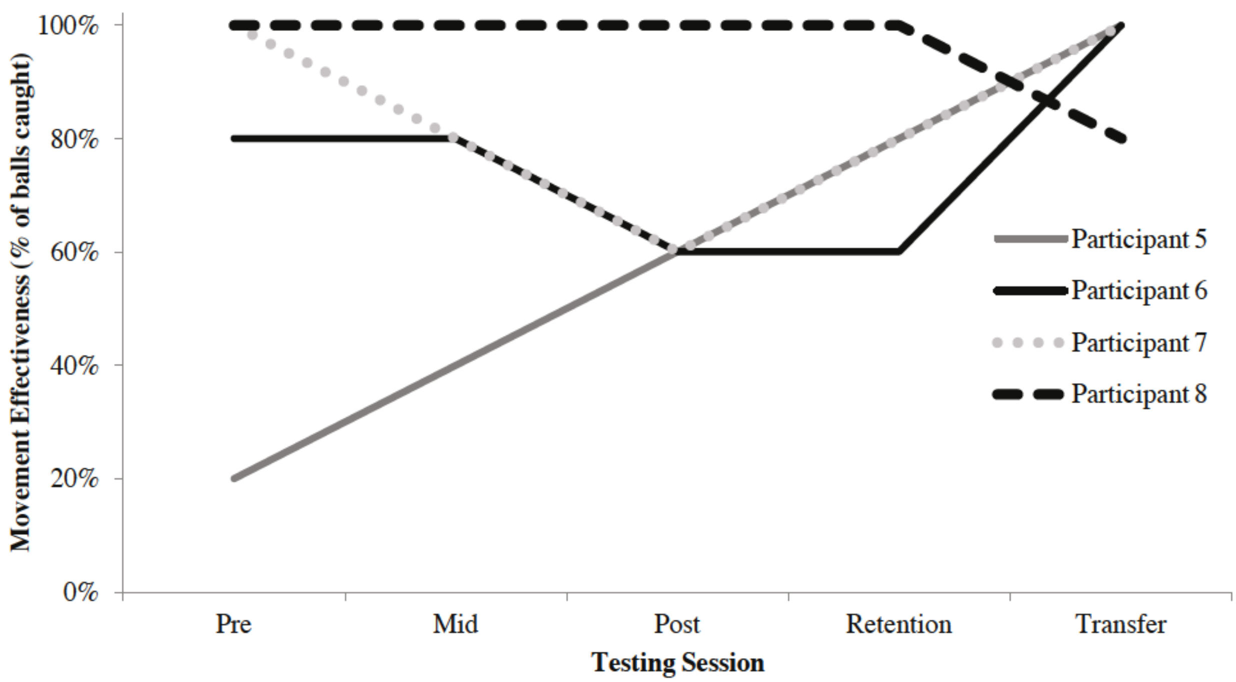


Figure 7: Movement effectiveness (% of balls caught) of typically functioning children, across testing sessions.

The method of measuring catching performance likely suffered from a ceiling effect within the typical group and a floor effect within the atypical group. Conceptually, when an instrument/measure proves to be insensitive to meaningful changes in performance, a floor/ceiling effect occurs (Andresen, 2000). In this case, the task was initially too simple for the typical group and too difficult for the atypical group for the performance variable (movement effectiveness) to capture any meaningful changes in the catching ability. It is therefore recommended that movement outcome be expressed not just in terms of the number of catches, but also in regards to the changes in ability to contact the ball, particularly when analyzing the changes in the atypical group. Additionally, it is also recommended that a lower degree of CI be used to reduce the difficulty of the intervention sessions. This can be accomplished either by reducing the number of velocities practiced, or by reducing the frequency at which the velocity is manipulated. In regards to the typically developing children, it is plausible that if the initial sampling method was focused on less skilled catchers, the changes in their performance may also be observed. As a result, it remains unclear if this type of practice affects typically developing children who are not experts at the task.

Intra-Limb Coordination

Shoulder-Elbow Relations. Previous research has shown that typically functioning children have a high degree of association between these two joints, with a coefficient of approximately 0.77 when performing a similar one-handed catching task (Mazyn et al., 2006). The present results pertaining to the typical group are consistent with the previous findings (M = 0.73, SD = 0.12 at pre-intervention). On the other hand, the atypical group exhibited considerably less coupling as inferred from lower a ICC value (M = 0.49, SD = 0.23 at pre-intervention). This finding is consistent with earlier research, which showed that typically functioning children displayed strong relations between the two joints, while atypical children did not (Przysucha & Maraj, 2013). The tight coupling observed within the typical group, and correspondingly high ICC values, indicated that both joints were actively involved throughout the movement (Przysucha & Maraj, 2014).

However, the findings from the current study are inconsistent with recent research carried out by Asmussen and colleagues (2014b), where atypically and typically functioning children performed a similar one-handed catching task. Their results demonstrated that atypically developing children had significantly higher correlation coefficients between the shoulder and elbow joints than typically functioning children, while the present study demonstrated the opposite. It is plausible that the differences in the values of ICC coefficients are due to the imposed task constraints. In the study by Asmussen and colleagues (2014b), the tennis balls were projected above the dominant shoulder of the participant, while here, the ball was projected at the midline of the participant at approximately chest height. This lower point of contact reduces the amount of flexion that is necessary to occur at the shoulder, and thereby alters the ICC values. Thus, the differences between the tasks may account for the discrepancy in the findings.

In order to confirm the inferences emerging from the outcome measures, angle-angle plots were also examined. However, the inferences emerging from the relevant plots (Figures 2 and 3) failed to support the differences between groups in their intra-limb coordination at the shoulder-elbow. Although the joints were coupled to a different degree, both the atypical and typical group tended to initiate the catching movement by flexing the elbow, followed by flexion at the shoulder (Figures 2 and 3). This demonstrated that the atypical and typical children had analogous coordinative tendencies and solved the degrees of freedom problem in a similar way (Assmussen et al., 2014b). The angle-angle plots (Figures 2 and 3) also demonstrated that, with the exception of participant 3, the atypical group was comparable to the typical group in terms of the stability of the movement pattern. However, it should be pointed out that despite the similarities in coordination, there was a considerable difference in the groups' ability to catch the ball. This may indicate that coordination of the shoulder-elbow is not essential to successful performance of the one handed catch, as the similarities at the organizational level did not coincide with the functional outcomes (Asmussen et al., 2014b).

Variable type of practice is directed at strengthening the schema and improving parameterization of movement control. Thus, it was hypothesized that neither the atypical or typical children would demonstrate any significant changes in mean ICC or intra-individual variability values. The results confirmed this hypothesis, as no significant changes occurred across testing sessions in terms of the degree of coupling between the joints. The same was true for intra-individual variability of the ICC values. The atypical group remained relatively similar across pre- (M = .49, SD = .15), mid- (M = .44, SD = .24), post-intervention (M = .40, SD = .14), and retention (M = .47, SD = .19). The typical group also remained relatively similar across pre- (M = .73, SD = .12), mid-(M = .84, SD = .08), post-intervention (M = .82, SD = .05), and retention (M = .71, SD = .21). However, individual analysis of the angle-angle plots suggested that, in terms of intra-individual variability, there were notable changes within the atypical group (Figure 2). Participants 1, 2, and 4 became more consistent in their coordination of the shoulder-elbow joint pair during the 6-week intervention. On the other hand, the typical group began the intervention relatively stable, and did not demonstrate substantial changes in stability of the movement pattern. The decrease in variability over time within the atypical group is an indication that motor learning has occurred, and that these individuals are in an early stage along the motor learning continuum (Newell, 1985). At this point, no other studies have demonstrated changes in coordination in children with DCD resulting from variable type of practice. When the transfer test was examined, inferential statistics and angle-angle plots confirmed the hypothesis as both groups generalized the original movement pattern to the new task demands. This is an indication that rather than selecting a novel motor program, the schema has parameterized the spatial-temporal aspects of the GMP to accomplish the task.

In summary, the results confirmed that atypically functioning children did not coordinate the shoulder-elbow to the same degree as their typically developing peers when performing interceptive tasks (Asmussen et al., 2014a; Asmussen et al., 2014b; Przysucha & Maraj, 2013). However, qualitative analysis of the angle-angle plots (Figures 2 and 3) demonstrated a different pattern of results as considerable similarities in the emerging movement patterns were evident. Furthermore, both the intra-individual variability of ICC values and the corresponding angle-angle plots showed that the groups were not considerably different in the stability of their respective movement patterns. Additionally, at the group level, as expected variable practice did not significantly alter the movement patterns or the degree of stability within the atypical or typical groups.

Elbow-Wrist Relations. Previous research has shown that atypically functioning children exhibit weak coupling of the elbow-wrist as compared to typically developing children (Asmussen et al., 2014a; Przysucha & Maraj, 2013). The results from the current study only partially supported earlier research. At retention, the atypical group exhibited significantly weaker coupling (M = .48, SD = .07) than the typical group (M = .79, SD = .16). However, this distinction was only present at retention, so inferences regarding differences in the degree of coupling should be treated with caution. Additionally, no significant differences were found between groups in the degree of stability of the movement patterns, as inferred from intra-individual variability of ICC values. This finding was contrary to earlier research by Asmussen and colleagues (2014b), but in support of research carried out by Przysucha and Maraj (2013).

Qualitative analysis of the relevant angle-angle plots demonstrated that although similar in the degree of association between the joints, there were meaningful differences in the emerging movement patterns. As depicted in Figures 4 and 5, the atypical group showed a tendency to flex and extend the wrist throughout the movement. This is a movement pattern that has been observed in earlier research (Przysucha & Maraj, 2014). On the other hand, the typical group exhibited substantially fewer adaptions as the participants tended to gradually extend the wrist until ball contact. It is assumed that the movement used by the typical group is the more functional one, as it coincided with high movement effectiveness. The repeated flexion and extension of the wrist employed by the atypical children likely resulted in less than optimal orientation of the catching hand in space to allow for successful interception. However, the angle-angle plots demonstrated a comparable degree of stability in the movement pattern across trials, thus indicating that although different both patterns were relatively stable. Thus, collectively the results suggested that although the atypical group employed a qualitatively different movement pattern than the typical group, they exhibited a similar degree of coupling between the joints, and executed it with similar consistency. Consequently, it appears that children with DCD are consistently “wrong”, as they exhibited a less than optimal coordination mode between the elbow and the wrist, and they do not tend to alter that action across trials. Thus, conceptually, it appears that children with DCD either have difficulties programming the emerging coordination pattern, or alternatively, experience difficulties at the response selection stage choosing the appropriate motor program to accomplish the task.

In terms of changes across the sessions, neither group demonstrated significant differences in mean values or intra-individual variability of ICC values from pre-intervention to retention. Qualitative analysis of the corresponding angle-angle plots (Figures 4 and 5) to a large extent supported these findings. Participants in both the atypical and typical groups appeared to demonstrate some changes in the general movement pattern from pre-intervention to retention, which is contrary to what was expected given the goal of variable type of practice (Schmidt, 1975). When presented with the novel transfer task, inferential statistics and analysis of the angle-angle plots supported the conceptual frame work as both groups used the same qualitative movement pattern and exhibited similar consistency across trials as they did at retention. This is evidence that both groups used the same GMP on both retention and transfer and generalized their movement to the new ball speed and trajectory.

Summary of Intra-Limb Coordination. The results of the current study were mixed when quantitative and qualitative data were analyzed. Quantitative analysis demonstrated that the atypical children exhibited weaker coupling between the shoulder-elbow and similar coupling between the elbow-wrist, as compared to the typical children. However, examination of the relevant angle-angle plots revealed that the atypical children used qualitatively similar movement patterns at the shoulder-elbow, but not the elbow-wrist. This is consistent with proximal-distal pattern of development (Asmussen, 2014b; Jensen et al., 1995; Przysucha & Maraj, 2013). This difference in the emerging action at the elbow-wrist coincided with differences in movement effectiveness. Consequently, it appears that optimal coordination of the elbow-wrist is essential in successful one-handed catching (Asmussen et al., 2014b).

Spatial Control

Between Group Differences. It was expected that the groups would be significantly different in spatial control of the one-handed catch. The current literature suggested that children with DCD exhibit greater avoidance reaction (i.e. more hip extension) (Przysucha & Maraj, 2010; Sekaran et al., 2012), increased shoulder flexion (Sekaran et al., 2012; Utley, Steenbergen, & Astill, 2007; Van Waelvelde, De Weerdt, De Cock, & Smits Engelsman, 2004), decreased angular displacement of the elbow, and increased wrist displacement when catching (Sekaran et al., 2012). The findings of the current study did not support the aforementioned differences. The only difference was evident at the wrist during the retention test, where the atypical children exhibited significantly greater range of motion than the typical group. Considering that this difference was found only at one of the testing sessions, it appears that overall both groups exhibited the same degree of spatial adaptions. It was also expected that the atypical children would exhibit greater variability in spatial control when compared to the typical children (Henderson et al., 1992; Przysucha & Maraj, 2014; Sekaran et al., 2012). Contrary to previous research, no significant differences were found at the hip, shoulder, or wrist (Sekaran et al., 2012). The differences between groups emerged exclusively in spatial adaptions of the elbow at mid-intervention, where the atypical group was less stable across trials. However, since the difference in stability of elbow angular displacement between the atypical group (M = 8.29°, SD = 3.57°) and the typical group (M = 5.69°, SD = 1.32°) was significant only at mid-intervention, and the difference was marginal, once again it could be concluded that collectively no meaningful differences existed between the groups. However, since considerable differences between the groups existed in the number of balls caught, these findings warrant caution from the conceptual standpoint (Newell, 1985). It is speculated that possibly the functional difficulties exhibited by children with DCD stem from less than optimal control of more subtle changes to hand position (e.g., position of the fingers/palm) rather than the adaptions of the elbow and wrist joints (e.g., Deconinck et al., 2006).

Within Group Differences. It was hypothesized that both groups would increase the amplitude of angular displacement in the joints of the catching arm, and exhibit less avoidance reaction (i.e. less hip extension) following the intervention. This hypothesis was in line with earlier research which demonstrated that improvements in catching proficiency coincided with similar spatial adaptations (Mazyn et al., 2007; Utley et al., 2007). Functionally, these adaptations would allow the performer to catch the ball further from his/her body. The current data did not support such changes, as there were no significant differences evident from pre-intervention to retention for either group at any of the measured joints. In terms of intra-individual variability across sessions, previous research has shown that as a learner acquires an open skill, such as this one, execution of the movement becomes more consistent across trials (e.g. Button, MacLeod, Sanders

& Coleman, 2003; Mazyn et al., 2007). Thus, it was hypothesized that the children in both groups would demonstrate a reduction in intra-individual variability. The results did not support the hypothesis, as neither group became more consistent in their control of the spatial variables from pre-intervention to retention. Given that the children are likely at different stages of motor learning, these findings are conceptually in line with Newell's (1985) model. The failures exhibited by the atypical group to make the desired adaptations at the measured joints is further indication that they have yet to progress to a stage of motor learning where they can optimally control the spatial components of the movement. The typical children, on the other hand, were already highly skilled in their control of the measured joints, and thus no improvements were necessary.

When the performance at the transfer test was examined, it was expected that significant adaptations would occur in the spatial domain. Previous research has demonstrated that when ball velocity is decreased, performers will adapt to intercept the ball farther from the body (Mazyn et al., 2006). A significant difference was found for the atypical group, in regards to mean angular displacement of the elbow between pre-intervention and transfer. The atypical group significantly increased angular displacement of the elbow at transfer ($M = 61.49°$, $SD = 20.97°$), as compared to pre-intervention ($M = 42.01°$, $SD = 14.79°$), and achieved ball-hand contact farther away from the body. Although this was an expected adaptation, it did not coincide with improved movement effectiveness, or the expected adaptations at the other joints. The change demonstrated by the atypical group can likely be attributed to the original task being too difficult to be performed successfully. It is plausible that the positioning of the hand closer to the body at the earlier testing sessions was due to not having enough time to move the elbow though a large a range of motion (Przysucha & Maraj, 2014). When presented with the slower ball velocity, and therefore reduced time constraints, the atypical children could fully execute the movement and contact the ball farther away from their body. On the other hand, the typical group did not demonstrate any differences in mean values of spatial control measures between the transfer test and the previous testing sessions. Thus, the typical children performed the novel task nearly identically to the previous testing conditions despite the reduced time constraints and altered ball trajectory. Possibly, the change in the environmental/task constraints was not substantial enough to induce any spatial adaptations (Przysucha & Maraj, 2014). Thus, the typical children were able to maintain movement functionality without making any changes to the spatial elements of the required actions.

It was also expected that significant adaptations would be evident in intra-individual variability of angular displacement at transfer. Earlier research by Mazyn and colleagues (2006) demonstrated that when temporal constraints decrease, there is a marked improvement in spatial accuracy (i.e. decreased variability) when compared to catching attempts at faster velocities. Thus, intra-individual variability of spatial control was expected to decrease when presented with the reduced ball velocity at transfer. Within the atypical group, the only adaptations found was for variability of wrist action between post-intervention ($M = 6.49°$, $SD = 4.35°$) and transfer ($M = 4.24°$, $SD = 1.86°$). However, a change of 2° in displacement of the wrist would not contribute to a considerably different orientation of the catching hand, and should not be considered as indicative that adaptations to the novel constraints has occurred. As for the typical group, there were no adaptations made under the novel constraints. This indicates that the typical children were as consistent at controlling the one-handed catch under the novel task constraints as they were under the previous testing conditions. As previously pointed out, it is likely that the changes in the constraints were not strenuous enough for any adaptations to be required (Przysucha & Maraj, 2014).

Summary of Spatial Control. Collectively, the results failed to demonstrate that any changes in spatial control have occurred from pre-intervention to retention for either group. Furthermore, neither group made meaningful spatial adaptations at transfer, contrary to previous research in the context of changing ball velocities (Mazyn et al., 2007). A possible explanation is that the atypical children have not advanced to a stage of motor learning where adaptations in spatial control will occur (Newell, 1985). On the other hand, the level of difficulty implemented during the intervention and transfer tasks was not demanding enough for the typical children to require any adaptations. The results also did not support the current literature regarding the differences in spatial control between children with DCD and typically functioning children (Asmussen et al., 2014a; Sekaran et al., 2012).

Temporal Control

Between Group Differences. It was expected that the atypical children would execute the movement slower than the typical group, as inferred by peak wrist velocity. This is in line with the "general slowness" hypothesis regarding this population's performance of ballistic, goal directed actions (e.g. Henderson et al., 1992). However, the results suggested that both groups were equally as fast when moving the end-effector. Thus, these findings failed to support the initial hypothesis, and are inconsistent with recent research which showed that children with DCD moved slower (Sekaran et al., 2012), as well as earlier research which showed that children with DCD moved faster as compared to their typically functioning peers (Astill & Utley, 2008). The findings are however consistent with a study by Przysucha and Maraj (2014), who showed no difference in movement velocity between children with and without DCD when a ball was projected at a similar speed (6.8 m/s vs. 7 m/s here). Therefore, it does not appear that control of peak wrist velocity was a limiting factor in catching performance for the atypical children.

When relative time to peak wrist velocity was examined, it was expected that significant differences would exist between groups. Conceptually, relative time to peak wrist velocity represents the proportion of the movement time that was spent achieving peak wrist velocity (i.e. the acceleration phase). Although previous research has not explicitly examined relative time to peak wrist velocity in children with DCD, a study by Przysucha, Taylor, and Weber (2007) has demonstrated a tendency of over-reliance on preprogrammed control in these children. It was speculated by the researchers that this over-reliance may translate into failure in tasks that emphasize precise positioning of limbs in space and time, such as interceptive tasks. As a result, it was expected that the atypical children would achieve peak wrist velocity relatively later in the movement than the typical children, indicative of reliance on preprogrammed control. The results did not support this hypothesis. Both groups achieved peak wrist velocity, and transitioned from the acceleration to the homing phase of the catch, at relatively the same time. This suggested that the atypical children did not control the acceleration phase of the catching movement differently than the typical children.

In terms of differences in intra-individual variability, it was expected that the atypical group would exhibit less stability of both peak wrist velocity and relative time to peak wrist velocity (Henderson et al., 1992). Generally, there were no differences in intra-individual variability of peak wrist velocity, as inferred by the results at 4 of the 5 testing sessions. Significant difference was only evident at post-intervention between the atypical (M = .29 m/s, SD = .25 m/s) and typical group (M = .09 m/s, SD = .03 m/s). Thus, these findings did not support the stated hypothesis. The results are however consistent with the findings by Przysucha & Maraj (2014), who demonstrated a comparable degree of consistency in movement velocity across trials between children with and without DCD. When intra-individual variability of relative time to peak wrist velocity was examined, the results did not support the hypothesis, and suggested that the atypical children were as stable as the typically functioning individuals. However, the inferences emerging from these findings should be taken with caution. Although there were no differences in temporal control during the acceleration phase of the catch, there was nonetheless considerable differences in the number of successful catches. It may be that the variables chosen in this study were not essential to catching performance under the imposed constraints at the testing sessions. It is therefore speculated, as it was the case with spatial control, that the more pronounced differences between groups would emerge at faster ball velocities, or if the actions associated with fine-tuning of the hand prior to ball hand-contact were delineated. This is in line with previous research (Deconinck et al., 2006; Przysucha & Maraj, 2013), however given that these issues were not explicitly measured in the current study, such inferences remain speculative.

Within Group Differences. It was hypothesized that both groups would demonstrate changes in temporal control across testing sessions. Earlier research involving novice performers has shown that an increase in peak velocity of the hand accompanied an increase in performance (Mazyn et al., 2007). Additionally, intra-individual stability in temporal control variables is related to skilled performance (Laurent et al., 1994). Therefore, it was expected that the children in both groups would exhibit a higher peak wrist velocity and lowered intra-individual variability of peak wrist velocity across trials as the intervention progressed. The results failed to support the hypothesis as neither group demonstrated an increased velocity of the wrist from retention to transfer, or in the degree of consistency in peak velocity across trials.

Successful one-handed catching emerges when the performer has adequate time to fine-tune the movement in relation to the characteristics of the ball flight (Mazyn et al., 2007). This can be achieved by increasing the time available to decelerate the wrist and make corrections prior to ball-hand contact (Jeannerod, 1981). Therefore, it was expected that as the performers become more skilled the transition from pre-programmed component of the movement to the sensory-based sub movement would occur earlier in the action. This adaptation would be evident by a smaller value of relative time to peak wrist velocity across sessions. Also, enhanced performance was expected to coincide with greater stability in relative time to peak wrist velocity across trials. The results did not support these hypotheses, as neither group adapted relative time to peak wrist velocity, and only the typical group demonstrated significant changes in stability. The typical group exhibited a decrease in variability from pre- (M = .06, SD = .02) to mid-intervention (M = .03, SD = .01), however no further differences existed, meaning they demonstrated similar stability at retention/transfer as compared to their baseline measures. Therefore, no inferences should be made regarding improvements in stability of temporal control for either group.

Considering that contextual interference within the practice sessions was achieved through the manipulation of ball velocities, participants were given the opportunity to improve parameterization of the temporal features of the movement. Thus, when the transfer test was administered, it was expected that both groups would adapt peak wrist velocity to the slower ball velocity. The decrease in peak wrist velocity from retention to transfer was approaching significance for both the atypical and the typical groups, thus it appears that the desired adaptions did take place. The individual analysis revealed that all four atypically functioning individuals decreased their peak wrist velocity in response to the slower ball at transfer, as did 3 of the 4 typical children. This adaptation is consistent with adult-like performance of one-handed catching under similar conditions (Laurent et al., 1994; Mazyn et al., 2007). It was also expected that both groups would adapt the relative time to peak wrist velocity under the novel constraints. Research by Laurent and colleagues (1994) demonstrated that skilled performance of the one-handed catch involved a shift in relative time to peak wrist velocity as ball speed changed. When presented with increasing ball speeds, the time to peak wrist velocity remained unchanged while the deceleration phase was shortened, meaning that peak wrist velocity occurred relatively later in the movement (see Figure 8). Conversely, peak wrist velocity occurred relatively sooner in the movement at slower ball velocities. Therefore, it was expected that the children in both groups would exhibit a lower value for relative time to peak wrist velocity in response to the slower incoming ball. However, neither group made the expected adaptation, contrary to previous research (Laurent et al., 1994; Mazyn et al., 2006).

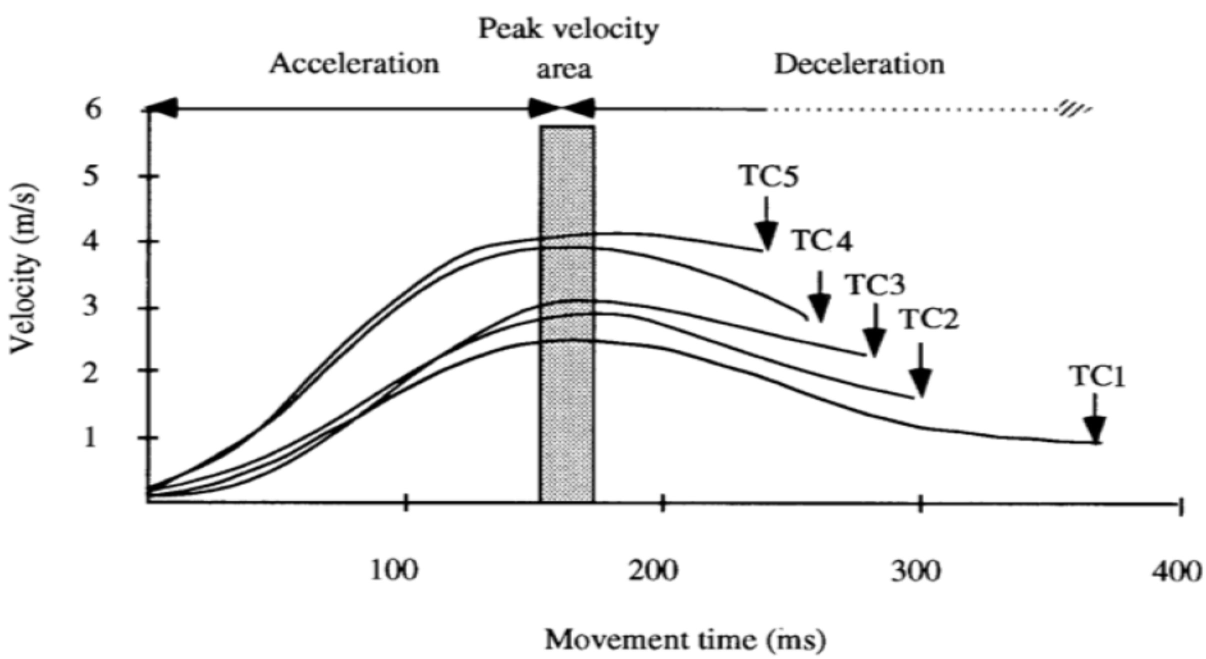


Figure 8: Velocity profile (m/s) of the wrist for one participant under changing temporal constraints (Laurent et al., 1994).

When individual performance of the atypical children was examined, it was evident that there were considerable intra-group differences in terms of the adaptations made at the transfer test. Two children (participants 1 and 2) slightly decreased the relative time to peak wrist velocity thus demonstrating the desired adaptation which allowed for more time to decelerate the wrist and make necessary adjustments to its trajectory (see Figure 9).

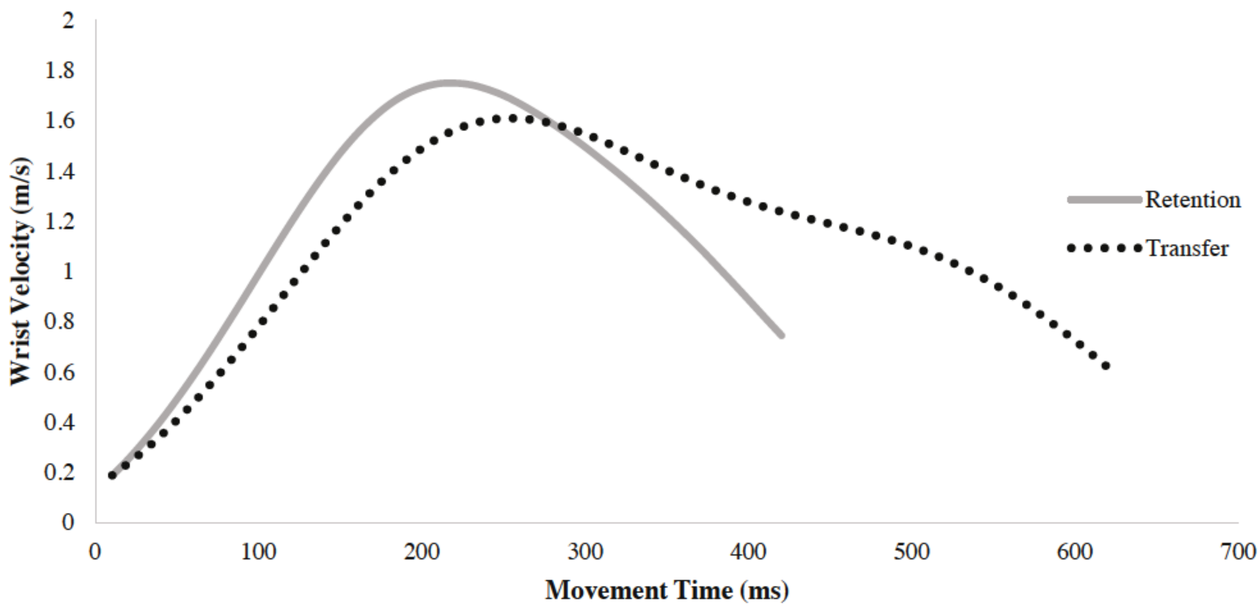


Figure 9: Velocity profiles (m/s) of the wrist of the same atypical child (participant 2) for one attempt at retention and transfer.

Participants 3 and 4, however did not make the expected adaptations as peak wrist velocity occurred at nearly the same time at both retention and transfer, while there was almost no difference in total movement time. Therefore, relative time to peak wrist velocity was invariant across the conditions (Figure 10).

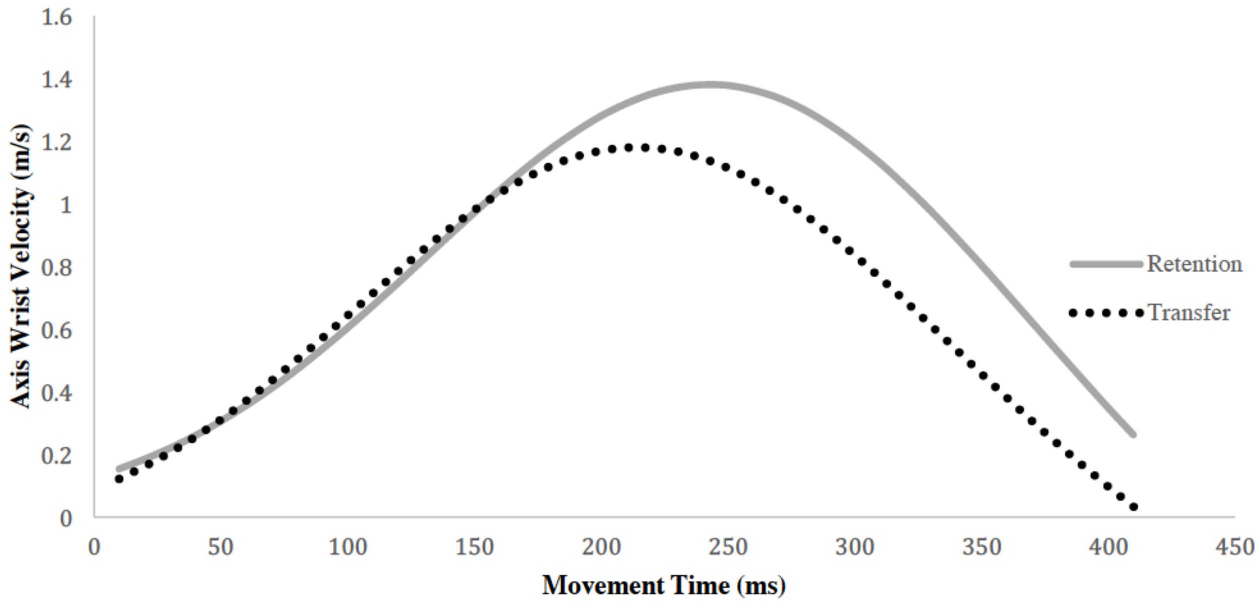


Figure 10: Velocity profiles (m/s) of the wrist of the same atypical child (participant 3) for one attempt at retention and transfer.

At the transfer test, the incoming ball velocity was reduced from ~7m/s to ~3.96m/s, and the distance of ball release was decreased from 5 meters to 4 meters. Thus, the time available to execute the movement increased from ~0.71 seconds to ~1.01 seconds. In order for movement time to remain unchanged under these conditions, the movement must have been initiated later. Thus, some atypical children (participants 3 and 4) simply delayed movement onset and reduced wrist velocity without altering the relative time to peak wrist velocity. This adaptation (Figure 10) is likely the result of the imposed task demands. The transfer test involved bouncing the ball to the participant, rather than it being ejected from the tennis ball machine. A plausible explanation is that some participants did not initiate the movement when the ball exited the examiner's hand, but waited until the ball bounced off the ground. This was confirmed through qualitative analysis of the raw video.

When the individual velocity profiles of the typical children were examined, there was not considerable intra-group differences in regards to the adaptations emerging at the transfer test. The performance by participant 6 (Figure 11) is representative of the adaptations exhibited by participants in the typical group. The results indicated that the typical children simply delayed movement onset, reduced peak wrist velocity, and maintained relative time to peak wrist velocity unchanged. It is also plausible that they consciously delayed movement onset until the instance when the ball was bounced, expecting that the trajectory would be altered. This behaviour coincided with high movement effectiveness, and thus may be regarded as the appropriate response to the novel task demands.

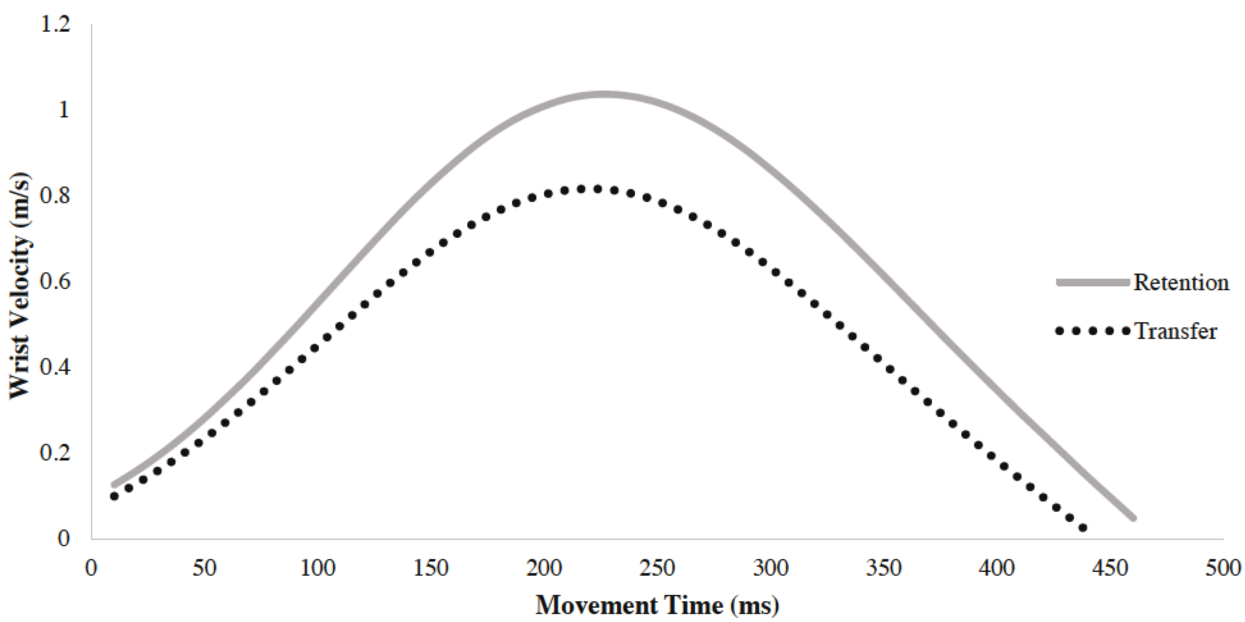


Figure 11: Velocity profiles (m/s) of the wrist of the same typical child (participant 6) for one attempt at retention and transfer.

Summary of Temporal Control. Overall, the results failed to show the expected changes in temporal control that should occur with practice (Mazyn et al., 2006). The lack of changes may provide further evidence that the atypical children were still at the first stage of motor learning involving the refinement of the coordinative pattern rather than learning to control it (Newell, 1985). Furthermore, although the performance of both groups on the transfer task was not consistent with previous research (e.g. Laurent et al., 1992; Mazyn et al., 2007), the analysis of the individual velocity profiles indicated that this might have been the appropriate adaptation given the task demands. Nevertheless, inferences regarding improvements in parameterization should be made with caution, as the adaptations did not result in higher catching success, particularly within the atypical group. Thus, although some learning has likely taken place, further adaptations were required to improve catching performance. The results also failed to support earlier research regarding the differences in temporal control between children with and without DCD (Astill & Utley, 2008; Sekaran et al., 2012).

Conclusion

The primary purpose of the study was to investigate the effect of variable type of practice on atypically functioning children suspected of having DCD. Conceptually, variable type of practice is directed at strengthening the schema, which would allow for more efficient control and improved parameterization of the GMP. Thus, it was expected that the children in both groups would improve movement effectiveness across sessions, which would coincide with no substantial changes in coordination and various adaptations in spatial and temporal control.

The results demonstrated that 3 of the 4 atypical children did not improve movement effectiveness as a result of the intervention. The same was true for the typical group, although their effectiveness was high to begin with. This may be due to ceiling effect within the typical group, and a floor effect within the atypical group. Generally, the task was too difficult for the atypical children and likely too simple for the typically functioning individuals, as inferred by their near perfect baseline performance. Consequently, no improvements in catching ability were captured.

When coordination across sessions was examined, as expected, no changes occurred in the degree of coupling between joints, or in intra-individual stability across trials. However, individual analysis of the relevant angle-angle plots suggested that some of the children within the atypical group improved stability. Thus, for some participants, changes in the nature of movement coordination may have taken place. When changes in spatial and temporal control were examined from pre-intervention to retention, the results demonstrated that neither group made the expected improvements in this aspect of motor organization.

At transfer, the ICC values and the angle-angle plots suggested that both groups used the same GMP to accomplish the new task, and therefore that the schema was parameterizing the spatial-temporal aspects of the movement. Both groups made adaptations in the temporal domain (Laurent et al., 1994), but, contrary to previous research (e.g. Mazyn et al., 2006), failed to make adaptations in the spatial domain. Although the atypical children responded to the transfer task in a similar way as their typically functioning peers, inferences regarding improved parameterization should be made with caution. These changes emerged at the statistical level but they did not coincide with improvements in movement effectiveness, particularly within the atypical group. This may indicate that although some learning has taken place, the novel task required further adaptations in order to place the hand in the correct position in space to intercept the ball.

The secondary purpose was to identify differences between the groups in performance of the one-handed catch. The results are consistent with earlier research that children with DCD are less effective at catching one-handed, as inferred by the number of balls caught (Sekaran et al., 2012; Utley et al., 2007). These differences may be attributed to the fact that they demonstrated different coordinative strategies, particularly at the distal joints (Przysucha & Maraj, 2014). Inferential statistics and examination of corresponding angle-angle plots demonstrated that the groups used qualitatively similar coordinative tendencies at the shoulder-elbow, but not the elbow-wrist. This difference may be explained by the fact that coordination develops in a proximal to distal manner (Asmussen, 2014b; Jensen et al., 1995). Moreover, this finding suggested that the atypical children are in the early stages of the motor learning continuum, and have yet to acquire the movement pattern (Newell, 1985). Examination of spatial and temporal control variables revealed that the atypical group was not significantly different from their peers in terms of mean or stability measures, contrary to earlier research (Astill & Utley, 2008; Sekaran et al., 2012). Given the differences in movement effectiveness and coordination, this result warrants caution from the conceptual standpoint (Newell, 1985). It is possible that differences in movement control did not emerge due to the selected variables being non-essential to successful performance of the one-handed catch. Ball catching is composed of two sub-movements. One that transports the catching hand to the correct position in space, and the other one that fine-tunes the hands/fingers to control the ball. The present study investigated the former issue. It is plausible that the substantial difference in movement effectiveness may be attributed to differences in spatial and temporal control during the fine-tuning of the distal joints of the hand. Although this issue has been studied in earlier research (e.g., Deconinck et al., 2006), the current study did not investigate hand aperture or velocity of hand closure, and therefore these inferences remain speculative.

In summary, the 6-week intervention involving variable type of practice did not result in meaningful improvements in movement effectiveness in 3 of the 4 atypical children. Thus, variable type of practice may not be an effective learning tool for atypically functioning children when practicing ballistic interceptive skills, such as one-handed catching. It is likely that the atypical children have not progressed to a stage of motor learning where such adaptations may occur (Newell, 1985). From a clinical standpoint, coaching/teaching efforts should be focused on developing the movement pattern via constant type of practice or variable practice with lower degree of contextual interference. In regards to the typically functioning children, the possible effects on coordination and control were difficult to delineate due to their optimal coordination and control exhibited at baseline.

Limitations and Future Research

This thesis offers potential evidence regarding the ineffectiveness of variable type of practice on children with DCD. However, a major limitation of the study was sample size. Pragmatic considerations limited the number of cases to four participants per group. It is possible that a larger sample size would produce results more representative of this population, as the findings from this study may only be applicable to the sample that was drawn. It is also important to consider that the participants in this study were not explicitly diagnosed as having DCD. Thus external validity of the inferences may be limited.

The current study suffered from a ceiling effect with respect to the performance of the typical group and a floor effect within the atypical group. Operationalizing movement effectiveness as number of successful catches created these effects. The inherent difficulty of the task gave rise to a scenario where the task was too simple for the typical group to demonstrate any improvements in the number of balls caught, and too difficult for the atypical group. It is possible that by using performance measures capturing the degree of hand aperture (Deconinck et al., 2006) or orientation of the fingers, the results would have allowed for further inferences regarding the differences between groups and potential improvements. Thus, further research is recommended to investigate the effect of variable type of practice using different performance measures, other than successful catches.

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Appendix A

Formal Recruitment Letter

Recruitment Letter
Title: The effect of variable type of practice on one handed catching in children with DCD

Dear Potential Participant.

I, Daniel Carlson, a Master's of Science Student at Lakehead University in the School of Kinesiology, would like to formerly invite your child to participate in a research study. The purpose of the study is to see if your child, whom experiences movement difficulties, can improve his coordination and ability to successfully catch a ball using two hands. Your child may be eligible to participate if he falls between the ages of 8-12 years old and meets the criteria to participate (eligibility is determined based on responses to the questionnaires provided at the first information session).

Your child will be asked to do an initial baseline measurement of coordination, which will involve placing reflective markers on his hips, shoulders, elbow, wrists, and 5^{th} finger, while he attempts to catch 10 balls delivered at 5.7m/s to 7m/s. These reflective markers will be used to digitize his performance and to assess his coordination. I will use two high-speed cameras to film your child's catching. Your child will then participate in multiple practice sessions, 2 times per week over 6 weeks of 30 practice trials, where he will practice catching under conditions of random speeds and locations in an attempt to improve his ability to coordinate his arms.

After 3 weeks, then again after the 6 weeks, your child will be asked to return again to collect information about potential improvements in his/her coordination ability. The same protocol as the first session will be used, and reflective markers will be used once again to collect the data.

Your child is at very minimum risk of harm through the entire study, as the maximum velocity the balls will travel at is 7 m/s, comparable to an underhand toss. In the event your child fails to catch a ball, and is struck by it, it will cause no physical harm to them. Your child may experience general improvements in postural control and performance of the two-handed catch over the course of the study.

Participation in the study is completely voluntary, and your child may stop participating at any time during the study without any consequences. You and your child may refuse to answer any questions asked, and refuse to participate in any part of the study. Confidentiality will be maintained throughout the study, as I will replace your child's name with a number. Any results from the study will contain only participant numbers, and no names. Only my supervisor and I will have access to results. As per Lakehead University's policies, the results will be kept for 5 years at Lakehead University on a password protected hard drive.

You and your child may access individual or overall results of the study upon request. If you would like to participate or you have any questions or concerns, please contact me at 807-621-6482 or at dkcarlso@lakeheadu.ca

Thank you very much for reading and for your consideration,
Daniel Carlson,

Appendix B

Consent Form

Consent Form

I ____________________, agree to allow my child participate in a study being conducted by a graduate student at Lakehead University. I agree that I have read and fully understand all the information presented in the recruitment letter. I understand that my child will participate in a pre-, mid-, and post intervention session as well as 12 practice sessions over the next 6 weeks. I understand the procedures used to collect data, and I understand what is to occur during the practice sessions. I agree to complete all necessary questionnaires and to answer them truthfully. I understand all potential risks, as well as all potential benefits to my child and to society associated with participation in this study. I understand that participation is completely voluntary and that my child and I may refuse to answer any questions and stop participating at any time with no consequences. I understand that all information provided by my child and I will remain completely confidential and we will remain anonymous in all results coming from the study. I understand that all information will be stored at Lakehead University for 5 years, and will only be accessed by the researcher and supervisor. I understand that I may receive my child's results at any time by contacting the researcher after the study is complete.

Participants Name: __________________
Participants Age: ______
Parent/ Guardian's Name: __________________
Parent/ Guardian's Signature: _________________
Child's Signature: ____________________
Phone Number: __________________
Email (optional): ___________________
Would you wish to view child's results (circle one)? (Yes/No)
Date: _____________________
Does your child have any medical condition that may interfere with performance? (y/n)

Appendix C

Assent Form

Assent Form

I _________ agree to be in the study by the Lakehead University student. I fully understand everything I have to do, and that my ability to catch is going to be measured. I know my ability will be measured at the start and at the end of the study, and I will practice many times in the next 6 weeks. I understand the risks of being in the study, and know that I may improve my ability to catch in the next 6 weeks. I understand that I can stop being in the study any time if I want to. I understand that I don't have to answer any questions I don't want to and that there is nothing wrong with that. I understand my name will be kept secret during the study, and that I can get my results from the researcher simply by asking him. I understand that all the information will be kept at Lakehead for 5 years and will only be looked at by the researcher and his supervisor.

Participant Name: ________
Participant Age: _________
Participant Signature: ________

Appendix D

Developmental Coordination Disorder Questionnaire (DCDQ)

THE DEVELOPMENTAL COORDINATION DISORDER QUESTIONNAIRE 2007©
(DCDQ'07)

Wilson, BN, Kaplan, BJ, Crawford, SG, and Roberts, G
October 2007

Alberta Children's Hospital
Decision Support Research Team
2888 Shaganappi Trail NW
Calgary, Alberta, Canada T3B 6A8
http://www.dcdq.ca

DSRT calgary health region Children's HOSPITAL FOUNDATION

DSKT — calgary health region — Alberta Children's Hospital Foundation — Faculty of Medicine, University of Calgary

COORDINATION QUESTIONNAIRE (REVISED 2007)

	Year	Mon	Day
Today's Date:			
Birth Date:			
Child's Age:			

Name of Child: ______________________

Person completing Questionnaire: ______________________

Relationship to child: ______________________

Most of the motor skills that this questionnaire asks about are things that your child does with his or her hands, or when moving.

A child's coordination may improve each year as they grow and develop. For this reason, it will be easier for you to answer the questions if you think about other children that you know who are the same age as your child.

Please compare the degree of coordination your child has with other children of the same age when answering the questions.

Circle the one number that best describes your child. If you change your answer and want to circle another number, please circle the correct response twice.

If you are unclear about the meaning of a question, or about how you would answer a question to best describe your child, please call ______________________ at ______________________ for assistance.

	Not at all like your child	A bit like your child	Moderately like your child	Quite a bit like your child	Extremely like your child
	1	2	3	4	5

1. Your child *throws a ball* in a controlled and accurate fashion.

   1 2 3 4 5

2. Your child *catches* a small *ball* (e.g., tennis ball size) thrown from a distance of 6 to 8 feet (1.8 to 2.4 meters).

   1 2 3 4 5

3. Your child *hits* an approaching *ball* or *birdie* with a bat or racquet accurately.

   1 2 3 4 5

4. Your child *jumps* easily over obstacles found in garden or play environment.

   1 2 3 4 5

5. Your child *runs* as fast and in a *similar* way to other children of the same gender and age.

   1 2 3 4 5

6. If your child has a *plan* to do a motor *activity*, he/she can organize his/her body to follow the plan and effectively complete the task (e.g., building a cardboard or cushion "fort," moving on playground equipment, building a house or a structure with blocks, or using craft materials).

   1 2 3 4 5 (OVER)

	Not at all like your child 1	A bit like your child 2	Moderately like your child 3	Quite a bit like your child 4	Extremely like your child 5

7. Your child's printing or *writing* or drawing in class is *fast* enough to keep up with the rest of the children in the class.

1 2 3 4 5

8. Your child's printing or *writing* letters, numbers and words is *legible*, precise and accurate or, if your child is not yet printing, he or she *colors and draws* in a coordinated way and makes pictures that you can recognize.

1 2 3 4 5

9. Your child uses appropriate *effort* or tension when printing or writing or drawing (no excessive *pressure* or tightness of grasp on the pencil, writing is not too heavy or dark, or too light).

1 2 3 4 5

10. Your child *cuts* out pictures and *shapes* accurately and easily.

1 2 3 4 5

11. Your child is interested in and *likes* participating in *sports or active* games requiring good motor skills.

1 2 3 4 5

12. Your child learns *new motor tasks* (e.g., swimming, rollerblading) easily and does not require more practice or time than other children to achieve the same level of skill.

1 2 3 4 5

13. Your child is *quick and competent* in tidying up, putting on shoes, tying shoes, dressing, etc.

1 2 3 4 5

14. Your child would ***never*** be described as a *"bull in a china shop"* (that is, appears so clumsy that he or she might break fragile things in a small room).

1 2 3 4 5

15. Your child does ***not*** *fatigue easily* or appear to slouch and "fall out" of the chair if required to sit for long periods.

1 2 3 4 5

Thank you.

Decision Support Research Team
Alberta Children's Hospital
2888 Shaganappi Trail NW, Calgary, AB, Canada T3B 6A8
http://www.dcdq.ca

DSRT calgary health region Alberta Children's HOSPITAL FOUNDATION

COORDINATION QUESTIONNAIRE (DCDQ'07): SCORE SHEET

MEDICINE CALGARY

Name: ______________________________ Date: ______________

Birth Date: ______________________________ Age: ______________

	Control During Movement	Fine Motor/ Handwriting	General Coordination
1. Throws ball			
2. Catches ball			
3. Hits ball/birdie			
4. Jumps over			
5. Runs			
6. Plans activity			
7. Writing fast			
8. Writing legibly			
9. Effort and pressure			
10. Cuts			
11. Likes sports			
12. Learning new skills			
13. Quick and competent			
14. "Bull in shop"			
15. Does not fatigue			

TOTAL ____/30 Control during Movement + ____/20 Fine Motor/ Handwriting + ____/25 General Coordination = ____/75 TOTAL

For Children Ages 5 years 0 months to 7 years 11 months
15-46 indication of DCD or suspect DCD
47-75 probably not DCD

For Children Ages 8 years 0 months to 9 years 11 months
15-55 indication of DCD or suspect DCD
56-75 probably not DCD

For Children Ages 10 years 0 months to 15 years
15-57 indication of DCD or suspect DCD
58-75 probably not DCD

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