Hand Function With Touch Screen Technology in Children With Normal Hand Formation, Congenital Differences, and Neuromuscular Disease

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**Purpose** To measure and compare hand function for children with normal hand development, congenital hand differences (CHD), and neuromuscular disease (NMD) using a function test with touch screen technology designed as an iPhone application.

**Methods** We measured touch screen hand function in 201 children including 113 with normal hand formation, 43 with CHD, and 45 with NMD. The touch screen test was developed on the iOS platform using an Apple iPhone 4. We measured 4 tasks: touching dots on a 3 × 4 grid, dragging shapes, use of the touch screen camera, and typing a line of text. The test takes 60 to 120 seconds and includes a pretest to familiarize the subject with the format. Each task is timed independently and the overall time is recorded.

**Results** Children with normal hand development took less time to complete all 4 subtests with increasing age. When comparing children with normal hand development with those with CHD or NMD, in children aged less than 5 years we saw minimal differences; those aged 5 to 6 years with CHD took significantly longer total time; those aged 7 to 8 years with NMD took significantly longer total time; those aged 9 to 11 years with CHD took significantly longer total time; and those aged 12 years and older with NMD took significantly longer total time.

**Conclusions** Touch screen technology has becoming increasingly relevant to hand function in modern society. This study provides standardized age norms and shows that our test discriminates between normal hand development and that in children with CHD or NMD. (J Hand Surg Am. 2015;■(■):■. Copyright © 2015 by the American Society for Surgery of the Hand. All rights reserved.)

**Type of study/level of evidence** Diagnostic III.

**Key words** Pediatric, hand, function.

Hand function tests are an important clinical tool to assess children’s functional daily task capabilities. Administration of such tests allows clinicians to measure performance more accurately, such as dexterity, strength, range of motion, and effectiveness of treatment. Emerging technology with use of a touch screen for education, work, and entertainment has highlighted new functional tasks needed, particularly in children. Use of emerging technologies as an important hand function has called for the creation of new types of hand function testing.
In pediatrics, hand function tests are also used to assess developmental progress by comparing age norms. Gogola et al. noted, “Having population norms for a functional test is particularly helpful with pediatric populations, because ability changes with growth and development. Even if the absolute values for a population are not expected to reach normal values, comparing the rate of development over time is valuable.” Age norms allow clinicians to evaluate the extent of injury or abnormality, track development, and monitor recovery progress.

Several validated hand function tests are currently in use, including the Purdue Pegboard, Bennett Hand Tool Dexterity Test, Rosenbusch Test of Finger Dexterity, Jebsen Hand Function Test, 9-Hole Peg Test, Box and Blocks, and Functional Dexterity Test. These hand function tests are valuable but they do not consider emerging technological trends, such as the use of touch screens. All of the hand function tests with pediatric norms measure manual manipulation of small objects. In a technologically evolving world in which communication, entertainment, and work increasingly rely on the ability to use touch screen devices, assessing hand function using a mobile device might be beneficial.

This report aimed to develop a hand function test using touch screen technology that could measure age norms for hand function for children with normal hand development and to discriminate differences in hand function for children with congenital hand differences (CHD) or neuromuscular disease (NMD).

MATERIALS AND METHODS

Development of the test

We developed the Minnesota Hand Function Test on the Apple iPhone 4 (Apple, Cupertino, CA) using their operating system known as iOS (Apple). Two hand surgeons, a therapist, and an avid technology user formed the working group to design the test. Hand function tasks with typical applications present on a touch screen phone were reviewed and deconstructed into 4 tasks. The first hand function, the ability to touch an item on the screen, was designed as “dots,” a 3 × 4 grid of dots that light up in random order. As the dots are lit, the subject must be able to accurately touch them. Once a dot has been touched, another will light up and the task will be repeated. The second hand function, the ability to touch and drag an item on the screen, is designed as “shapes,” which is 4 shapes displayed on the screen with an outline of a shape in the center of the screen. The subject must be able to touch and drag the shape accurately to match the shape in the center of the screen. The third hand function is the ability to hold the iPhone using 2 hands and to take pictures in different directions. The subject must point the phone toward the floor, ceiling, and wall while pushing the icon to take a picture. The fourth hand function, typing, is designed as a text message that is typed into the text message box. In addition, because of inherent difficulties in testing children, we wanted our test to be brief and easily administered in the outpatient setting. Owing to these aims, we designed each component of the test to be approximately equal in length for an experienced touch screen user, with each taking 15 to 30 seconds, for a total of 60 to 120 seconds. Finally, we designed an identical but shorter learning version of the test to familiarize participants with the test parameters and minimize any potential learning effect.

Phase I testing

Once the test had been developed, we obtained institutional review board approval for an initial study to determine whether the test was useful for discriminating between children with normal and impaired hand function. We administered the test to a total of 74 total subjects (32 were judged to be impaired and 42 were judged to be normal). Data demonstrated that the test showed an increase in completion time in the impaired group, but this difference was not statistically significant. We then expanded institutional review board approval to include more subjects so as to investigate this result further.

Testing protocol

The test was administered at Gillette Children’s Specialty Healthcare in St. Paul, Minnesota, at an upper extremity orthopedics clinic under the supervision of a board-certified pediatric orthopedic hand specialist. Participants were seated on a chair next to the computer desk in the clinic room. The test administrator opened the application on the Apple iPhone 4 and recorded demographic information. The learning mode was selected and the device was handed to the participant. On-screen instructions were provided with verbalization of these instructions by the test administrator before the start of each segment. Instructions for each segment were as follows: dots (Fig. 1A), “Tap the red dots”; shapes (Fig. 1B), “Move the correct colored shape into the white space”; camera, “Take a picture of the wall”; and text, “Type the sentence into the box below (there is no autocorrect).” At the end of each segment, a prompt
appeared asking, “Would you like to try again?” If at any point the test segment was unsuccessful for any reason (dropping the phone, turning off the phone, etc), this prompt allowed the test taker to restart the component. Once the participant completed the initial learning segment, the full-length test was selected with identical instructional prompts given. 

The program also recorded the time taken for each segment and a cumulative completion time for all tasks. The timer did not run during any of instruction prompt. Special care was taken during the camera portion to have the participant return the phone to a neutral position with hands in their lap so that the participant would actively have to move the phone to the appropriate place to take the next picture while the timer was running. In addition, participants who were unable to complete the texting portion owing to unfamiliarity with the QWERTY keyboard skipped the texting component.

Statistical validation

Data were analyzed as total completion time (seconds) and compared between children classified as having normal hand function or being impaired as a result of congenital or neuromuscular disease. Demographics taken included sex, age, amount of touch screen experience (measured as less than or greater than 6 mo), and hand dominance. We compared age group results by diagnosis using one-way ANOVA with post hoc testing and compared hand function classification by age group using 2-tailed Student t test. Secondary analysis was performed on sex, amount of touch screen experience, and hand dominance to assess these as potential confounders.

RESULTS

Normative data

A total of 113 children with normal hand formation (ie, normal morphology) completed the Minnesota Hand Function Test including 13 children aged less than 5 years, 14 aged 5 to 6 years, 11 aged 7 to 8 years, 33 aged 9 to 11 years, and 42 aged 12 to 19 years. The normative cohort included 58 girls and 55 boys, with 100 right-handed and 13 left-handed participants. All participants had more than 6 months’ experience using touch screen technology.

Normative values with standard deviations for each of the 4 subtests and total time for completion are shown in Figure 2 and Appendix A (available on the Journal’s Web site at www.jhandsurg.org). For the 4 subtests and total time to completion, normative data for age groups showed significantly less time (P < .010) to complete each task as age increased.

Pediatric hand function in NMD and CHD

We evaluated 43 children with CHD including 25 girls and 18 boys, 28 of whom were right-handed and 15 were left-handed. Figure 3 shows results for the 4 subtests and total time to completion. Forty-five children with NMD were evaluated including 18 girls and 27 boys; 31 were right-handed and 14 were left-handed. A total of 26 children had cerebral palsy.

FIGURE 1: A A child with only 2 digits uses the little finger to complete the “dots” subtest while tapping the dots as they turn red. B The child complete the “shapes” subtest while dragging the correctly matched shape into the center of the screen.
and 19 had other NMDs. Results for the 4 subtests and total completion time are shown in Figure 4.

As shown in Figure 5, there were insignificant differences in completion times for children with CHD and NMD compared with normative data ($P = .070$). Children aged 5 to 6 years with CHD had significantly longer test completion times than normal children ($P = .050$). Compared with normal children aged 7 to 8 years, patients with NMD had significantly longer times to completion ($P < .010$). In children aged 9 to 11 years, those with CHD had significantly longer times ($P = .010$) compared with normal children the same age. Children aged 12 years and over with NMD had significantly longer total completion times ($P = .001$) than normal children.

**FIGURE 3:** Completion time for children with CHD by age for 4 subtests and total completion time. *A maximum score of 50 seconds was assigned for children unable to complete the subtest more quickly.

**FIGURE 4:** Completion time for children with NMD by age for 4 subtests and total completion time. *A maximum score of 50 seconds was assigned for children unable to complete the test more quickly.

**FIGURE 5:** Completion time comparing children with normal hand development, CHD, and NMD by age for total completion time.

### DISCUSSION

Touch screen technology has become increasingly available and used in the mainstream as a means of communication, entertainment, and education and for performing work. Increasingly younger children are using this technology. Traditional concepts of dexterity and hand function$^{4,6-8}$ may not be relevant, or at least may become less important in interfacing with the world around us. As such, touch screen technology may be facilitating for individuals with upper extremity dysfunction. Nevertheless, differences in touch screen hand function exist between groups and individuals, and it may be worthwhile to develop a means to measure them.

Our study showed that at age less than 5 years the test did not distinguish unaffected individuals from those with NMD or CHD. This may indicate that young children have not yet developed sufficiently fine motor skills to distinguish normal from affected individuals. At this stage of test development, we do not recommend our touch screen test for children aged less than 5 years as a means of comparing children. However, it may be appropriate to obtain a baseline measurement for a child as a means to track development.

We found that under age 9 years, the texting portion of the examination was generally too complex for subjects to complete. For these age groups, text completion times were excessively long and varied or were altogether incomplete. Thus, we assigned each examinee 50 seconds for the texting portion if they did not complete that segment in less time. This maximum time was chosen because children over age 9 years had times clustered between 30 and 50 seconds for the texting portion. Our study results indicate that by age 9 years, most children become accomplished at reading and writing skills and familiar with the QWERTY keyboard, so that
texting results were more consistent and reliable. Most commonly, the text portion of the examination was not helpful for children aged 5 to 6 years because they are not developmentally capable of completing the task. For children aged 7 to 8 years, some could complete the text portion but most could not. For children aged over 9 years, we expected completion of the text section in less than 50 seconds.

The age ranges we chose to report are not uniform. Initially, subjects were grouped by 2-year increments starting at age 3 years and up to age 16 years. However, in the initial phase we found that under age 5 years there was little correlation between age and performance. As the data for children aged 5 and 6 years were analyzed, we found that they were similar to one another but different from children aged 7 and 8 years. Similarly, there was no clear distinction between completion times in children aged 9, 10, and 11 years, so we grouped them together. Finally, children over age 12 years were indistinguishable in their completion times, and thus were grouped together.

With increasing age, children became increasingly faster at completing the tasks (Fig. 2 and Appendix A [available on the Journal’s Web site at www.jhandsurg.org]). This was true for the average completion time for every task in all age categories.

The cumulative completion times for children aged 5 to 6 years were significantly better in normal children compared with those with CHD, but no such differences were seen compared with the NMD group.

Our results demonstrated significantly better completion times in normal children aged 7 to 8 years than in those with NMD. Types of NMD included cerebral palsy (26 of 45 children) and other conditions (19 of 45 children) including but not limited to arthrogryposis with bilateral hand contractures. There was no statistically significant difference between unaffected children aged 7 to 8 years and those with CHD.

Children aged over 12 years with NMD had significantly longer average total completion times than did unaffected individuals in the same age category. It is possible that this demonstrates a plateau in the function of children with NMD because the total average completion time did not improve from age 9 to 11 years to the group aged 12 years and older group, whereas unaffected children and those with CHD continued to improve across this age jump.

There was no statistical difference in completion times between unaffected individuals and those with CHD. This could demonstrate a narrowing of the functional gap between these groups with age. Once fine motor skills are fully developed, children with CHD may find ways to work around their deficits.

We observed that the 4 tasks did not equally distinguish hand function differences between groups. Whereas average completion times for each task diminished with increasing age in all groups, the dots and shapes tasks had only small differences between individuals who were unaffected and those with CHD or NMD. The camera and texting tasks had larger differences between groups. This makes intuitive sense because completion of the dots and shapes tasks requires the use of a single finger, albeit precisely placed. The camera and text tasks require more complicated, bi-manual manipulation of the device or precise touch. Furthermore, use of the hands in a prescribed position was not required. Standard phone grasping positions or adaptive mechanisms could be used. Only time and ability to complete task were recorded, not a qualitative description of how the task was completed.

Weaknesses of this study include relatively small numbers in each group, which would potentially allow a single outlier in any group to affect results. This may have been true for the group of children aged 5 to 6 with NMD, those aged 7 to 8 years with CHD, those aged 9 to 11 years with NMD, and those aged 12 years and older with CHD. In effect, a single minimally impaired individual in any of those groups could have brought the group’s average time down enough to make the difference from normal statistically insignificant. Also, we did not attempt to subclassify the severity of the disability in the groups of children with CHDs or NMD. Not all children with a CHD or MND have equivalent severity of disease or disability. In addition, we did not measure intelligence for these subjects. Whether differences in speed resulted from limitations of hand function or limitations in intelligence is unknown. This article only presents normative data for use on the iPhone 4. Use with other touch screen devices will require further investigations. Finally, this report does not include a comparison with other standardized hand function tests.

This report has several strengths. Modern hand function for children includes the use of touch screen technology, and this test measures and provides age norms. The Minnesota Hand Function test is a free application available in the iPhone App Store. Its use allows any investigator to measure touch screen hand function in less than 5 minutes with results e-mailed in a Health Insurance Portability and Accountability Act–compliant context to interested
recipients. Finally, this test provides a platform for further investigation into the relationships between touch screen hand function and other measurements of hand dexterity and investigation of additional diagnoses affecting children.

REFERENCES

### APPENDIX A. Mean Normative Data for Touch Screen Hand Test by Age Category, mean (SD)

<table>
<thead>
<tr>
<th>Age, y</th>
<th>Dots, s</th>
<th>Shapes, s</th>
<th>Camera, s</th>
<th>Text, s</th>
<th>Total, s</th>
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<td>58 (41)</td>
<td>63 (22)</td>
<td>50*</td>
<td>207 (53)</td>
</tr>
<tr>
<td>5–6</td>
<td>24 (4)</td>
<td>27 (8)</td>
<td>37 (10)</td>
<td>50*</td>
<td>137 (16)</td>
</tr>
<tr>
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<td>20 (2)</td>
<td>21 (5)</td>
<td>33 (10)</td>
<td>50*</td>
<td>124 (13)</td>
</tr>
<tr>
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<td>16 (2)</td>
<td>27 (7)</td>
<td>39 (10)</td>
<td>102 (15)</td>
</tr>
<tr>
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<td>15 (3)</td>
<td>23 (6)</td>
<td>26 (10)</td>
<td>82 (15)</td>
</tr>
</tbody>
</table>

*A maximum score of 50 seconds was assigned for children unable to complete the test more quickly.*