Innovative evaluation of dexterity in pediatrics

Susan V. Duff EdD, PT, OTR/L, CHTa,*, Dorit H. Aaron MA, OTR, CHT, FAOTA b, Gloria R. Gogola MDc, Francisco J. Valero-Cuevas PhD d

a Thomas Jefferson University, Department of Physical Therapy, 901 Walnut St., Suite 510, Philadelphia, PA 19107, USA
b Aaron & Winthrop Hand Therapy Services, Inc, 2723 Amherst, Houston, TX 77005, USA
c Shriners Hospitals for Children, Houston, 6977 Main St, Houston, TX 77030, USA
d University of Southern California, Biomedical Engineering Department and Division of Biokinesiology & Physical Therapy, 3710 S. McClintock, RTH 402, Los Angeles, CA 90089, USA

A R T I C L E  I N F O

Article history:
Received 22 December 2014
Received in revised form
12 January 2015
Accepted 12 January 2015
Available online 22 January 2015

Keywords:
Dexterity
Measurement concepts
Functional Dexterity Test
Strength–Dexterity

S T U D Y  D E S I G N: Review paper.

I nt roduct ion: Hand dexterity is multifaceted and essential to the performance of daily tasks. Timed performance and precision demands are the most common features of quantitative dexterity testing. Measurement concepts such as rate of completion, in-hand manipulation and dynamic force control of instabilities are being integrated into assessment tools for the pediatric population.

P urpose: To review measurement concepts inherent in pediatric dexterity testing and introduce concepts that are infrequently measured or novel as exemplified with two assessment tools.

M ethods: Measurement concepts included in common assessment tools are introduced first. We then describe seldom measured and novel concepts embedded in two assessment tools; the Functional Dexterity Test (FDT) and the Strength–Dexterity (SD) Test.

D iscussion: The inclusion of novel yet informative tools and measurement concepts in our assessments could aid our understanding of atypical dexterity, and potentially contribute to the design of targeted therapy programs.

Dexterity measurement

Dexterity can be measured by observing task performance, recording from a checklist or using a standardized assessment tool. Common features of standardized tools are timed performance and precision. The time for task completion is often measured in seconds or minutes using a timer.2 Precision is illustrated by the expectation to place small rings on thin pegs as in the Purdue Pegboard Test.2 Table 1 outlines features of dexterity testing measured with common tools that have normative values for children. Normative reference values are useful with pediatric populations, where it is important to distinguish between expected developmental changes and the effects of intervention.

Features of dexterity that are not often measured or are more difficult to measure include: 1) rate of completion; 2) in-hand manipulation; and 3) dynamic force control. For example, in-hand manipulation has been explored but not fully integrated into dexterity testing (see Table 1). To better understand the value of including innovative measurement concepts in our assessments, pediatrics and introduce innovative concepts embedded within the design of a few sample instruments.
we will review the concepts and describe a few dexterity tests that incorporate them.

**Rate of completion and in-hand manipulation**

In addition to measuring the time to task completion, performance can be expressed as a rate of task completion (i.e., speed). This scoring strategy allows for statistically valid numerical comparisons against other quantitative functional variables and graphing of rate of completion along a continuous age scale. Although useful, this scoring strategy is rarely used in dexterity testing.

**In-hand manipulation (IHM)** is defined as movement or adjustment of an object as it is held with one hand. Although there are other taxonomies for IHM, the classification scheme by Exner is described here by three main features: shift (movement across finger pads), translation (finger-to-palm and palm-to-finger), and rotation (simple and complex). The three components of IHM are assessed with the task of picking up a coin and placing it in a vertical slot. In this example, shift is displayed when we move the coin across the finger pads. Palm-to-finger translation is demonstrated when we move the coin from the palm to the finger pads. Finally, complex rotation is illustrated when we turn the coin on its axis with the fingers before placement in a slot.

IHM develops between 18 months and 7 years of age. By 3 years of age, IHM has developed to the point that standardized testing can be reliably performed. IHM is required to complete the Functional Dexterity Test (FDT).

**Functional Dexterity Test (FDT)**

The Functional Dexterity Test (North Coast Medical, Gilroy, CA) is a timed pegboard instrument. The FDT is not new but employs the unique concepts of rate of completion and in-hand manipulation that are not commonly measured. When validated in adults, the FDT had excellent test-retest (ICC = 0.95) and intra-rater (ICC = 0.91) reliability. When compared against performance tests that assess activity and participation, it had the highest ratings for clinimetric quality. Adult FDT normative reference values are published and were recently updated. Pediatric normative values are also available. The FDT consists of 16 cylindrical pegs (4 cm x 2.2 cm) arranged in four rows of four pegs each (Fig. 1). It requires a tripod pinch and two aspects of IHM: rotation and shift. Participants turn over all pegs (rotation) in a specified order by manipulating each peg with the finger pads (shift). Participants complete one practice trial and the second trial is timed. Results are recorded as the number of pegs completed divided by time elapsed (pegs/time). This calculation of a test score provides a measure of speed. The original FDT scoring involved assessing penalties and adding their point values to the test completion time to arrive at a final score. Even though the penalties were subsequently modified for children, they proved inadequate. As grasp and movement patterns develop, a true assessment of pediatric penalties would require a menu of changing, age-specific items, which hampers the ease of test administration. Inefficient movements are reflected in decreased speed, thus do not require the additional adjustment for penalties. The FDT is sensitive enough to detect functional inefficiencies of IHM; therefore, penalties have been eliminated from pediatric FDT scoring.

Normative FDT speed (pegs/sec) for the dominant and non-dominant hands among typically-developing children increases linearly with age at a constant rate of 0.037 pegs/sec/year between 3 and 17 years of age (Fig. 2). There are no gender differences through 17 years of age. Dominant hands are faster than non-dominant hands at all ages and the difference between the two remains constant.

Presenting normative values as a “growth chart” of FDT speed versus age facilitates easy visualization of expected speed for any given age using a continuous age scale. The use of regression on fractional age provides a more precise estimate of performance than would be possible by presenting the data in a table grouped by

![Image](image_url)
arbitrary age ranges. Clinicians who treat children are accustomed to this “growth chart” format for tracking height and weight. It has also been successfully used to report pediatric hand strength.25,26 Based on linear regression analysis, age and hand dominance can predict speed. The available norms allow clinicians to compare both speed and rate of change over time of pediatric clients against the norms for typically-developing children.

The FDT has been used in children to assess dexterity after pollicization27 (surgically replace an absent thumb with a functional finger)28 and performance in children with congenital conditions. We used the FDT to assess the unaffected hands of children ages 4–17 years of age with unilateral congenital differences and found that the unaffected hands were slower than the age-matched norms (unpublished). The results revealed that dexterity in the unaffected hands of unilaterally affected children does not develop at the same rate as typically-developing peers, thus strengthening the notion that contralateral hands should be included in therapeutic programming. Current work includes instrumenting the individual FDT pegs with wireless inertial sensors equipped with an accelerometer and gyroscope in order to acquire movement data (smoothness, jerk, and accuracy) in addition to speed.

The FDT is an example of a tool that requires IHM and measures the unique feature of rate of completion. It is easy to administer and accommodates a child’s short attention span and clinical time constraints. It reliably measures the performance of young children with and without congenital hand differences. Finally, it can detect subtle deficits missed with visual observations or simpler grasp and release dexterity instruments.

**Dynamic force control**

Hand-held dynamometers and pinch meters have been used extensively to quantify normative and clinical levels of static grip and pinch strength.31 Unfortunately, these measures of force magnitude are not informative of the dexterous capabilities of the person as they include the potential confounds of motivation, pain avoidance, etc. Interestingly, Lee-Valkov and colleagues24 found that in typically-developing children pinch strength correlated poorly with dexterity based on the FDT. In addition, the prehensile forces necessary to engage in activities of daily living (ADL) are surprisingly low.32 Therefore, although clinically useful for other reasons, maximal static force magnitude may not be an essential component of dexterity measurement.

Skilled grasp and manipulation of objects requires grading of fingertip forces to prevent slips and breakage.33 We grade grip (squeeze) and load (lift) force in advance of object contact (anticipatory control) and modify these forces based on somatosensory feedback during manipulation.34 Fingertip force magnitude and the rate of onset are usually low when we grasp a potato chip and increase when we lift a full glass of water. In adults, grip and load force increase in a parallel, synergistic manner. Conversely, young children increase fingertip forces sequentially,35 exhibiting long durations for each phase of the grip-lift task. This suggests that early in development a feedback strategy dominates.35 After two years of age, both feedback and anticipatory control strategies are evident by the display of parallel increases in force and shorter phase durations during manipulation of static objects.35

Dynamic manipulation (as opposed to grip-lift tasks) requires that the direction and magnitude of fingertip force vectors be continuously modified to maintain object stability during task performance.36–38

---

**Fig. 2.** Normative FDT scatterplot showing speed as pegs/second (pps) versus age. The continuous “growth chart” style (versus arbitrary age groupings) allows for more precise comparison to typically-developing children 4–17 years old. Dominant hands are shown in red, non-dominant hands in blue.13 (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.) Permission to reprint from Gogola et al13 was received.

**Fig. 3.** A) Four springs used for a pediatric version of the Strength-Dexterity Test.35 Note the SD Test shown is a particular instance of the SD paradigm (Fig. 4). B) In this SD Test, miniature load cells mounted on either end of the spring over plastic end caps. The compression requires force magnitudes <3 N. The task requires a two-finger palmar pinch or a lateral pinch to compress and hold the spring at the maximal compression force without buckling. Permission to reprint from Dayanidhi et al37 was received.
The method used to capture the capacity to grade fingertip forces is based on the information desired. Indirect assessment can be done through task performance such as stacking checkers during the Jebsen Test of Hand Function. Objective measurement of performance on static grip-lift tasks usually involves laboratory-based instruments equipped with single or multi-axial force transducers. Dynamic manipulation must be assessed by the ability to regulate fingertip force vectors to control unstable objects. While a measure of dynamic force control would be useful, the challenge is how to quantitatively measure it in the clinic.

**Strength—Dexterity Test**

To quantify the dynamic regulation of magnitude and direction of fingertip forces, Valero-Cuevas et al. developed the Strength—Dexterity (SD) paradigm using an SD device. The SD Test has been used to assess hand dexterity in typical and atypical adults and children. Although it is not yet commercially available, details of the SD device are described in previous publications. In the SD Test, individuals use the fingertips to compress a slender and compliant spring that is prone to buckling (Fig. 3). Buckling is a form of instability, which becomes exacerbated as the spring is compressed further. Note that the force magnitudes needed to compress the spring to the limit of instability are very low, on the order of <3 N. Retaining control of the spring requires dynamic regulation of the magnitude and direction of the finger movements and fingertip force vectors. To obtain quantitative data, the compression spring can be fit with two miniature compression load cells (ELB4-10, Measurement Specialties, Hampton, VA) to record dynamic compression forces, as depicted in Fig. 3. The maximal level of compression (units of force) is indicative of the maximal level of instability that the neuromusculoskeletal system is able to control. This metric serves as an informative measure of neuromotor control for dexterous manipulation.

In the SD paradigm, the mechanical design of the spring determines the force magnitudes needed to compress it to the limit of instability. The current SD Test expands upon work in pediatric populations, with the current version designed to require very low force magnitudes c. 2e3 N. Retaining control of the spring regardless of the task goal and our ability to maintain stability of the grasped object by aptly responding to perturbations or task dynamics. Improvement in dynamic manipulation progresses into late adolescence, as influenced by the development of the neuromuscular system, experience and gains in sensorimotor control.

The quantification of sensorimotor skill needed to stabilize objects using the dexterity score exemplifies the features of dynamic force control and precision. Results from this research have been used to better understand the local and distributed neural mechanisms associated with maturation, muscle contractile speeds, functional neural connectivity and neural networks across gender, age and clinical populations. Results from a pediatric population are shown in Fig. 6. Work is in progress to bring the SD paradigm into clinical practice.
performance time on the FDT. The relationship between performance on ADL tasks and the Nine-Hole Peg Test, the FDT or other tools has not been examined in children.

The SD paradigm measures a dimension of sensorimotor capability different from strength, whole-arm motion, and reach-to-grasp behavior. Thus, the SD Test’s assessment of a child’s ability to stabilize objects is unique and informative. Studies are needed that relate performance on the SD Test for children to select ADLs requiring dexterity and manipulation.

Summary

The evaluation of dexterity in a pediatric population requires consideration of the developmental level of the child and the clinical condition being evaluated. These factors influence the skill level and dexterity we should expect, thus directing us to the appropriate assessment tool. Although the number of tests available continues to grow, it is important to closely examine the features of dexterity that the tool measures and the measurement concepts involved in scoring. Innovative scoring strategies are characteristic of tools such as the FDT and SD Test. The FDT is commercially available with pediatric normative data, while the SD Test is being examined for clinical utility. As the data becomes available, the SD Test could provide the pediatric clinician with a unique outcome measure of dynamic force control.

Obtaining a comprehensive view of dexterity requires administration of a combination of assessments. For instance, the combined use of the FDT and SD Test could provide measures of rate of completion, in-hand manipulation, and dynamic force control. Validation of common and novel assessments employing unique scoring strategies will add to our understanding of the underlying mechanisms of atypical dexterity and provide pediatric clinical practitioners and researchers with information useful in the design of targeted interventions.

Acknowledgments

This publication was supported by a grant from the Eunice Kennedy Shriver National Institute of Child Health and Human Development of the National Institutes of Health under award number T32HD064578. Research reported was supported by National Institute of Arthritis and Musculoskeletal and Skin Diseases of the National Institutes of Health under award numbers R01AR050520 and R01AR052345 to FVC. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Disclosures: FVC holds US Patent No. 6,537,075 on some of the technology used, but has no active or pending licensing agreements with any commercial entity. None of the other authors have any financial or personal relationships with other people or organizations that could inappropriately influence this work.

References

JHT Read for Credit
Quiz: #362

Record your answers on the Return Answer Form found on the tear-out coupon at the back of this issue or to complete online and use a credit card, go to JHTReadforCredit.com. There is only one best answer for each question.

#1. In addition to reviewing traditional measures of dexterity the authors discuss the following two novel tools
   a. CCF and RSD
   b. PPR and MLB
   c. FDT and SD
   d. MFR and ATT

#2. In selecting measurement tools it is key that the clinician take into consideration the
   a. developmental level of the patient
   b. environment of the clinical setting
   c. wishes of the parents
   d. instructions of the surgeon

#3. Traditional features of standardized tools are
   a. a sensory and motor component
   b. their ease of using and their low cost
   c. high sensitivity and low specificity
   d. timed performance and precision

#4. The authors identify all of the following except ___________ as features of dexterity that are not often measured or are more difficult to measure
   a. rate of completion
   b. in-hand manipulation
   c. rapid exchange rates
   d. dynamic force control

#5. The authors conclude that understanding atypical dexterity should not contribute to the design of targeted therapy programs
   a. true
   b. false

When submitting to the HTCC for re-certification, please batch your JHT RFC certificates in groups of 3 or more to get full credit.