Paper Presented at the AARE Annual Conference, Melbourne 2010
Australian Association for Research in Education
Paper code: 2472

Midline crossing movements: A teachable skill for developing children

Scott Pedersen
University of Tasmania
Scott.Pedersen@utas.edu.au

Matthew Young
University of Tasmania
Matthew.Young@utas.edu.au

Abstract:

It has been suggested in the motor learning literature that the ability to perform efficient midline crossing movements can contribute to skill acquisition requisite for successful physical activity and sport participation (Ayres, 1972; Surburg & Eason, 1999; Pedersen, Heath, & Surburg, 2007). The present study was conducted to determine if a single bout of deliberate laterality practice could facilitate the initiation of midline crossing movements in children between the ages of 8 and 11. Thirty children were randomly assigned to one of three treatment groups. Each group received one treatment, 30 minutes in duration, spaced between a pre- and post-assessment of upper extremity choice response time, which required the participant to perform goal-directed reaching movements to a contralateral stimulus across the midline, to the midline, or to an ipsilateral stimulus that did not require a midline crossing movement. Response time was divided into reaction time (RT) and movement time (MT), with RT being the dependent variable of interest. The first group performed contralateral ball-bouncing (CBB) exercises that only involved arm movements that crossed the midline of the body; the second group performed ipsilateral ball-bouncing (IBB) tasks that only required arm non- midline crossing movements; and the control group played the Nintendo DS. Children in the CBB group became significantly faster at contralateral RT during the post-test, whereas the other two groups made no improvements in midline crossing RT. In fact, the control group became significantly slower at midline crossing movements after the 30 minutes of video game play. Even after a short bout of deliberate laterality practice children that practiced contralateral movements significantly improved their ability to initiate complex, midline crossing movements; whereas the children that did not practice midline crossing movements did not exhibit any improvement in midline crossing behaviour. Physical education teachers can utilise this developmental-appropriate approach when designing games and activities for children who could benefit from laterality practice. In turn, this development may facilitate a child's potential to successfully participate in physical activity or sport.

Introduction

It is a primary responsibility for physical education (PE) teachers to teach children how to develop age-appropriate motor skills. Children who learn these skills in a timely fashion are more likely to be successful during sport and game play, which may increase the likelihood that they will develop a lifelong interest in physical activity (Olds et al., 2004). Contrary to this, children who do not receive suitable PE instruction are less likely to take an interest in lifelong physical activity pursuits and may become at risk of health and wellbeing related issues later in life (CDCP, 1997). Therefore the PE teacher has a pivotal role in influencing the health and wellbeing outcomes of his/her students. This suggests that it is the responsibility of the physical educator to be aware of the developmental nature of motor skill attainment in all students.

One way to benchmark the developmental progress of children is to assess their ability to achieve motor milestones. An example of a developmental motor milestone that PE teachers may observe in children is the ability to efficiently perform midline crossing movements with the arms and legs during game play. The ability to cross the midline of the body is an integral facet of many activities in both sport and everyday life. This capacity to incorporate midline crossing movements into sport and game play may provide developing children with a larger repertoire of movement choices possibly allowing them to achieve greater success. Kephart (1971) proposed that the ability to perform contralateral arm movements, or movements that cross the midline of the body, is more complex than the initiation of ipsilateral reaching movements that do not involve midline crossing. Therefore, he suggested that contralateral movements will only be instigated by children after simpler ipsilateral movements have been mastered, implying this ability is a developmental phenomenon. Motor control theorists have suggested that midline crossing movements are more complex because they involve neural processing by both cerebral hemispheres, whereas simpler ipsilateral movements can be processed within one hemisphere (Marzi, Bisiacchi, & Nicoletti,1991). Several studies on children have provided empirical data to support this proposition (Ayres, 1972; Cermack, Quintero, & Cohen, 1980; Stilwell, 1981; 1987; Wapner & Cirillo, 1968). However, the validity of these midline crossing assessments has been questioned due to a lack of temporal constraints on the participants (Schofield, 1976). Using a simple reaction time (RT) assessment Brizzolara, Ferretti, Brovedani, Casalini, and Sbrana (1994) suggested that by the time children reach puberty the corpus callosum is fully myelinated and therefore these children should be able to integrate contralateral reaching into their movement repertoire. Eason and Surburg (1993) suggested that employing information processing theory with a choice response time apparatus, midline crossing behaviour could be indexed in children as a function of choice RT speed. This method of assessing midline crossing behaviour in a corpus of 8- to11-year-old children was utilised in the present study.

Besides investigations into the developmental nature of midline crossing behaviour, knowledge about this important motor skill attribute is relatively unknown. This poses a problem for PE teachers expected to design developmentally appropriate curricula for their students. It would be beneficial for PE teachers to have knowledge of when children are able to successfully perform midline crossing movements. If midline crossing behaviour in developing children can be facilitated by practice then this could be of value to PE teachers when designing games and lessons. It is well documented that information processing, as measured by RT, can be improved in children with deliberate practice (Elliott, 1972; Hale, Fry, & Jessie, 1993; Kail, 1991); however, it has yet to be established whether improvements in processing speed can be specifically trained as a function of laterality. Thus, it is unknown if contralateral RT can be reduced by deliberately practicing contralateral movements. To test this hypothesis the current training study was designed using tenants of Ericsson, Krampe, & Tesch-Romer's (1993) theory of the effect of deliberate practice on expert performance, and the specificity of training principle commonly discussed in the exercise science literature (Reilly, Morris, & Whyte, 2009). The purpose of this investigation was to determine if midline crossing arm movements can be initiated quicker as a result of deliberate laterality practice in a corpus of children between the ages of 8 and 11, and to see if the attainment of this motor milestone can be realised by children in this age range using a temporally constrained RT assessment.

Method

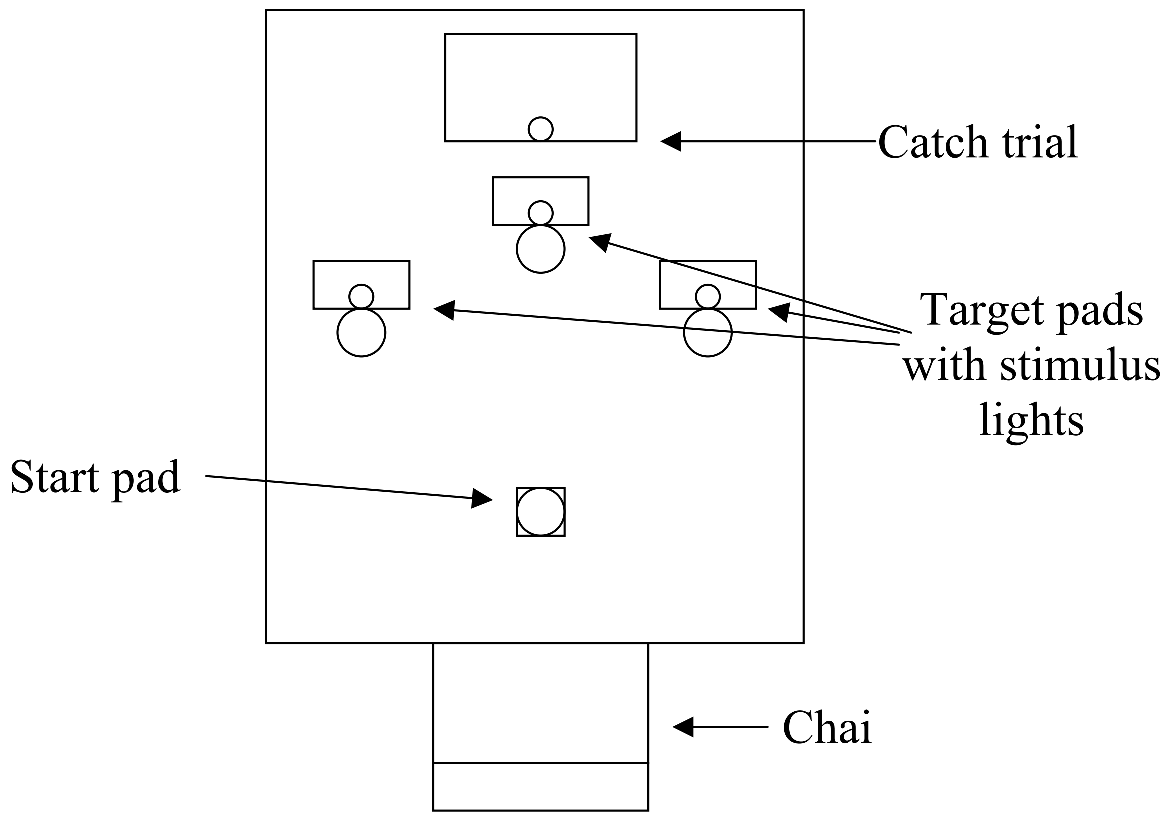
Participants

Thirty children (boys = 16, girls =14), between the ages of 8 years 0 months and 11 years 11 months, were randomly selected from several Tasmanian communities by means of flyer, newspaper, and webpage advertisements. All children were pre-screened by phone interview with their parent/guardian and found to have no developmental, physical, sensory, or cognitive disabilities. Each child and parent/guardian provided informed consent as regulated by the university's human research ethics committee. All of the participants were right-handed according to Bryden's (1977) shortened five-item version of the Oldfield handedness questionnaire. Only right handed children were selected because it has been suggested the left handed individuals have increased efficiency of between hemispheric interactions (Cherbuin & Brinkman, 2006). Once inclusion criteria were met and consent was received, participants were divided into two age groups: 8-9 year olds and 10-11 year olds. They were then randomly assigned without replacement to one of three treatment groups. The first two experimental groups performed either contralateral or ipsilateral ball bouncing games, and the third control group played the Nintendo DS in which the children did not perform any lateral arm movements. Participants were tested and trained on an individual basis in an isolated room with adequate lighting.

Assessment

Before and after the 30-minute treatment (experimental and control) all children were assessed on a custom made upper-extremity, three-choice response time apparatus (figure 1) which required the participant to perform goal-directed arm movements to either a contralateral stimulus across the midline, a midline stimulus, or an ipsilateral stimulus that did not require a midline crossing arm movement. The response time apparatus allowed movement processing, or RT (time from presentation of stimulus light to release of pressure from the start pad), to be separated from movement execution, or MT (time from release of pressure from the start pad until contact with the target pad). The primary dependent variable in this investigation was RT which was used to determine if the processing speed of directional arm movements can be facilitated by teaching children lateral ball bouncing manoeuvres. Movement time scores were provided to the participant after each trial to serve as a motivation tool to encourage the participant to perform each trial as fast as possible.

Figure 1 Choice Response Time Apparatus



To perform the task the participant was asked to depress a releasable microswitch (i.e., start pad) located 12 cm from the front edge of the apparatus. The three target pads, each defined by a 5 cm diameter plastic target and red light-emitting diode (LED), required 30.6 cm of upper-limb displacement from the start pad in three separate directions (i.e., contralateral, midline, ipsilateral). To limit anticipation to the stimulus a randomly selected foreperiod, of either 1.5, 3.0, or 4.5 seconds, preceded the onset of the target stimulus LED. In addition, three catch trials were embedded within a block of empirical trials to invoke an uncertainty of occurrence. Once the randomly selected empirical target stimulus illuminated the participant was instructed to move his/her arm to the corresponding target pad as quickly as possible. When the catch trial stimulus illuminated the participant was instructed to not move from the start pad. This stimulus appeared 4.6 seconds after the auditory warning cue had been presented. For data collection a portable laptop computer interfaced through a standard parallel printer port captured the temporal measures associated with this task. Custom-built computer software generated randomized blocks of trials and stimulus presentations.

During the pre-test each participant performed a total of 54 empirical trials of goal-directed aiming movements with the left and right arms. Within a trial block, the participant completed nine trials to each of the three target positions (i.e., contralateral, midline, and ipsilateral) presented in a pseudo-randomized fashion. Performance of the left and right arms was completed in separate trial blocks, with the extremity order counterbalanced across participants.

This same assessment was repeated after the 30-minute treatment during the post-test accumulating 108 upper extremity response time trials for each participant. An entire data collection session (including pre-test, treatment, and post-test) lasted approximately 90 minutes.

Treatment

In between pre and post upper extremity response time assessments each participant performed 30 minutes of treatment in one of three groups (n=10): contralateral ball bouncing (CBB) experimental group, ipsilateral ball bouncing (IBB) experimental group, and Nintendo DS control group. Children in the CBB group were exposed to deliberate practice involving two-handed ball-bouncing exercises that only utilised contralateral arm movements in order to bounce and catch a ball that crossed the midline of the body. In other words, if the bounce was made with the right hand, then the catch was made with the left hand on the opposite side of the body in which the bouncing ball originated from. Children in the IBB group practiced two-handed ball-bouncing and catching games that involved only ipsilateral arm movements that did not require midline crossing. In other words, if the bounce was made with the right hand, then the catch was also made with the right hand on the same side of the body in which the bouncing ball originated from. Likewise, if the bounce was made with the left hand, the catch was made with the left hand on the ipsilateral side of the body. The children in the control group did not perform any arm movement exercise; instead they played a typical hand-held video game on the Nintendo DS while seated. Only bilateral thumb movements were elicited during this control treatment.

All treatment sessions were lead by the primary investigator in an isolated room free of furniture, except for a chair that was made available to the control participants while they played the Nintendo DS. The balls used in the experimental treatments were high quality rubber balls (57 mm in diameter; red, blue, green, and yellow in colour). Before treatment each participant was provided a five-minute instruction period to become familiar with the activities where correct body movements were demonstrated to ensure the participant would experience a level of success. The goal of the experimental treatments was to improve the lateral arm movement skills of the participant through deliberate practice. More specifically, the CBB group was deliberately taught to become more efficient at contralateral arm movements, whereas the IBB group was trained to improve purposeful ipsilateral movements. To accomplish these goals each training session was structured to introduce more complex ball games once the participant successfully accomplished the simpler tasks. For example, at first the participant would bounce one ball with their dominant hand and catch that ball with their dominant hand (IBB), or with their non dominant hand (CBB). Once this initial skill was successfully realised by the participant, he/she was then instructed to perform a slightly more difficult task. This progression was continued throughout the intervention as long as the participant was able to successfully complete the current task. Task difficulty was raised in several ways depending on the skill level and confidence of each individual. Examples of increased complexity included utilizing the non-dominant hand to initiate the lateral movements, performing the lateral movements with two balls at the same time, bouncing the balls behind the individual's back, or bouncing the balls off of a wall; whilst emphasising that all bounces cross the midline in the CBB group, or all bounces do not cross the midline in the IBB group. Several other strategies were utilised to increase the complexity of the games during the training session once the participant reached competency with the initial task and was deemed ready for the next challenge by the primary investigator. These tactics included having the participant: use his/her non-preferred hand; perform the stationary tasks while walking; bounce the ball off of a wall before catching; and play the games with a partner (the primary investigator), which increased the speed of the games. The primary investigator led each of the activities with a demonstration, and provided corrective skill feedback to motivate the participant to be successful at the current game before moving on to a more complex game. The ball bouncing games for both experimental conditions were adapted from the Bal-A-Vis-X training program (Hubert, 2001). The general structure of the experimental treatment was to enable each child to practice through the games at their own pace, with each child progressing at different rates, and there always being a more challenging game to move onto once the current lateral skill was achieved.

Data Analysis

Originally, the dependent variable was scrutinised using a frequency distribution analysis for each participant within each block of trials to determine normality. Values that landed outside of the +/- 3 standard deviation range were declared outliers and were replaced with the median score of that particular trial block. These outlying scores represented lapses in attention, and would only confound attempts to measure information processing in children (Clarke & Zaidel, 1989). Less than 2 % of all trials were found to represent outliers. Prior to inferential analyses, RT and MT scores were compared using a Pearson Product Moment Correlation to determine any relationships. The relationships between RT and MT for the three treatment groups across both tests and all directions were low. The correlation coefficients ranged from $r = -0.08$ to $r = 0.23$. The statistical independence of these two variables, further justified the strategy to inferentially test RT alone using an analysis of variance (ANOVA) procedure. Independent variables manipulated in this study included treatment group (contralateral exercise, ipsilateral exercise, control), age group (8-9 year olds, 10-11 year olds), gender (male/female), side of body (right, left), test (pre-test, post-test), and movement direction (contralateral, midline, ipsilateral). Reliability estimates using intraclass correlation coefficients were calculated for the dependent variable across each level of all independent variables. An initial analysis of variance was conducted to see if either the gender or side of the body independent variables should be included in the inferential design, however there were no significant differences between the right and left arms $F(1,54) = 0.01$, $p > 0.05$, and between boys and girls $F(1,24) = 1.39$, $p > 0.05$. Therefore, a 3 (treatment group) X 2 (age group) X 2 (test) X 3 (direction) mixed design ANOVA with repeated measures on the last two factors was used to test for significant differences, with an alpha level set at 0.05. Only significant main effects and interactions were reported in the results section. Significant interactions were further examined using simple effects analyses. Post hoc comparisons were performed using paired sample *t*-tests (Seaman, Levin, & Serlin, 1991). Effect size values were reported using Cohen's d^2 statistic to describe the meaningfulness of the findings by offering a standard of comparison for future related studies.

Results

Reliability

The reliability coefficients for RT in the three treatment groups ranged between 0.89 and 0.96. This finding is in accordance with past investigations of reliability using this apparatus to assess RT in children (Woodard & Surburg, 1999; Pedersen et al., 2004).

Inferential findings

The mixed design ANOVA indicated a treatment group by test by direction interaction $F(4, 48) = 6.53$, $p < 0.05$. The significant simple main effects are further detailed below and can be viewed in table 1. The CBB group exhibited significantly faster contralateral RT, $F(1, 54) = 16.45$, $p < 0.05$ with a small to moderate effect size of $d^2 = 0.26$, as a result of the experimental treatment. This finding was not apparent in the other two groups. In fact, the control group became significantly slower at contralateral RT, $F(1, 54) = 10.06$, $p < 0.05$ with a small effect size of $d^2 = 0.17$, after 30 minutes of playing the Nintendo DS. After deliberate practice, the IBB group demonstrated significantly faster ipsilateral RT values, $F(1, 54) = 7.66$, $p < 0.05$ with a small effect size of $d^2 = 0.14$, and significantly faster midline RT values, $F(1, 54) = 4.84$, $p < 0.05$ with a small effect size of $d^2 = 0.13$; while the CBB demonstrated significantly slower ipsilateral RT, $F(1, 54) = 7.24$, $p < 0.05$ with a small effect size of $d^2 = 0.18$, in the post-test compared to the pre-test.

Table 1. Reaction time means and standard deviations for treatment group as a function of test and direction

	Pre-test			Post-test		
Treatment / Direction	Contra	Mid	Ipsi	Contra	Mid	Ipsi
CBB Group	507+/-144	488+/-137	472+/-119	474+/-112^	474+/-128	494+/-121$^+$
IBB Group	480+/-175	445+/-138	454+/-169	470+/-162	427+/-146^	431+/-154^
Control Group	470+/-140	466+/-145	461+/-143	496+/-161$^+$	467+/-159	466+/-149

Values are denoted in milliseconds
^ denotes post-test value is significantly faster than the corresponding pre-test value
$^+$ denotes post-test value is significantly slower than the corresponding pre-test value

A treatment group by age group by test significant interaction, $F(2,24) = 4.83$, $p < 0.05$ was also found. The older children (10-11 year olds) had significantly faster RTs, with large effect sizes ranging from $d^2 = 0.92 – 0.95$, compared to the younger children (8-9 year olds) for each treatment group's pre-test and post-test (table 2).

Table 2. Reaction time means and standard deviations for treatment group as a function of test and age group

	Pre-test		Post-test	
Treatment / Age	8-9 yo	10-11 yo	8-9 yo	10-11 yo
Contralateral Exercise	585+/-135	425+/-89^	552+/-120	433+/-94^
Ipsilateral Exercise	491+/-170	428+/-146^	470+/-147	415+/-158^
Controls	547+/-146	384+/-78^	582+/-147	370+/-71^

*Values are denoted in milliseconds
^ denotes older age group value is significantly faster than the corresponding younger age group value

In addition to these two significant interactions, main effects for age group $F(1, 24) = 12.53$, $p < 0.05$ and direction $F(2, 48) = 10.07$, $p < 0.05$ were significant. Across all comparisons the older children had significantly faster RT scores (mean = 411 +/- 113 ms) compared to the younger children (mean = 536 +/- 152 ms). In like manner, contralateral RT (mean = 483 +/- 151 ms) was significantly slower than midline RT (mean = 461 +/- 144 ms) and ipsilateral RT (mean = 463 +/- 145 ms).

Discussion

Physical education teachers that are able to foster developmentally appropriate skills in their students can provide meaningful learning experiences through movement-based activities. As suggested in this paper one strategy to accomplish this goal is to teach children how to perform efficient lateral arm movements through ball-bouncing games. The findings of the present study indicated that even after a short bout (30 minutes) of deliberate practice children between the ages of 8 and 11 demonstrated performance improvements in processing lateral movements. More specifically, the children in the CBB group who only bounced and caught balls that crossed their body's midline significantly improved their ability to initiate complex motor movements that involved crossing the midline of the body. In like manner the children in the IBB group, who only performed ipsilateral arm movements when bouncing and catching balls, became significantly faster at initiating ipsilateral and midline movements that did not involve midline crossing. These findings provide support that the specificity of training principle, common in the exercise science literature (Reilly, Morris, & Whyte, 2009), may extend to the field of motor learning. There were several more findings to further support this claim. First, the children in the control group who only played the Nintendo DS did not improve their RT from pre-test to post-test, in fact these children got significantly slower at contralateral RT. Second, the CBB group who did not practice ipsilateral arm movements performed significantly slower on ipsilateral RT during the post-test compared to the pre-test. Finally, the IBB group did not improve their contralateral RT from pre-test to post-test assumingly because they did not practice midline crossing movements. Collectively, these findings indicate that the performance improvements noted in this study cannot be simply attributed to test-retest effects, and therefore must have been caused by the deliberate practice specific to each experimental condition. To the knowledge of the authors, there have been no published studies specifically investigating the effects of deliberate practice on the processing speed of lateral movements in children. Nonetheless, the results of the present study support that the specificity of training principle may extend to the field of motor learning (Barnett, Ross, Schmidt, & Todd, 1973), and that deliberate practice can facilitate motor learning processes (Ericsson, Krampe, & Tesch-Romer, 1993). Based on these findings it appears that laterality movement training should be considered for inclusion in the PE delivery for all children.

Effective PE teachers should have an understanding of motor learning concepts to adequately design their curriculum activities (Rukavina & Jeansonne, 2009). Motor skill learning may occur at many levels within the central nervous system, such as the stimulus identification, response selection or response programming stage (Schmidt & Wrisberg, 2008). A decrease in information processing speed at any one of these stages may facilitate movement initiation in children. For example, PE teachers that expose their students to bright coloured ball exercises, like we did in this study, may be able to reduce processing time during the stimulus identification stage. This can benefit students by helping them prepare appropriate motor responses for the desired outcomes. Likewise, the response selection and/or response programming stages may have been enhanced by several tactics used in our deliberate practice treatment. First, during treatment children practiced several versions of lateral (contralateral for the CBB group, and ipsilateral for the IBB group) ball bouncing and catching manoeuvres. This introduction of a variety of lateral movements may have had a fortuitous impact on the stimulus-response compatibility during the post assessment task. In addition, the complexity of the ball bouncing games was gradually increased during the training session. Before each child was challenged with a more difficult ball bouncing game, mastery of a simpler task had to first be demonstrated. This foundation building strategy may have enabled children to make quicker decisions or program quicker responses during the more complex games. This progressive repetition may have had a positive effect on their post assessment RT. Finally, anticipatory skills were developed during the experimental treatment by having the child bounce and catch a ball repetitively. Successful anticipation is a requisite skill to accomplish any ball bouncing and catching task because of the time constraint that gravity places on the child to make the catch before the ball drops to the ground. The repetitive nature of this deliberate practice forced each child to prepare his/her lateral catching movement within a short period of time in order to be successful at the task, hence reinforcing his/her temporal ability. In summary, PE teachers may incorporate any or all of the above deliberate practice strategies that we employed in the design of our treatment, to improve the lateral movement processing of developing children in their classes. These types of practice strategies will allow children to learn developmentally appropriate skills which may enable them to experience greater success when participating in sport and physical activity.

Physical education teachers will relish the finding that the control group demonstrated no improvements in information processing after playing the Nintendo DS. In fact, they exhibited significantly slower contralateral RT scores during the post-test. While playing the hand-held video game children were required to focus their visual attention towards their midline to view the screen and respond with their thumbs. Perhaps this midline focussed attention negated their lateral proficiency, which in turn caused them to be slower at processing lateral movements. The post-test RT scores for these children indicated similar midline RTs compared to the pre-test, whereas their ipsilateral RTs were slower, and their contralateral RTs were significantly slower. This suggests that playing a hand-held video game held at the midline of the body may cause a deleterious effect on the processing of lateral arm movements, with a more serious effect on complex motor skills that involve crossing the midline of the body. Unfortunately, more and more children spend copious amounts of time playing hand-held video games like the Nintendo DS, instead of voluntarily participating in developmentally appropriate physical activity (Foley & Maddison, 2010). The findings from this study can be utilised by PE teachers to educate parents about the need to incorporate the lessons from the PE curriculum throughout their child's day. The more time children engage in the deliberate practice of developmentally appropriate motor skills, and the less time they spend playing hand-held video-games may benefit their overall developmental movement abilities.

When the dependent variable was deduced as a function of age, 10-11 year olds initiated movements significantly faster than their younger counterparts (8-9 year olds) across every treatment group and pre/post-test comparison. This supports previous investigations that have compared the processing speed of children of different ages (Kail, 1991; 1993; Brewer & Smith, 1989). Despite this agreement, the age-related reductions in RT were not a function of directionality. The significant main effect for direction indicated that all children in this study exhibited midline crossing inhibition, which is contradictory to past research that purports older children should have fully integrated cross lateral movements by this age (Cermack, Quintero, & Cohen, 1980; Stilwell, 1981; 1987; Wapner & Cirillo, 1968). Physical education teachers that are aware of when children are developmentally ready to efficiently perform cross lateral movements can be better prepared to select appropriate activities to help foster these skills in children who need help with organizing these complex movements. There is a lack of agreement among developmental theorists in the literature concerning the age range of when normal developing children should be able to perform midline crossing movements as efficiently as movements made to the ipsilateral space. Perhaps the sensitivity of using choice RT to assess midline crossing reaching movements should be further used to examine the attainment of this developmental phenomenon in children.

Conclusions drawn from these research findings should be interpreted with caution due to research design limitations, such as a small sample size of children. Although the effect sizes for mean differences were only small to moderate, Speed and Andersen (2000) proposed that small effects may still indicate meaningful findings when interpreting the mean differences of physiological variables such as RT. Mean differences quantified in milliseconds could possibly be the difference in winning or losing an event. Because this research design only included a pre-test and a post-test and lacked a retention or transfer test, conclusions should be limited to performance improvements, and not to actual motor skill learning. From this single investigation it cannot be determined if performance improvements were simply the result of a warm-up or tuning in effect. Future research that utilises a larger sample, longer training interventions, and retention or transfer tests may be able to demonstrate that improvements in directional information processing speed can be trained and sustained with deliberate laterality practice.

In conclusion, deliberate laterality practice had a significantly positive effect on the processing of lateral movements in the children sampled in this study. Of particular interest, children who practiced contralateral ball bouncing movements were able to attenuate midline crossing inhibition and initiate contralateral movements faster than ipsilateral movements. Considering that all children in this age range still demonstrated midline crossing inhibition, this has implications for the developmental programming selected by PE teachers who can help children achieve this motor milestone by including deliberate laterality practice into their lesson plans. This type of instruction may make a difference in the lives of young children who experience difficulties with motor skill acquisition. By preparing young children with developmentally appropriate motor skills, such as those that involve crossing the midline of the body, we may facilitate their developmental readiness to become successful in competitive sports that rely on efficient cross lateral processing speed such as football, soccer, basketball, hockey, tennis, or cricket.

References

Ayres A. J. (1972). Types of sensory integrative dysfunction among disabled learners. *American Journal of Occupational Therapy, 26,* 13-18.

Barnett, M.L., Ross, D., Schmidt, R.A., & Todd, B. (1973). Motor skills learning and the specificity of training principle. *Research Quarterly, 44,* 440-447.

Brewer, N. & Smith, G.A. (1989). Developmental changes in processing speed: Influence of speed-accuracy regulation. *Journal of Experimental Psychology, 118,* 298-310.

Brizzolara, D., Ferretti, G., Brovedani, P., Casalini, C., & Sbrana, B. (1994). Is interhemispheric transfer time related to age? A developmental study. *Behavioural Brain Research, 64,* 179-184.

Bryden, M.P. (1977). Measuring handedness with questionnaires. *Neuropsychologia, 15,* 617-624.

Center for Disease Control and Prevention (CDCP). (1997). Guidelines for school and community programs to promote lifelong physical activity among young people. *Journal of School Health, 67,* 202-219.

Cermack, S., Quintero, E., & Cohen, P. (1980). Developmental age trends in crossing the body midline in normal four through eight-year-old children. *American Journal of Occupational Therapy, 34,* 313-319.

Cherbuin, N., & Brinkman, C. (2006). Do the cerebral hemispheres interact differently in left-handed individuals? *Neuropsychology, 20,* 700-707.

Clarke, J.M. & Zaidel, E. (1989). Simple reaction times to lateralized light flashes. *Brain, 112,* 849-870.

Eason, B. & Surburg, P.R. (1993). Effects of midline crossing on reaction time and movement time with adolescents classified as mildly, mentally retarded. *Adapted Physical Activity Quarterly, 10,* 269-280.

Elliott, R. (1972). Simple reaction time in children: Effects of incentive, incentive-shift and other training variables. *Journal of Experimental Child Psychology, 13,* 540-557.

Ericsson, K.A., Krampe, R.T., & Tesch-Romer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100,* 363-406.

Foley, L. & Maddison, R. (2010). Use of active video games to increase physical activity in children: A (virtual) reality. *Pediatric Exercise Science, 22,* 7-20.

Hale, S., Fry, A.F., & Jessie, K.A. (1993). Effects of practice on speed of information processing in children and adults: Age sensitivity and age variance. *Developmental Psychology, 29,* 880-892.

Hubert, B. (2001). *Bal-A-Vis-X: Rhythmic balance/auditory/vision exercises for brain and brain-body integration*. Wichita KS: Bal-A-Vis-X, Inc.

Kail, R. (1991). Developmental change in speed of processing during childhood and adolescence. *Psychological Bulletin, 109,* 490-501.

Kail, R. (1993). Processing time decreases globally at an exponential rate during childhood and adolescence. *Journal of Experimental Child Psychology, 56,* 254-265.

Kephart, N.C. (1971). The slow learner in the classroom (2nd ed.). Columbus, OH: Merrill.

Marzi, C. A., Bisiacchi, P., & Nicoletti, R. (1991). Is interhemispheric transfer of visuomotor information asymmetric? Evidence from a meta-analysis. *Neuropsychologia, 29,* 1163-1177.

Olds, T., Dollman, J., Ridley, K., Boshoff, K., Hartshorne, S., & Kennaugh, S. (2004). Children and sport: Full report. Belconnen, ACT: Australian Sports Commission.

Pedersen, S.J., Surburg, P.R., Heath, M., & Koceja, D.M. (2004). Fractionated lower extremity response time performance in boys with and without ADHD. *Adapted Physical Activity Quarterly, 21,* 315-329.

Pedersen, S.J., Heath, M., & Surburg, P.R. (2007). Lower extremity response time performance in boys with ADHD. *Journal of Attention Disorders, 10,* 343-349.

Reilly, T., Morris, T., & Whyte, G. (2009). The specificity of training prescription and physiological assessment: A review. *Journal of Sport Sciences, 27,* 575-589.

Rukavina, P.B. & Jeansonne, J.J. (2009). Integrating motor learning concepts and learning strategies into physical education using guided discovery. *Journal of Physical Education, Recreation and Dance, 80*, 23-30, 65.

Schmidt, R.A. & Wrisberg, C.A. (2008). *Motor learning and performance: A situation-based learning approach* (4th ed.). Champaign, IL: Human Kinetics.

Schofield, W.N. (1976). Do children find movements which cross the body midline difficult. *The Quarterly Journal of Experimental Psychology, 28,* 571-582.

Seaman, M., Levin, J., & Serlin, R. (1991). New developments in pairwise multiple comparisons: some powerful and practicable procedures. *Psychological Bulletin, 110,* 577-586.

Speed, H.D. & Andersen, M.B. (2000). What exercise and sport scientists don't understand. *Journal of Science and Medicine in Sport, 3,* 84-92.

Stilwell, J.M. (1981). Relationship between development and the body-righting reaction and manual midline crossing behavior in the learning disabled. *The American Journal of Occupational Therapy, 35,* 391-438.

Stilwell, J.M. (1987). The development of manual midline crossing in 2 to 6 year old children. *The American Journal of Occupational Therapy, 41,* 783-789.

Surburg, P. & Eason, B. (1999). Midline crossing inhibition: an indicator of developmental delay. *Laterality, 4,* 333-343.

Wapner, S. & Cirillo, L. (1968). Imitation of a model's hand movements: age changes in transposition of left-right relations. *Child Development, 39,* 887-895.

Woodard, R. & Surburg, P.R. (1999). Midline crossing behavior in children with learning disabilities. *Adapted Physical Activity Quarterly, 16,* 155-166.