Lower Extremity Movement Preparation and Children With Attention Deficit Hyperactivity Disorder

Scott J. Pedersen
New Mexico State University

Paul R. Surburg
Indiana University

This study investigated the movement preparation (reaction time) and movement execution (movement time) of children with and without ADHD by manipulating the uncertainty of occurrence. Participants performed a seated lower extremity choice response time protocol, which contained either 10% catch trials or 30% catch trials along with 27 empirical stimuli to one of three target directions. Results indicated that children with ADHD were significantly slower at processing lower extremity movements than their peers for the condition with increased number of catch trials, but not the condition with fewer catch trials. These findings suggest that children with ADHD are more affected by the uncertainty of an empirical stimulus during the preparation phase of a movement response than their age-matched peers are.

The inability to control certain aspects of their own motor behavior is a characteristic displayed by children with attention deficit hyperactivity disorder (ADHD). This symptom of hyperactive behavior often creates conflict with the peers in their immediate environment. The literature on motor dysfunction in children who experience symptoms of ADHD suggests that they exhibit higher order cognitive-motor impairments (Barkley, 1998; Barkley, Grodzinsky, & DuPaul, 1992). Within the information processing paradigm, perceptual-motor deficits can be evaluated using a conventional response time protocol that separates reaction time (RT) from movement time (MT; Eason & Surburg, 1993; Epstein, Conners, Erhardt, March, & Swanson, 1997; Lewis & Surburg, 2006; Sergeant & Scholten, 1983). Kephart (1971) recognized that the perceptual-motor abilities of all children must be considered prior to designing appropriate learning activities. This type of convention has been the focus of many researchers interested in the movement behavior of children with ADHD. Several investigators have measured upper extremity simple (Beyer, 1999; Cohen & Douglas, 1972; Gordon & Kantor, 1979; Hefley & Gorman, 1986; Pitcher, Piek, & Barrett, 2002) and choice (Sheppard, Bradshaw, Georgiou, Bradshaw, & Lee, 2000; Vickers, Rodrigues, & Brown, 2002)

Scott J. Pedersen is with the Human Performance, Dance, and Recreation Department at New Mexico State University in Las Cruces. E-mail: pedersen@nmsu.edu. Paul R. Surburg is with the Department of Kinesiology at Indiana University in Bloomington.
response time to explore why children with ADHD symptoms have such difficulty executing their movements. The aggregate result of these findings was that children with ADHD experience delays in information processing that are not experienced by their age-matched peers.

There have been a few studies unable to distinguish children with ADHD from their peers when comparing upper extremity simple response time scores (Sartory, Heine, Müller, & Elvermann-Hallner, 2002; Strandburg et al., 1996; Yan & Thomas, 2002). Perhaps a choice response time protocol may discriminate between children with ADHD and their peers because increased task complexity will limit the degree of planning available to perform the movement imperative. More specifically, randomized targets reduce prior knowledge about the response requirements, such as the direction and amplitude of the required movement.

In like manner, a careful examination into the lower extremity choice response time performance of children with ADHD may help clarify the ambiguity in previous reports. Peters (1988, 1990) first suggested that tests of lower extremity movement may be better suited to detect developmental differences in children. He contended that upper extremity lateral preference is unavoidable and may confound the results of certain measurements, such as reaction time. Li and colleagues (1998) performed a cross sectional study on normal developing individuals to measure the developmental characteristics of upper and lower extremity psychomotor performance. These researchers reported that the lower limbs were more sensitive to deficiencies in central nervous system function. Perhaps assessing lower extremity motor function may be more revealing as to the movement abnormalities experienced by children who display hyperactive symptoms. Harvey and Reid (2003) conducted a meta-analysis on the motor performance of children with ADHD that inferred a lack of attention devoted to lower extremity studies. In summation, a deeper investigation into the preparation of lower extremity movements for children with ADHD is warranted. In the current study, a lower extremity choice response time protocol was utilized to assess the integrity of perceptual-motor processing ability of children with and without ADHD. Operationally defined, RT was assumed to represent aspects of movement preparation and MT denoted aspects of movement execution.

An investigation using a similar protocol to the one used in this study found that children with ADHD demonstrated inferior central processing ability when compared to age-matched peers (Pedersen, Surburg, Heath, & Kocee, 2004). These authors fractionated RT into premotor time and motor time and found that children with ADHD had significantly slower premotor time scores compared to age-matched peers. Motor time values representing peripheral processing were not significantly different between the two groups. More interesting was the finding that children with ADHD exhibited inefficiency in preparing movements that required crossing the midline of the body, when compared to age-matched peers. It has been previously reported that cross lateral integration, or the ability to make contralateral movements that cross the midline of the body as rapid as ipsilateral movements to the same side of the body, is a significant marker of central nervous system maturity (Ayres, 1972; Cermack, Quintero, & Cohen, 1980; Schofield 1976; Stilwell, 1987, 1981; Surburg & Eason, 1999). The additional processing time associated with contralateral movements may reflect the time requirements associated with between-hemisphere communication (Aglioti, Dall’Agnola,
Research specific to children with ADHD has demonstrated that two regions in the anterior corpus callosum are markedly smaller when compared to age-matched peers (Giedd et al., 1994; Hynd et al., 1991). This may limit transmission capacity between the two brain hemispheres. Perhaps the interhemispheric communication required to efficiently perform contralateral movements is compromised in individuals with ADHD due to variable corpus callosum size.

To delve further into the lower extremity movement characteristics of children with ADHD, we decided to focus this investigation on the movement preparation time required to respond to a stimulus. Preparation, the development of a state of readiness to make a planned movement (Henry & Rodgers, 1960), plays an important role in the initiation of movement tasks. During a traditional response time protocol, as time passes following a warning signal, the participant becomes aware that an empirical stimulus is forthcoming and therefore increases preparation (Surburg, 1985). An important aspect of preparation is expectancy, or the subjective probability of the delivery of a stimulus (Naatanen & Merisalo, 1977). A popular method used to examine preparation and expectancy is the Donders type C task, which incorporates the random presentation of catch trials embedded within a block of empirical trials to invoke an uncertainty of occurrence (Buckolz & Rodgers, 1980; Donders, 1868; Gottsdanker, 1970; La Berge, 1971; Mowbray, 1964). Uncertainty of occurrence refers to a situation in which the participant is increasingly aware that an empirical stimulus will not be presented (Naatanen, 1972). During a catch trial a warning signal is followed by the absence of an empirical stimulus, which precludes the participant from completing the task. Presumably this type of experimental distraction will prolong the temporal processing required for an efficient motor response. Reaction time is often slower when catch trials are included within a response time protocol than when an uncertainty of occurrence is omitted (Drazin, 1961; Gordon, 1967). It has also been found that the presence of catch trials increases the RTs of children (Ozmun, Surburg, & Cleland, 1989); however these data are lacking for children with motor processing deficiencies, like ADHD.

The purpose of this study was to investigate the lower extremity movement preparation (RT) and movement execution (MT) of children with and without ADHD as a function of catch trial frequency and target direction. The working hypotheses for this investigation are increased catch trial frequency and movement complexity will negatively affect the movement preparation of children with ADHD and will have no effect on the group of children without this disorder. This type of investigation may provide insight into the perceptual-motor processing ability of children with ADHD.

**Method**

**Participants**

Twelve boys ($n = 9$; mean age = 8.42 years ± 6 months) and girls ($n = 3$; mean age = 8.33 years ± 3 months) with ADHD and twelve control participants matched on age (+/- two months), gender, hand and leg preference participated in this study.
Each participant and the parent/guardian of each participant provided informed consent in accordance with guidelines established by the university’s office of human research and the Declaration of Helsinki.

Children with ADHD were recruited from local pediatric outpatient units and diagnosed with ADHD by a team of qualified child psychiatrists via the guidelines of the *Diagnostic and Statistical Manual of Mental Disorders* issued by the American Psychiatric Association (2000); ADHD subtype was not assessed by this team of professionals. Children without ADHD were recruited from a community sample. All participants were free of any comorbid disorders and had a verbal-IQ rating score of at least 80, using the short form of the Wechsler Intelligence Scale for Children–III (Wechsler, 1992) to ensure that delays were not due to intellectual disability. Participants with ADHD were required to be withdrawn from their medication for at least 24 hours before the test was administered (Whitmont & Clark, 1996).

**Apparatus**

The custom-built aiming apparatus was a floor mounted wooden board (146 cm by 61 cm) consisting of a releasable microswitch (i.e., start pad) located 17 cm from the front edge of the apparatus, and three target pads, each defined by a 10 cm diameter hardened rubber target and red light-emitting diode (LED). The three target positions required 35.6 cm of lower-limb displacement from the start pad and were oriented 0 degrees relative to the start pad (i.e., the midline target) and 45 degrees to the left and right of midline (see Figure 1). Additionally, a yellow LED, located 20 cm directly anterior to the midline target LED, served as a fixation point and catch trial stimulus. For data collection, a portable laptop computer interfaced through a standard parallel printer port recorded the temporal measures associated with this task. Custom-built computer software generated randomized blocks of trials and stimulus presentations.

![Figure 1 — Response time apparatus.](image)
Procedures

Each participant was tested on an individual basis in an isolated room with adequate lighting. Each testing session lasted approximately 30 min and involved goal-directed aiming movements performed with the left and right leg. A total of 108 lower extremity trials were collected for each participant. The protocol called for two days of data collection; each participant was randomly assigned to be tested for either the 10% catch trial condition or the 30% catch trial condition first. All participants were tested in the morning because researchers have reported that the performance of children with ADHD is optimized at this time (Zager & Bowers, 1983).

Before data were collected, each participant engaged in an orientation session to familiarize himself/herself with the data collection procedure. Each participant had a minimum of six practice trials (three with each foot) per condition until they demonstrated an acceptable level of competence performing the task. During this orientation session upper and lower extremity preference tests were performed. Upper extremity laterality was determined using the Edinburgh Inventory (Oldfield, 1971). Lower extremity laterality was assessed by asking the participant to ascend a set of stairs, kick a soccer ball, and finally step on an imaginary bug. The leg used as the swing leg in two out of the three tasks was determined the preferred extremity (Gabbard & Hart, 1996).

To measure response speed (RT and MT) of the lower extremities, each participant was required to sit during testing with his/her shoes off. To establish a midline in the seated position, the participant sat with his/her non-testing leg off to the side of the apparatus so that the femur of the testing leg was aligned with the start pad and the midline target pad. The participant was asked to attend to the fixation point prior to each trial. A randomly selected foreperiod, of either 1.5, 3.0, or 4.5 seconds, preceded the onset of the target stimulus LED. Once the randomly selected target stimulus was illuminated, the participant was instructed to move his/her leg to the corresponding target pad as quickly as possible. Performance of the left and right legs was completed in separate trial blocks, with the order of the start leg counterbalanced across participants. Within a trial block, the participant completed nine trials to each of the three target positions (i.e., contralateral, midline, and ipsilateral) based on stratified random presentation. The addition of catch trials to each testing condition included either three catch trials (10% condition) or nine catch trials (30% condition) within the random assignment of 27 empirical trials. 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. Any type of premature response during a catch trial situation was considered an anticipation error. No specific verbal knowledge of results was provided during the testing session.

Independent variables manipulated in this analysis included group (children with ADHD and children without ADHD), stimulus occurrence uncertainty (10% catch trials and 30% catch trials), and movement direction (contralateral, midline, and ipsilateral). The dependent variables measured in this study were RT (time from presentation of stimulus light to release of pressure from the start pad) and MT (time from release of pressure from the start pad until contact with the target pad). Only significant interactions and effects are reported below. Tukey’s post
hoc test was applied if further investigation was indicated. Intraclass correlations were first calculated to determine the reliability of the lower extremity RT and MT scores for the two groups across testing days.

**Results**

**Reliability**

The reliability coefficients for both dependent variables in both groups of children ranged between 0.93 to 0.98. This finding is in accordance with past investigations of reliability using this apparatus to assess RT and MT in atypical populations (Eason & Surburg, 1993; Surburg & Eason, 1999).

**Independency of Dependent Variables**

The relationship between RT and MT for the two groups across both conditions of uncertainty was low. The correlation coefficients ranged from $r = -0.02$ to $r = 0.30$. Based on the statistical independence of these two variables, RT and MT were inferentially analyzed through separate ANOVAs.

**Reaction Time**

To test these data, we utilized a three-way mixed ANOVA with group as a between factor, and stimulus occurrence uncertainty and movement direction as repeated measures factors. There was a significant interaction between group and stimulus occurrence uncertainty, $F(1, 22) = 6.29, p = 0.02$ and a significant main effect for movement direction, $F(2, 44) = 15.03, p < 0.01$. As depicted in Figure 2, simple

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**Figure 2** — Group by stimulus occurrence uncertainty for reaction time.
main effects for the interaction indicated that children with ADHD had significantly slower RTs than the control group for the 30% catch trial condition, $F(1, 22) = 6.66, p = 0.01$ but not the 10% catch trial condition, $F(1, 22) = 1.03, p = 0.32$. Tukey’s post hoc tests for the significant direction main effect indicated that the contralateral RTs (532 ms) were significantly slower when compared to the midline (503 ms) and ipsilateral (497 ms) directions for all children in this age range (at the $p = 0.01$ alpha level).

**Movement Time**

The MT dependent variable, also analyzed by a three-way mixed ANOVA using the same factor distribution, demonstrated a significant main effect for stimulus occurrence uncertainty, $F(1, 22) = 10.82, p < 0.01$. The MTs of all children were significantly slower for the 10% catch trial condition (302 ms) compared to the 30% catch trial condition (282 ms).

**Effect Size**

We further evaluated the meaningfulness of these findings by investigating the effect size, or the strength of association, between the mean differences of the dependent variables (Thomas, Salazar, & Landers, 1992). Eta-squared values of 0.80, 0.50, and 0.20 are considered to represent large, moderate, and small treatment effects, respectively (Cohen, 1988). Eta-squared values for the interactions and main effects found in the analyses of these two dependent variables ranged between 0.76 and 0.90. These large effect sizes provide support for the interpretation of our inferential findings.

**Within Participant Variability**

Two separate 2 (group) × 2 (stimulus occurrence uncertainty) mixed ANOVAs were conducted on the dependent variables using the standard deviations scores, instead of the means, to determine if the within participant variability of this sample contributed to the findings. There was a significant group main effect for RT, $F(1, 22) = 13.67, p < 0.05$. Movement preparation was significantly more variable in the group of children with ADHD than their age-matched peers (ADHD $s = 133$ ms; control $s = 104$ ms). There was also a significant group main effect found for MT, $F(1, 22) = 9.68, p < 0.05$. Again, children with ADHD had significantly more variable movement execution than their non-affected peers (ADHD $s = 106$ ms; control $s = 65$ ms).

**Discussion**

The most common neurological-based symptoms of ADHD include hyperactivity and inattention (Barkley et al., 1992). Inattention, some researchers believe, is the cause of the information processing delays experienced by these children (Reid & Borkowski, 1984; Whitmont & Clark, 1996; Yan & Thomas, 2002). Since movement tasks require attention of some type, an attention deficit can be expected to produce inferior results on these tasks, particularly on tasks in which
the participant cannot control the arrival of the stimuli (Rosenthal & Allen, 1978; Sykes, Douglas, & Morgenstern, 1972); however, whether or not attentional focus is solely responsible for this unwelcome perceptual-motor behavior remains to be determined. To discern if the deficits in information processing characteristic of children with ADHD are a function of movement task preparation and/or cross lateral integration the present study was conducted.

Stimulus Uncertainty of Occurrence

Our findings indicated that children with ADHD demonstrated significantly slower RTs than age- and gender-matched peers when catch trial frequency was increased (30% of the responses) but had similar RT performance when catch trial frequency was decreased (10% of the responses). It appears that children with ADHD were more hesitant with the initiation of their movements when there was greater likelihood that an empirical stimulus would not be presented. This hesitancy was not displayed by the group of normal developing peers; in fact, this group was slightly faster to respond when there was an increased percentage of catch trials. Several others have suggested that an individual’s willingness to prepare a response for subsequent trials is affected by the decreased likelihood that a response will occur (Buckolz & Rodgers, 1980; Gottsdanker, 1970; Mowbray, 1964; Surburg, 1985). Our findings support that response completion may influence preparation for future attempts, especially in children with ADHD. It is well documented that children with ADHD process information slower than age-matched peers (e.g., Harvey & Reid, 2003; Sheppard et al., 2000; Vickers et al., 2002; Yan & Thomas, 2002); however, the results of our study indicate that this behavioral anomaly may be a function of uncertainty of occurrence. When overall body tension is established and not released, this may create a hindrance to efficient motor processing reducing a participant’s willingness to prepare appropriate responses in subsequent trials (Ozmun et al., 1989). Children who have difficulty with processing information, like children with ADHD, may be more vulnerable to stimuli manipulation, causing a deleterious effect on preparing for a movement task.

When a catch trial is substituted for an empirical trial, peak readiness is sustained for a longer time period. This may result in a type of mental fatigue (Naatanen, 1972). It is possible that when removed from their stimulant medication, children with ADHD may be more prone to this symptom of prolonged anticipation when faced with an increased chance of uncertainty. When not aided by stimulant medication, these children must contend with the symptoms of their disorder (e.g., hyperactivity and/or inattention). The minor distraction of a catch trial may trigger these impeding behaviors, which then become competing stimuli during testing. Unfortunately, there are no available data to corroborate this finding in children with ADHD.

Cross Lateral Integration

By using a choice response time apparatus to measure the speed of contralateral movements that required midline crossing and ipsilateral movements that did not require midline crossing, we were able to index cross lateral integration in a corpus of children with and without ADHD. Our lower extremity assessment of this
developmental motor milestone indicated that this ability had not been achieved by any of the children in our sample. Several investigations assessing upper extremity responses have suggested that normal developing children are able to integrate cross lateral movements by the age of eight or nine (Ayres, 1972; Cermack et al., 1980; Schofield, 1976; Stilwell, 1981). The validity of these tests to predict the achievement of this motor milestone, however, has been brought into question (Eason & Surburg, 1993). These authors suggested that cross lateral integration could be measured using choice RT scores to provide an index of information processing speed. Others have suggested that lower extremity motor performance may provide more accurate information into the developmental maturity of the central nervous system (Li et al., 1991; Peters, 1988, 1990; Surburg & Eason, 1999). Explanations of these findings may be the sensitivity of using RT to quantify information processing ability, or lower extremity assessment is a better indicator of developmental maturity. At the present time, it remains unclear when this developmental motor milestone is realized by children with and without ADHD using this protocol.

The results of our study indicate that the movement preparation speed exhibited by children with ADHD is a function of task complexity. This finding is in agreement with previous work from our laboratory (Pedersen & Surburg, 2005; Pedersen et al., 2004). It appears that the lower extremity motor behavior of these children may be quite revealing concerning their developmental motor maturity. The complexity of our protocol was more difficult to negotiate for this group of children as evidenced by the group mean comparisons. In addition, this was illustrated by the significantly greater within participant variability demonstrated by the group of children with ADHD for both dependent variables. The high variability commonly associated with the motor behavior performance of children with ADHD should be a concern for those who research this disorder and should be documented statistically for comparative purposes.

**Movement Time**

The analysis of MT, when using a choice response time protocol, is a bit more difficult to interpret. Factors such as movement direction, movement amplitude, and incompatible agonist/antagonist muscle synergies create comparative issues that reduce the accuracy of peripheral temporal analysis (Anson, 1982). In light of this, we found that all children had significantly slower MT for the condition with fewer catch trials compared to the condition with greater catch trials. This difference may be the result of greater muscle tension built up during the latter condition, which may have created a potentiation effect in the large muscles responsible for lower extremity movement. Since this variable did not interact with any other independent variables (group, direction), this finding may simply be due to the biomechanical constraints associated with the nature of this task (Carey, Hargreaves, & Goodale, 1996). Considering groups did not differ for the MT variable, it appears that response time differences for children with and without ADHD can be isolated to movement preparation and not movement execution.

To our knowledge, no other studies have reported lower extremity MT differences between children with and without ADHD. Previous studies concerning the influence of stimulant medication on upper extremity MT of children with ADHD
demonstrated no effect (Gordon & Kantor, 1979; Hefley & Gorman, 1986; Reid & Borkowski, 1984). When assessing the lower extremities, however, Pedersen and Surburg (2005) reported that stimulant medication did in fact facilitate MT. The disparity in these reports warrants further investigation comparing the upper and lower extremity response time performance of children with coordination problems, such as ADHD.

In light of the findings reported herein, it is recommended that future research fractionate RT to better discern where these information processing deficits lie within the neuromuscular system of children with ADHD. Marzi et al. (1991) and others suggested that the additional processing time required for contralateral movements is associated with between-hemisphere communication (Aglioti et al., 1991; Brizzolara et al., 1994); therefore, simply using RT to infer about information processing may not be a sensitive enough measurement. Fractionating RT to remove motor time, or the peripheral processing component, from total response time may be better suited to differentiate children with and without ADHD regarding MCI. Future research is also needed to identify an age range that cross lateral integration is attained by normal developing children and children with developmental disabilities utilizing this midline crossing protocol. This type of investigation should measure the upper and lower extremity choice response time performance of a cross section of children (e.g., between the ages of 6 and 16) with and without disabilities. Accurate knowledge of this developmental phenomenon will enable practitioners to develop appropriate physical education curricula to meet the needs of all children.

In conclusion, the use of catch trials to influence the preparation of movement appears to affect specifically the RT processes of motor performance in children with ADHD. The differences found between children with and without ADHD were more apparent in the preparation (or central processing) phase of lower extremity movement as opposed to the actual movement execution. Our findings support that catch trials could be used to regulate the level of attention required for a motor response task by children with ADHD. Assessing this parameter with quantitative data can in turn be used to evaluate various teaching strategies to improve attention in this population of children. The findings of our report lead us to suggest that the increase in catch trial frequency, when using a lower extremity choice response time assessment, is a variable that may be able to identify motor characteristics of ADHD in developing children. The findings of this study make a strong case for the inclusion of lower extremity assessments when attempting to describe the perceptual-motor difficulties that accompany most developmental disabilities.

References


