The Relationship between Postural Control and Fine Manual Dexterity

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This is an Accepted Manuscript of an article published by Taylor & Francis in Physical & Occupational Therapy In Paediatrics 2008 available online: http://www.tandfonline.com/ http://dx.doi.org/10.1080/01942630802224934
Abstract

The influence of the development of postural control of the trunk and center of the body on the development of fine manual dexterity ability is a common assumption. The objectives of this study were: (1) to examine the relationship between the adult version of the Nine-Hole Peg Test and the “children’s version” in order to establish construct validity for the latter, and (2) to investigate the relationship between postural control and fine motor performance of children developing typically aged five to six. The study sample included 47 children, 25 males and 22 females, with a mean age of 5 years and 8 months and a standard deviation of 3.8 months. Two tests were administered: (1) The balance subtest of the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP; Bruininks, 1978); and (2) the Nine-Hole Peg Test (NHPT; Kellor, Frost, Silberg Iversen & Cumming, 1971), as well as the “children’s version” of rotation and translation tasks (Case-Smith, 1993, 1995). The adult version of the NHPT revealed significant moderate correlations with most of the BOTMP tasks for both hands. Secondary results of the study support the concurrent validity of the two “children’s version” tasks. Results show low to moderate correlations between performance on the NHPT subtests and the BOTMP subtest tasks, with significant correlations ranging from -.31 to -.47. Given the negative and low correlations obtained in this study, it is suggested that more extensive longitudinal research examine the relationship between postural control and fine motor manual dexterity performance.
Introduction

The influence of the postural control of the trunk and center of the body on fine manual dexterity ability is a common assumption (Shumway-Cook & Woollacott, 1995). The postural system is intimately linked with practically all central nervous system (CNS) centers that control muscular tension (tonus), process sensory information, and coordinate motor responses (Kohen-Raz, 1986). Specifically, the pyramidal system transmits “action plans” generated in the motor areas of the cortex. This system controls both the complex posture involving voluntary control as well as versatile maneuvers of arms, hands and fingers. The assumption that there is a strong relationship between postural control and fine motor abilities has influenced the study of the development of motor control, as well as treatment procedures in occupational and physical therapy (Ayres, 1974; Bobath, 1971; Bobath & Bobath, 1972; Case-Smith, Fisher, & Bauer, 1989; Farber, 1982; O’Brien & Hayes, 1995; Pedretti, 1996; Shumway-Cook & Wollacott, 1995; Stockmeyer, 1967). The development of trunk stability and central axis control is considered to be a prerequisite to upper extremity function and hand usage. It is hypothesized that proximal stability allows for the independent use of the arms and hands in manipulative and purposeful activity.

The reciprocal relations between posture and fine manual dexterity is evident in descriptions regarding the developmental sequence of acquiring movement control (Case-Smith et al., 1989; Gilfoyle, Gardy, & Moore, 1990, Pedretti, 1996). Observations of motor development suggest that children first gain control over the shoulder, followed by learning to coordinate fine movements of the elbow, wrist, and fingers (Skinner, 1979). Investigators have suggested that emerging balance reactions are necessary precursors to the acquisition of associated developmental milestones (Shumway-Cook & Wollacott, 1995). According to the sequence mentioned, skilled
movement requires complex patterns of muscular coordination based on motor patterns acquired during early life. All movements require constant change of posture and adjustment in the center of gravity (Erhardt & Cook Merrill, 1998). Upper extremity function, such as reaching, grasping, and manipulating objects requires a dynamic stability of the shoulder girdle on a stable trunk and an independent movement of the head and arms from the shoulders (Scherzer & Tscharnuter, 1990).

Postural control or balance refers to the ability to maintain the center of body mass or a body part over a stable or moving base of support (Crutchfield, Shumway-Cook, & Horak, 1989). It is actually the ability to control the body’s position in space for the purpose of stability and orientation (Shumway-Cook & Wollacott, 1995).

The ability of people to use their hands in order to accomplish everyday activities depends on the anatomical integrity, sensation, coordination, strength, and dexterity of the hands (Backman, Cork, Gibson, & Parsons, 1992). The purpose of this study is to investigate the relationship between postural control and one aspect of hand function—fine manual dexterity or the manipulative skill. The term “dexterity” is defined by Latash & Turrey (1996) as a “harmony in movements” (pp. 20). Dexterity is a type of fine coordination usually demonstrated in upper extremity function (Kohlmeyer, 1998). In the literature, some authors refer to dexterity as the performance measured by pegboard tests and similar tasks, without providing a specific definition (Kellor, Frost, Silberberg, Iversen, & Cummings, 1971; Mathiowetz, Weber, Kashman, & Volland, 1985). Others make a connection between dexterity and fine motor coordination and suggest that the latter can be defined as the smooth and harmonious action of groups of muscles working together to produce a desired motion. In-hand manipulation typically develops during the ages of 1 through 7 years. The term refers to the movement of an object within a person’s hand, such as retrieving coins from a
purse or pocket, moving them from fingers to palm, and back from palm to fingers in order to insert them into a machine slot, one at a time (Exner, 1989).

In the present study, dexterity or the manipulative skill is defined as fine, voluntary movements used to manipulate small objects during a specific task. In order to evaluate both simple hand dexterity and the in-hand manipulation skills, two different tests were used: The original Nine Hole Peg Test (NHPT) (Mathiowetz et al., 1985) to evaluate simple hand dexterity, and two tasks developed for the evaluation of in-hand manipulation in children (Case-Smith, 1991). For the purpose of this study, these two additional tasks will be termed the “children’s version.”

Studying the relation between the stability mechanism and hand functioning, Amiel-Tison and Grenier (1980) observed that proper posture and/or support provided for newborns enabled them to perform more movements in space. Richards, Olson, and Palmiter-Thomas (1996) observed that changes in forearm position resulted in changes in grip strength, although the rest of the body remained in the same position. Grip strength in both hands was strongest when the forearm was supinated (in an anatomical position) and weakest when pronated. A study conducted for the validation of the Bruininks-Oseretsky Test of Motor Proficiency found a positive correlation (r=.67) between equilibrium reactions, posture and fine manual dexterity (Bruininks, 1978).

Samson & De-Groot (2000) indicated that poor postural control had a significant influence on several domains of development, including hand function. Smyth & Mason (1998) emphasized that the proprioceptive system is an important basis for a good performance on complex tasks such manual dexterity and balance. Jeka & Lackner (1995) found that light touch cues from the fingertips in conjunction with
proprioceptive signals about arm configuration provide information about body sway that can reduce mean sway amplitude through postural muscle activation.

In a study focused on evaluating treatment efficacy, Tojo (1998) found an immediate change of posture as a result of the treatment for the upper extremity. In addition, improvement of hand reaching performance resulted from increasing postural stability (Fallang, Saugstad, & Hadders-Algra, 2000).

The assumption of a relationship between postural control and fine motor dexterity is commonly among occupational and physical therapists during evaluation and treatment procedures. The few studies of postural control and fine manual ability that do exist are not recent, and focus on laboratory research with monkeys or clinical research with children (Case-Smith et al., 1989).

Neurophysiological studies found that there are separate motor control systems in the brain for postural control and fine motor function (Kuypers, 1963; Lawrence & Kuypers, 1965, 1968). Other studies conducted with monkeys have found that these postural control and fine motor functions are developed in a predictable sequence. The motor system of the arm is organized mainly at the level of the brain stem and usually matures before the distal motor system of the palm is organized at the cortical level (Lawrence & Hopkins, 1972). In a later study conducted by Fontaine and le-Bonniec (1988), it was found that the absence of postural control during the first months of life can be considered an obstacle to the expression of prehension. Although the importance of posture has been demonstrated, these studies do not provide evidence that fine motor control is dependent on postural control.

It is important to understand the developmental sequence of manual functioning and the variables influencing it, as limitations in manual dexterity functioning, can cause difficulties in everyday life. The assumption regarding the reciprocal relations
between posture and hand functioning needs to be established scientifically. Unless such studies are conducted, one cannot rely on the theories assuming that postural control is necessary for the development of fine motor skills (Case-Smith et al., 1989). The purpose of this study was to analyze the relationship between postural mechanisms and manual dexterity in 5 to 6 year old children developing typically.

The objectives of the current research are:

1. To examine the relationship between the adult version of the Nine-Hole Peg Test and the children’s version in order to establish construct validity for the children’s version.

2. To examine the relationship between postural mechanisms, as tested by the balance subtest of the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP), and the fine motor skill of manual dexterity, as tested by the two versions of the Nine-Hole Peg Test (NHPT).

Method

Participants

A convenience sample of 47 kindergarten children developing typically, included 25 males and 22 females. Children with developmental disabilities, those who were being treated with Ritalin, and those with mixed dominance were excluded from the study. Demographic data was collected from the parents. (See table 1)

Insert table 1 about here

Instruments

Participants were tested individually in sessions lasting 30 to 35 minutes. Arm and leg preference were determined prior to testing, using the criteria of the
Bruininks-Oseretsky Test of Motor Proficiency (BOTMP; Bruininks, 1978). The following tests were administered: The balance subtest of the BOTMP and the Nine-Hole Peg Test (Kellor, Frost, Silberberg, Iversen, & Cummings, 1971), with the addition of the rotation and translation tasks (Case-Smith, 1993, 1995) for the children’s version used in this study.

The Bruininks-Oseretsky Test of Motor Proficiency (BOTMP; Bruininks, 1978) is a standardized battery for children 4.5 to 14.5 years that provides a comprehensive index of motor proficiency, as well as separate measures of gross and fine motor skills (e.g., Beyer, 1999; Jobling, 1999; O’Brien & Hayes, 1995). The test is divided into eight subtests: four gross motor tasks, three fine motor tasks, and one combined task. In this study, the 8 tasks of the balance subtest were administered. Scoring for these tasks was measured by seconds or by the number of steps completed within a set time. Raw scores were converted to the point scores scale for each item, with a range from 0 to 1 or from 1 to 15 points. Reliability studies indicate fair to good test-retest and interrater reliability for the total test and for the short form of the test (.80) (King-Thomas & Hacker, 1987; Wilson, Polatajko, Kaplan, & Faris, 1995). The balance subtest has the lowest test-retest reliability (.49).

Two versions of the Nine-Hole Peg Test (NHPT) were used in this study: the adult version (age 20-94), developed by Kellor et al. (1971); and the “children’s version” (age 5 and up), developed by Case-Smith (1991). The adult version is a quick, standardized measure commonly used to test finger dexterity. In the original NHPT test, subjects were asked to rapidly place small pegs one at a time into nine holes and then remove them, using each hand independently. Scoring for this test was measured in seconds for each hand (Mathiowetz et al., 1985). Test-retest reliability for the right-hand was .69 and for the left-hand, .43. Interrater reliability for the right-
hand was .97 and for the left-hand, .99 (Mathiowetz et. al., 1985). Validity, reliability and norms have not yet been established for the children’s version.

Widner and Presson (1998) conducted a study to estimate the reliability of the NHPT test with elementary school children and found high interrater agreement (.98) and moderate test-retest reliability (.72). Smith et al. (2000) established norms for the test on elementary school children aged 5 to 10.

Studies using the “children version” of the Nine-Hold Peg Test were characterized by variations of the test tasks, tasks, and administration (Case-Smith, 1991, 1993, 1998; Mathiowetz et al., 1985; Smith, Hong, & Presson, 2000). Therefore, we decided for the purpose of this study to use the original adult instrument (Mathiowetz et al., 1985) and to incorporate Case-Smith’s (1991) method and tasks. According to Case-Smith’s (1991) children’s version, two sub-tests were added to investigate two components of in-hand manipulation: translation and rotation. In the translation task, subjects were asked to pick pegs (up to 5) out of the board one by one, hide them in the palm and then to bring them out back to the board. In the rotation task, subjects are asked to grasp each peg, turn it over, and replace it in its original hole (Case–Smith, 1991). This task was performed twice. Scoring for this test was measured in seconds for each hand separately.

For the purpose of this study, an overall score was computed by adding the two scores of the original NHPT scores (dominant and non-dominant hand) and the six scores of the two children’s version subtests.

**Data Collection**

The first author carefully trained three research assistants, and interrater reliability was determined (r = .97). The children were individually tested in their
kindergarten classes. Half of the participants performed the BOTMP first, and the other half performed the NHPT first, to counterbalance learning effects from one test to the other. Both assessments were administered according to the procedures outlined in the training manuals.

**Statistical Analysis**

Descriptive statistics of group performance on the two different assessments were calculated correlations between performance on the NHPT and the BOTMP, as well as group performance of the NHPT subtests, performed using Pearson correlation coefficients.

**Results**

Mean performance and standard deviations on the different subtests of the NHPT are presented in table 2, with the scores representing time performance in seconds. Performance with the dominant hand was better than with the non-dominant hand in all subtests. Performance increased during the second trial.

Insert Table 2 about here

Mean performance and standard deviations on the different tasks of the BOTMP balance subtest are presented in Table 3.

Insert Table 3 about here

Pearson correlations between the NHPT and the children’s versions were calculated. The correlations between the children’s version tests and the total NHPT score ranged from 0.53 to 0.69 for rotation tasks and 0.75 to 0.75 for the translation tasks. Results show low to moderate correlation between performance on the NHPT
subtests and the BOTMP tasks, as presented in Table 4. No differences between gender and performance were obtained on either the NHPT or the BOTMP tests.

Insert Table 4 about here

Discussion

In examining the relationship between the adult version of the Nine-Hole Peg Test and the children’s version, the correlations between the overall NHPT score and the two children’s tasks were high. Although the addition of the two children’s tasks is important for sufficient assessment of dexterity, the reliability, validity and norms of the children’s version have not yet been established. In the current study, construct validity for the children’s version with the original NHPT was established but only for the total NHPT score.

Results of this study show very low correlations among the balance tasks of the BOTMP and the fine motor skill of dexterity, as measured by the two versions of the NHPT. The highest correlation of $r = -0.47$, $p<.001$ was found between the NHPT subtest of transferring with the non-dominant hand and the BOTMP tasks of standing with eyes closed. Thus, the main question posed by this study regarding the relationship between postural control and dexterity was negatively answered.

The literature on motor control suggests that postural adjustments are a part of the motor program for arm and hand movements (Lee, 1980; Schmidt & Wrisberg, 2000). When arm movements are organized, the motor program contains instructions to adjust posture and move the arm, so that the action is performed as a coordinated whole. Hence, hand movements and postural control are different parts of an integrated action that raises the arm while maintaining balance. Although these parts are combined and dependent on each other, no significant correlations were found in the current study between the two variables.
Case-Smith et al. (1989) studied the relationship between proximal and distal motor control with a sample of 60 normal infants ranging in age from two to six months. Postural and fine motor control were measured by respective sections of the Posture and Fine Motor Assessment of Infants (PFMAI; Case-Smith, 1987). The fine motor section of the assessment measures the developmental level of a wider range of hand function components than those measured in the current study: reach, grasp, and manipulation of objects. The findings of the Case-Smith et al. study were similar to our findings, as fine motor control was not strongly associated with postural control. The total postural scores explained only about 12% of the variance in the total fine motor scores. Overall, these low correlations are consistent with the results from Loria (1980) and Wilson and Trombly (1984), and do not provide strong support that these two aspects of motor function are developmentally dependent.

We strongly suggest that the relationship between postural control and fine motor skill be studied in larger and more representative samples. For instance, longitudinal studies could determine how the development of postural control is related to the development of relatively independent finger control (Von Hofsten, 1993a; b).

Limitations

There are three main limitations in this study. The first is the relatively small size of the groups under investigation, and the second is the lack of random sample selection. The third limitation is the fact that only one BOTMP subtest, rather than the whole test, was used. During three of the tasks-- standing on one’s preferred leg on the floor, walking forward on a demarcated line, and walking forward on a balance beam -- all subjects acquired the highest score, indicating that there is a ceiling effect. Although this test is widely used in the clinical setting, one must be cautious in
interpreting assessment results, specifically in the ages of 5 to 6, for those three tasks of the balance subtest. Consequently, care must be exercised in generalizing from this specific sample.

**Implications and future research**

Many school-aged children are referred to occupational therapy for intervention due to handwriting difficulties. The “postural and fine motor control relationship” assumption leads clinicians to focus on postural control in order to enhance performance of the child’s hands. This relationship was not supported by the results of this study. The assumption that these two system work together in a combined way (Schmidt & Wrisberg, 2000) does not assure that the level of activity in each system will correlate with the other.

**Acknowledgements**

We would like to thank Carmel Livyatan, Yael Grinberg and Keren Oster for the collaboration and assistance in data collection.
References


Table 1

Demographic Characteristics of the Sample (n=47)

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<tr>
<th></th>
<th>Range</th>
<th>Mean</th>
<th>Standard deviation</th>
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</thead>
<tbody>
<tr>
<td>Age (in months)</td>
<td>60-72</td>
<td>69.98</td>
<td>3.84</td>
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<tr>
<td>Height (in cm)</td>
<td>101-126</td>
<td>117.11</td>
<td>5.38</td>
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<tr>
<td>Weight (in kg)</td>
<td>14-31</td>
<td>21.44</td>
<td>3.26</td>
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<table>
<thead>
<tr>
<th></th>
<th>Frequencies</th>
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</tr>
<tr>
<td></td>
<td>Female</td>
<td>22</td>
</tr>
<tr>
<td>Dominance</td>
<td>Right</td>
<td>41</td>
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<tr>
<td></td>
<td>Left</td>
<td>6</td>
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Table 2
Descriptive Statistics for the Nine-Hole Peg Test and Two Added Tasks Performance
(In Seconds) (N=47)

<table>
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<tr>
<th>Subtest</th>
<th>Mean</th>
<th>Standard Deviation</th>
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<tr>
<td>Dominant hand (NHPT-Adults)</td>
<td>31.75</td>
<td>6.26</td>
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<tr>
<td>Non-dominant hand (NHPT-Adults)</td>
<td>33.71</td>
<td>6.08</td>
</tr>
<tr>
<td>Rotation dominant hand I</td>
<td>13.37</td>
<td>3.08</td>
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<td>Rotation dominant hand II</td>
<td>12.10</td>
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<td>Rotation non-dominant hand I</td>
<td>13.83</td>
<td>3.90</td>
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<tr>
<td>Rotation non-dominant hand II</td>
<td>14.58</td>
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<tr>
<td>Translation dominant hand</td>
<td>20.93</td>
<td>7.76</td>
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<tr>
<td>Translation non-dominant hand</td>
<td>23.15</td>
<td>6.04</td>
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Table 3
Descriptive Statistics for BOTMP Balance Subtest Performance (n=47)

<table>
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<tr>
<th>Subtest</th>
<th>Range</th>
<th>Mean</th>
<th>SD</th>
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<tr>
<td>Standing on preferred leg on floor</td>
<td>0-4</td>
<td>3.80</td>
<td>0.50</td>
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<td>Standing on preferred leg on balance beam</td>
<td>0-6</td>
<td>3.40</td>
<td>1.98</td>
</tr>
<tr>
<td>Standing on preferred leg on balance beam, eyes closed</td>
<td>0-7</td>
<td>1.40</td>
<td>1.00</td>
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<tr>
<td>Walking forward on walking line</td>
<td>0-3</td>
<td>3.0</td>
<td>.00</td>
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<tr>
<td>Walking forward on balance beam</td>
<td>0-4</td>
<td>3.12</td>
<td>1.09</td>
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<tr>
<td>Walking forward heel-to-toe on walking line</td>
<td>0-3</td>
<td>2.44</td>
<td>0.87</td>
</tr>
<tr>
<td>Walking forward heel-to-toe on balance beam</td>
<td>0-4</td>
<td>1.36</td>
<td>0.91</td>
</tr>
<tr>
<td>Stepping over response speed stick on balance beam</td>
<td>0-1</td>
<td>0.28</td>
<td>0.46</td>
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<tr>
<td>Final score</td>
<td>0-30</td>
<td>19.00</td>
<td>4.26</td>
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**Table 4**

Correlation between Performance on BOTMP and Nine-Hole Peg Test

<table>
<thead>
<tr>
<th></th>
<th>Standing on floor</th>
<th>Standing on beam</th>
<th>Standing eye close</th>
<th>Walking on beam</th>
<th>Heel-to-toe line</th>
<th>Heel-to-toe beam</th>
<th>Stepping</th>
<th>Bilateral</th>
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<td>-.31*</td>
<td>-.32</td>
<td>.05</td>
<td>-.33*</td>
<td>-.46**</td>
<td>-.31</td>
<td>-.34*</td>
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<tr>
<td>N. Dominant</td>
<td>-.27</td>
<td>-.46**</td>
<td>-.43**</td>
<td>-.15</td>
<td>-.25*</td>
<td>-.33*</td>
<td>-.22</td>
<td>-.44**</td>
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<tr>
<td>Rote D I</td>
<td>-.08</td>
<td>-.09</td>
<td>-.06</td>
<td>-.08</td>
<td>-.14</td>
<td>-.20</td>
<td>-.40**</td>
<td>-.14</td>
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<tr>
<td>Rote D II</td>
<td>-.02</td>
<td>.03</td>
<td>-.10</td>
<td>.09</td>
<td>-.18</td>
<td>-.19</td>
<td>-.12</td>
<td>-.04</td>
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<tr>
<td>Rote ND I</td>
<td>-.20</td>
<td>-.19</td>
<td>-.35*</td>
<td>-.18</td>
<td>-.09</td>
<td>-.29</td>
<td>-.21</td>
<td>-.25</td>
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<tr>
<td>Rote ND II</td>
<td>-.02</td>
<td>-.10</td>
<td>-.30*</td>
<td>.03</td>
<td>-.15</td>
<td>-.12</td>
<td>-.30*</td>
<td>-.14</td>
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<tr>
<td>Translation D</td>
<td>-.29</td>
<td>-.40**</td>
<td>-.42*</td>
<td>-.09</td>
<td>-.20</td>
<td>-.42*</td>
<td>-.45**</td>
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<td>Translation ND</td>
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<td>-.33*</td>
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<td>-.15</td>
<td>-.22</td>
<td>-.45**</td>
<td>-.10</td>
<td>-.42**</td>
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Dominant = Dominant hand (NHPT-Adults)
N. Dominant = Non-Dominant hand (NHPT-Adults)
Rote I= Rotation Dominant hand I
Rote II= Rotation Dominant hand II
Rote ND I= Rotation non-Dominant hand I
Rote ND II = Rotation non-Dominant hand II
Translation D = Translation Dominant hand
Translation ND = Translation non-Dominant hand

* p< .05
** p< .001