The Journal of Physical Therapy Science

Original Article

Relationships between grip strength, dexterity, and fine hand use are attenuated by age in children 3 to 13 years-of-age

Richard W Bohannon, PT, EdD[1)]*, Ying-Chih Wang, OT, PhD[2)],
Catherine Noonan, PT, DPT[1)]

[1)] Department of Physical Therapy, College of Pharmacy and Health Sciences, Campbell University: Lillington, NC, USA
[2)] College of Health Sciences, University of Wisconsin-Milwaukee, USA

Abstract. [Purpose] The purpose of this secondary analysis of data from the validation phase of National Institutes of Health Toolbox study was to describe the relationship between grip strength, dexterity, fine hand use, and age. [Participants and Methods] Children 3 to 13 years (n=132) contributed data. Grip strength was measured bilaterally with a Jamar dynamometer. Dexterity was measured bilaterally with the Nine-hole Peg Test. Fine hand use was characterized using 5 items of the Bruininks Oseretsky Test of Motor Proficiency. [Results] All grip strength and dexterity and fine hand use measures were correlated moderately to highly with one another and with age. The Cronbach's alpha for all measures was 0.88. Factor analysis suggested that all measures loaded strongly on a single component with the first factor explaining 75.6% of the total variance. Nevertheless, correlations between grip strength and dexterity and fine hand use measures were mostly negligible after controlling for age. [Conclusion] As moderate to strong relationships between grip strength and dexterity and fine hand use are attenuated by age in children of 3 to 13 years, we cannot recommend the use of any one measure over others to characterize motor function of the hand.
Key words: Pediatrics, Hand, Function

INTRODUCTION

As part of normal development, children's upper limbs demonstrate age-related gains in motor function. Prominent among such gains are increases in grip strength and improvements in dexterity and fine hand use (DFHU)[1, 2]. Hand-grip dynamometry is well ensconced as a test of upper limb strength in children[2–4]. Several options, however, have been recommended for measuring DFHU in children[5]. These include, but are not limited to, the Nine-hole Peg Test[2, 6, 7] and components of the Bruininks Oseretsky Test of Motor Proficiency (BOT)[8].

While measurements of DFHU have been shown to be related to one-another in children[7], relationships between measurements of grip strength and DFHU have not been described in this population. Such a delineation has practical implications—for if the measurements are highly related and reflective of a common construct (demonstrate convergent validity), conducting only one test or a subset of tests may suffice and save time. On the contrary, if some of the measurements are not related significantly and reflect different constructs (demonstrate discriminant or divergent validity), administering more than one test may be advisable.

The purpose of this secondary analysis of data from the validation phase of the National Institutes of Health (NIH) Toolbox project[9], therefore, was to describe the relationship between grip strength and DFHU in children 3 to 13 years of

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age. We anticipated that grip strength as measured with a grip dynamometer and DFHU as measured by the Nine-hole Peg Test and 5 component items of the BOT would be highly correlated and reflective of a single construct.

PARTICIPANTS AND METHODS

The NIH Toolbox validation project was initiated to identify brief performance measures applicable across the age span. It was approved by the institutional review boards of Northwestern University, NorthShore University Health Systems, University of Connecticut, and University of California, Los Angeles. Testing was conducted at the Rehabilitation Institute of Chicago, University of Connecticut, and University of California, Los Angeles, over a 4 month period (June–September) of 2009.

Convenience samples of apparently healthy, English or Spanish speaking, community-dwelling individuals 3 to 85 years of age were enrolled at the 3 sites. As our interest was in children and fine hand use only participants of 3 to 13 years of age were included in this analysis. Because of the participants' age, consent was obtained from a parent or guardian and assent was obtained from the children themselves.

Before testing began, information regarding age, gender, race/ethnicity, and dominant upper limb was obtained, as were height and weight. Thereafter, motor domain items were administered in a consistent order with rest provided as required. The present study focused on grip strength (left and right), Nine-hole Peg Test (left and right), and 5 BOT fine hand use items (preferred hand): 1) making dots in circles, 2) transferring pennies, 3) placing pegs, 4) sorting cards, and 5) stringing blocks. All testing was performed while participants were seated. The 5 BOT items were completed while at a table.

Grip strength was measured with a digital Jamar hand-grip dynamometer with its handle in the second position. During testing participants' arms were placed by their sides, their elbows were flexed 90 degrees, and their forearms were in a neutral position. Participants performed one submaximal and 2 maximal force grasps of 3 to 4 seconds with each hand; they received verbal encouragement during the maximal efforts. The force in kg of the first maximal effort on each side was the criterion measurement in this study.

For the Nine-hole Peg Test, a plastic 9-hole (3 × 3) peg board attached to a shallow molded dish was placed at mid-chest height, directly in front of the participants. To perform the test, participants were asked to move the pegs from the dish, to the pegboard, and back to the dish. They performed the task twice with each hand as fast as possible. A digital stopwatch was used to record the time in seconds to complete task. The time to complete the first trial on each side was the criterion measurement in this study.

For the BOT "making dots in circles" item, participants were provided with a pre-made score sheet printed with 80 circles. Participants held a pencil in their preferred hand and used it to make a dot in each circle. They practiced the task by placing dots in 5 circles before undertaking the actual test. The total number of circles with dots in them after 15 seconds was the criterion measurement in this study.

For the BOT "transferring pennies" item, participants were given a penny pad, pennies and a box (provided in test kit). The penny pad is marked with 20 penny circles on which pennies were placed. The penny pad was placed on the side of participants' preferred hand and the empty penny box was placed on the opposite side of the penny pad (participant's non-preferred side) on the square outline indicated for box placement. Participants were asked to pick up one penny at a time with their preferred hand, transfer it to their non-preferred hand, and then drop it into the penny box with their non-preferred hand. Instructions indicated that the hand should drop the penny over the box, not throw it into the box. Prior to item completion, the participant was given a practice round, dropping 3 pennies into the box. The number of pennies in the penny box after 15 seconds was the criterion measure in this study.

For the BOT "placing pegs" item, a box containing 30 pegs and a pegboard were placed in front of participants with the box of pegs on the side of their preferred hand. They held the pegboard with their non-preferred hand to stabilize it, picked up one peg at a time with their preferred hand, and placed it into the pegboard in any order. Participants performed a practice round with 3 pegs. The number of pegs put into the pegboard in 15 seconds was the criterion measurement in this study.

For the BOT "sorting cards" item, a deck of cards was placed in front of participants. The examiner placed 2 reference cards on either side of the deck, a card with a red square on one side of the deck and a card with a blue circle on the other side. Participants were asked to sort the cards according to color. A practice round, involving three cards, was performed. The total number of cards correctly sorted in 15 seconds, not including the reference cards, was the criterion measure.

For the BOT "stringing blocks" item, the examiner placed 15 blocks and string in front of the participants. They picked up and strung the blocks one at a time using their preferred hand while holding the string with their non-preferred hand. An initial practice round, involving the stringing 3 blocks was performed. The total number of blocks strung in 15 seconds was the criterion measure.

Descriptive statistics were used to summarize the demographic characteristics of the sample and summarize grip strength and DFHU measures. We calculated an inverse score for the Nine-hole Peg Test so that scores were in concordance with other grip strength and DFHU scores (i.e., higher scores indicating better motor performance). To allow head-to-head comparison of all grip strength and DFHU items, we transformed raw scores to z scores prior to graphing. The relationship between grip strength and DFHU measures and age was examined using Pearson and partial correlations. As more than 80 correlational hypotheses were tested, $p < 0.001$ was selected as significant. The recommendations of Mukaka were used to interpret the

magnitude of correlations: >0.9 (very high), 0.7 to 0.9 (high), 0.5 to 0.7 (moderate), 0.3 to 0.5 (low), and <0.30 (negligible correlation)[10]. The internal consistency of the GSDFHU measures was characterized using Cronbach's alpha. Factor analysis was used to describe the dimensionality of the grip strength and DFHU items, specifically we examined the factor loadings and variances explained by each factor. As suggested by Nunnally, items with factor loadings above 0.40 were considered informative[11].

RESULTS

Data from 132 of 144 children were included in the analysis (12 were missing data from 1 or more of the measures). Of the 132 children, 58 (43.9%) were males and 74 (56.1%) were females. By self-report, 115 (87.1%) of the sample was right hand dominant, and 98 (74.2%) were in excellent health. The sample consisted of White (36.4%, n=48), Asian (26.5%, n=35), Hispanic (22.0%, n=29), mixed (non-Hispanic) (8.3%, n=11), and Black (6.8%, n=9) participants. Table 1 presents the descriptive statistics of categorical data describing studying participants. Table 2 shows the summary of continuous data including age, height, body mass, and grip strength and DFHU scores.

Table 3 shows the Pearson correlations between the grip strength and DFHU measures. The Pearson correlations were all significant (p<0.001); their magnitude ranged from moderate (0.524 between left grip strength and the BOT stringing blocks item) to very high (0.978 between left and right grip strength). The Cronbach's alpha for the nine grip strength and DFHU items was 0.88. Factor analysis showed only one factor with an Eigen value greater than 1.0. That factor explained 75.6% of the variance. All GSDFHU items loaded highly on that factor. Specifically, the factor loadings ranged from 0.68 (BOT stringing blocks) to 0.94 (Nine-hole Peg test right).

The correlations between grip strength and DFHU measures and age were all significant (p<0.001) and ranged in magnitude from moderate (0.586 between the BOT stringing blocks item and age) to high (0.881 between right grip strength and age). Figure 1 shows a line graph of the z scores for performance at the 9 grip strength and DFHU tasks and age. Partial correlations between grip strength and DFHU items adjusted for age are presented in Table 3. All partial correlations were lower than the corresponding unadjusted Pearson correlations between grip strength and DFHU items. Excepting the partial correlations between left and right grip strength (0.913) and between left and right Nine-hole Peg Test performance (0.663), only half were significant and all were only negligible to moderate in magnitude.

Table 1. Summary of categorical data describing study participants

Variable	Category	Number (%)
Gender	Female	74 (56.1)
	Male	58 (43.9)
Dominant hand	Right	115 (87.1)
	Left	17 (12.9)
Health	Excellent	98 (74.2)
	Good	31 (23.5)
	Fair	3 (2.3)
Race/ethnicity	White (not Hispanic)	48
	Asian (not Hispanic)	35
	Hispanic	29
	Mixed (non-Hispanic)	11
	Black (non-Hispanic)	9
Age	3	13 (9.8)
	4	12 (9.1)
	5	17 (12.9)
	6	15 (11.4)
	7	12 (9.1)
	8	12 (9.1)
	9	8 (6.1)
	10	10 (7.6)
	11	17 (12.9)
	12	10 (7.6)
	13	6 (4.5)

Table 2. Summary of continuous data describing study participants

| Variable	Mean (SD)	Min-Max
Age (yrs)	7.6 (3.1)	3–13
Height (cm)	128.4 (19.7)	90.2–175.3
Mass (kg)	30.7 (14.1)	11.5–82.5
Grip strength: left (kg)	12.7 (7.8)	1.5–45.0
Grip strength: right (kg)	13.7 (8.2)	1.0–44.7
Nine-hole Peg Test: left (s)	27.6 (10.7)	14.5–61.8
Nine-hole Peg test: right (s)	24.5 (8.2)	13.8–58.3
BOT: making dots in circles (n)	25.0 (11.2)	4–59
BOT: transferring pennies (n)	12.4 (4.4)	1–20
BOT: placing pegs (n)	7.1 (1.9)	3–11
BOT: sorting cards (n)	13.8 (4.9)	4–26
BOT: stringing blocks (n)	5.3 (2.5)	1–9

BOT: Bruininks Oseretsky Test of Motor Proficiency.

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Table 3. Pearson and partial correlations between age, grip strength, and dexterity/fine hand use measures*

	Age	Grip (L)	Grip (R)	Peg (L)	Peg (R)	BOT (Dots)	BOT (Pennies)	BOT (Pegs)	BOT (Cards)
Grip strength (L)	**0.862**								
Grip strength (R)	**0.881**	**0.978**							
		0.913							
Nine-hole Peg Test: left (L)	**0.808**	**0.713**	**0.723**						
		0.054	0.041						
Nine-hole Peg Test: right (R)	**0.854**	**0.752**	**0.772**	**0.893**					
		0.059	0.082	**0.663**					
BOT: making dots in circles (Dots)	**0.790**	**0.697**	**0.701**	**0.750**	**0.801**				
		0.049	0.016	**0.309**	**0.395**				
BOT: transferring pennies (Pennies)	**0.802**	**0.726**	**0.739**	**0.829**	**0.868**	**0.785**			
		0.114	0.116	**0.513**	**0.588**	**0.413**			
BOT: placing pegs (Pegs)	**0.780**	**0.695**	**0.693**	**0.791**	**0.832**	**0.728**	**0.818**		
		0.070	0.018	**0.436**	**0.508**	**0.291**	**0.514**		
BOT: sorting cards (Cards)	**0.774**	**0.684**	**0.692**	**0.762**	**0.811**	**0.721**	**0.773**	**0.780**	
		0.054	0.035	**0.366**	**0.456**	**0.282**	**0.403**	**0.444**	
BOT: stringing blocks (Blocks)	**0.586**	**0.524**	**0.548**	**0.586**	**0.559**	**0.547**	**0.637**	**0.601**	**0.410**
		0.047	0.084	0.237	0.138	0.169	**0.346**	0.284	−0.084

Correlations significant at p≤0.001 are bold.

L: left; R: right; BOT: Bruininks Oseretsky Test of Motor Proficiency.
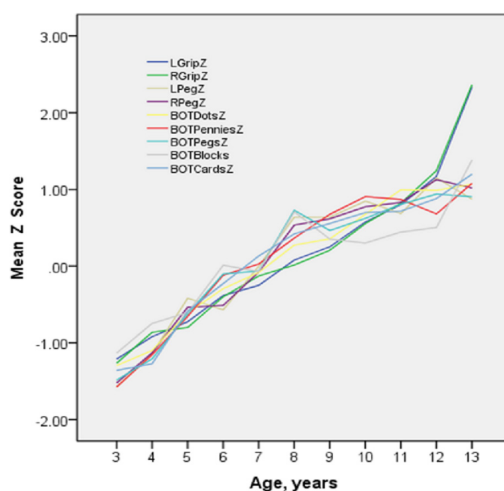
Fig. 1. Line Plot of Standardized Scores of Measures of Interest by Age.
LGripZ, RGripZ=standardized score of the grip strength for the left and right hand, respectively; LPegZ, RPegZ=standardized score of the Nine-hole Peg Test (left and right); BOTDotsZ to BOTCardsZ=standardized score of BOT items (preferred hand): (1) making dots in circles, (2) transferring pennies, (3) placing pegs, (4) sorting cards, and (5) stringing blocks.

DISCUSSION

The purpose of this study was to describe the relationship between grip strength and DFHU in children 3 to 13 years of age. We anticipated that grip strength as measured with a grip dynamometer and DFHU as measured by the Nine-hole Peg Test and 5 component items of the BOT would be highly related and reflective of a single construct. Indeed, Pearson correlations, Cronbach's alpha, and factor analysis all supported the relatedness of grip strength and DFHU task performance- suggesting that perhaps all reflect a construct such as "children's upper limb motor performance." However, partial correlations accounting for age markedly reduced the relatedness of the motor performance variables. So what construct does grip strength and DFHU capture? In children 3 to 13 years we would suggest the construct to be maturation of upper limb motor function.

Thus, while no measure can be used as a replacement of another at any particular age, it appears that any one may be of use for assessing maturation- BOT stringing blocks being the least supported.

This study had several limitations. First, it was cross-sectional. Thus, maturation of upper limb function can only be inferred. A longitudinal study would be required to see if age related changes in grip strength and DFHU are related. Second, the sample size was somewhat limited. While sufficient for the analyses conducted, it was not large enough to support the investigation of relationships within subgroups (eg, 3 year-old boys).

As moderate to strong relationships between grip strength and DFHU are attenuated by age in children of 3 to 13 years, we cannot recommend the use of any one measure in lieu of others to characterize motor function of the hand.

Funding and Conflicts of interest

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