



## Research paper

# Assessment of finger dexterity through the DIGITS joint tracking web application—An evaluation study with comparison to the nine-hole pegboard test



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## ABSTRACT

**Background:** Hand dexterity is an important clinical marker after hand surgery as it can greatly impact one's ability to perform their day-to-day activities. With the increased focus on remote patient monitoring after hand surgery, new technologies are required to remotely monitor hand dexterity.

**Purpose:** The purpose of this study is to identify dexterity outcomes using the web application "DIGITS" and compare these outcomes to the nine-hole-pegboard test (NHPT).

**Study Design:** Cross-sectional observational study.

**Methods:** This was a two-part study with a pilot of our remote dexterity design using DIGITS followed by a validation study comparing DIGITS to a gold-standard metric of dexterity, NHPT. The pilot study recruited 42 healthy subjects between the ages of 18–65 to perform a remote finger tapping exercise using DIGITS. The second part of the study included 50 subjects between the ages of 18–65. Participants completed a demographic questionnaire and then completed three finger tapping sequences for 20 seconds using DIGITS and three trials of the NHPT with each hand. Correlational analyses were done to compare the DIGITS dexterity test with the NHPT.

**Results:** Four outcome measures to assess dexterity were identified, which included (1) total sequences completed in 20 seconds, (2) time to complete 10 sequences, (3) average frequency per sequence, and (3) sequence accuracy. Significant negative correlations were found with the NHPT and total sequences completed in 20 seconds in both dominant and non-dominant hand trials. Additionally, significant negative correlations were found between the NHPT and the time to complete 10 sequences and average frequency in the non-dominant hand trials.

**Conclusions:** This study shows promising results for the use of DIGITS as a remote measure of hand dexterity. The total number of sequences completed significantly correlates with the NHPT and should be further explored in representative patient populations.

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## Introduction

Hand dexterity is a crucial skill and function for various professionals, such as musicians, surgeons, pilots, and mechanics. However, its significance becomes more evident when hand disorders impede this ability. Conditions like Dupuytren's disease and Parkinsonism, which cause finger joint stiffness, can affect a patient's dexterity. Poor hand function can negatively impact daily activities, emphasizing the strong association between an individual's independence and hand dexterity.

Thus, standardized specialized clinical assessments that can evaluate dexterity are essential. They can provide valuable insights into fields like hand surgery, physical rehabilitation, and neurocognitive studies.

Traditionally, specialized dexterity tests are completed by hand therapists in the clinic, which include: the nine-hole peg test (NHPT),<sup>1</sup> the Minnesota manual dexterity test,<sup>2</sup> and the box and block test.<sup>3</sup> Of the tests mentioned, the NHPT is considered the clinical gold standard and involves placing nine pegs in a board with nine holes. The scoring of NHPT is done by a trained hand therapist who records the time it takes to complete the task.

Furthermore, there is an increasing need for conducting remote assessments given that such specialized care may not be readily

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available to all communities, particularly in remote and rural areas. Current evidence suggests that transition to virtual assessments and follow-up for non-acute clinic visits increases access to care and medical equity. In a recent review by Gopal et al., several emerging remote dexterity tests currently under development were recognized for their potential in being a more objective measure of multiple domains of hand function.<sup>4</sup> Finger tapping speed,<sup>5–9</sup> hand tremor,<sup>10–14</sup> and finger task-based dexterity<sup>15–17</sup> were the three most studied domains and are often done by separate applications. There are many studies that utilized these software, which require tele-monitoring sensors and visual scoring using recorded footage. However, accessibility of the wearable sensors and other externalized devices remains a barrier to implementation. Additionally, for the example of finger tapping speeds, the tapping speed of the index finger on a touchscreen has been assessed in many studies but it is unclear whether this allows interpretation for quality of movement and generalizability for complete hand dexterity. One technology that could be utilized for the assessment of hand dexterity is the web application “DIGITS”<sup>18,19</sup> which utilizes augmented reality to track the bony landmarks of the hand. Compared to other remote-assessment techniques, DIGITS mitigates the aforementioned barriers of access as it does not require the use of external devices or wearable sensors beyond the initial electronic device with a functional camera.

We conducted a two-part study that evaluated the use of DIGITS, a remote clinical hand function assessment tool developed by our group, to assess hand dexterity via finger tapping speed and movement coordination analyses. The first part of the study utilized a small sample population to identify outcome measures that can be obtained from this device to reasonably estimate hand dexterity. The second part of the study utilized the outcome measures identified and compared them to the gold standard NHPT to determine if DIGITS could serve as a remote assessment tool for hand dexterity.

## Methods

### DIGITS application

Dexterity data was collected via the DIGITS web application,<sup>18</sup> a custom application created using the MediaPipe Hands pipeline.<sup>20</sup> The pipeline adopts two convolutional networks: one being a single-shot detector mode<sup>21</sup> that detects the palms, with a second model detecting the 2.5-dimensional landmarks within the hand (x, y, and relative depth z coordinates). These networks were created and trained by the MediaPipe authors in Tensorflow.<sup>22</sup> The DIGITS webapp tracks 21 landmarks on the hand which can then be used to determine the position in space of each finger for the dexterity exercises (Fig. 1). The landmark coordinates and timestamps were recorded into a comma separated values (CSV) text file and the vectors between each landmark were used to calculate the relative distance between each finger and the thumb throughout a 20-second time interval.

### Participant recruitment

This study adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.<sup>23</sup> For this study, we recruited healthy participants aged 18–65. Participants were recruited through advertisements on social media (i.e., Facebook) and word of mouth. After recruitment, participants were provided an information package outlining the details of the study and what is required from them and then gave written informed consent. Recruited participants were provided a set of instructions and a video outlining how to perform the exercise in a remote

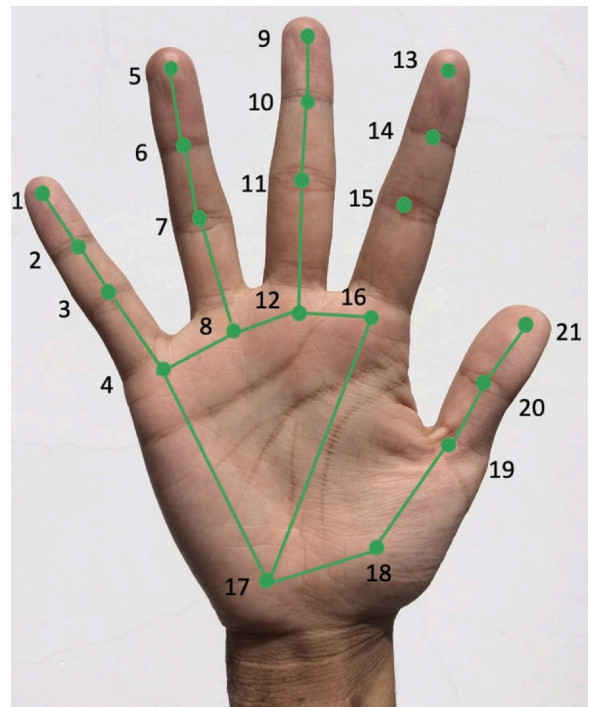


Fig. 1. The 21 landmarks that the ‘DIGITS’ web application uses to track joint motion.

setting (Supplementary Content 1 and 2). This project was approved by the Western Research Ethics Board with the project ID: 121533.

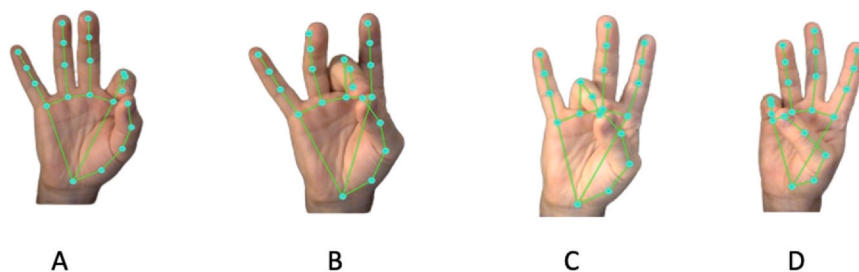
Supplementary material related to this article can be found online at [doi:10.1016/j.jht.2023.08.013](https://doi.org/10.1016/j.jht.2023.08.013).

### Dexterity exercise

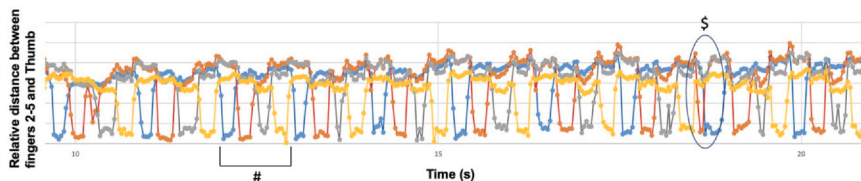
To assess dexterity, we asked participants to perform an exercise for 20 seconds in front of the DIGITS web application. To perform the exercise, participants held their dominant hand in front of the computer camera and tapped their index, middle, ring, and small finger to their thumb in that order as quickly and accurately as they could. They repeated this pattern for 20 seconds as shown in Figure 2.

### Data collection

Participants were asked to fill out a brief demographics questionnaire asking them their age, sex, hand dominance, current or previous artistic and/or musical experience and current or previous video game experience. To determine what outcome measures can be attained from the “Dexterity” application, a pilot study was conducted with a smaller sample population which performed the dexterity task once with their dominant hand. Participants were also characterized as high or low dexterous individuals to assess if previous dexterity related activities were associated with better dexterity scores on the DIGITS platform. Participants were sub-divided into high and low dexterity groups based on the following three categories: (1) 5+ years of experience playing a musical instrument, (2) 5+ years of experience in a high dexterity related artistic/vocational activity, (3) 5+ years of regular video game experience. These activities were chosen as they have been shown to be associated with increased dexterity.<sup>24–30</sup> Participants were given a point for each of the three dexterity-related experiences they recorded on the questionnaire. Participants with a score of one or more were categorized into the high dexterity group.



**Fig. 2.** A demonstration of the finger tapping activity the subjects did with the web app starting with (A) thumb to index finger, (B) thumb to third finger, (C) thumb to fourth finger, and (D) thumb to fifth finger.



**Fig. 3.** An example of a sequence collected from a sample participant in the study. The downward peaks represent when each finger touches the thumb. The colors correspond to fingers: blue (*index*), orange (*middle*), grey (*fourth*), and yellow (*fifth*). #Indicates one full sequence from index finger to fifth finger. \$Represents an error performed by the participant as the orange peak came before the blue peak, indicating that the middle finger came down to the thumb before the index finger. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

In part two of the study, participants completed the same dexterity exercise using the DIGITS platform for 20 seconds, three times with their dominant and non-dominant hand. Participants then completed the NHPT as described by Keller et al.<sup>31</sup> with their dominant and non-dominant hand, three times each. The time to place all of the pegs one at a time and then take the pegs out one at a time was recorded for each trial. Using an algorithm, the DIGITS application creates a graph for each DIGITS trial which is then used to extract the outcome measures from which is shown in Figure 3.

Pearson correlation analyses were done to compare the DIGITS dexterity test with the NHPT on R version 4.1.3.

## Results

### Participant demographics

Overall, 42 participants were included in part one of the study with an average age of 32.4 standard deviation (SD) of  $\pm 14.0\%$  and 92.9% right hand dominant (Table 1). Of these participants, 20 were grouped in the high dexterity group and 22 were grouped in the low dexterity group. There were no significant differences in age, sex, or hand dominance between dexterity groups. In part two of the study, there were 50 participants recruited with an average age of  $28.8 \pm 10.7\%$  and 92.0% of participants were right hand dominant (Table 2). Of these participants, 42.0% had greater than 5 years of

**Table 2**

Demographic data and dexterity measurements in participants included in part 2

Variables	Study population (n = 50)
Age	28.8 $\pm$ 10.7
Female (% , n)	36 (18)
Right hand dominance (% , n)	92 (46)
> 5 years of musical instrument experience (% , n)	42 (21)
> 5 h per week of video game playing (% , n)	34 (17)

Values shown as mean  $\pm$  standard deviation.

musical instrument experience, 34.0% had > 5 hours of video game playing experience per week, and 12.0% of participants had dexterous experiences through artistic hobbies.

### Pilot study

There were four outcome measures that were identified from the initial dexterity trials in part one to be included in the second part of the study. The outcome measures collected from the DIGITS dexterity exercise included (1) total number of sequences completed in 20 seconds, (2) the percent accuracy of completed sequences, (3) the average frequency (sequences per second), and (4) the time it took to complete 10 sequences. Figure 3 illustrates how these outcome measures were assessed.

**Table 1**

Demographic data and dexterity measurement outcomes in the participants in part 1

Variables	Total population (n = 42)	High dexterity (n = 20)	Low dexterity (n = 22)	p-value
Age	32.4 $\pm$ 14.0	28.7 $\pm$ 11.3	35.7 $\pm$ 15.6	0.11
Female (% , n)	45.2 (19)	50.0 (10)	41.0 (9)	0.55
Right hand dominance (% , n)	92.9 (39)	90.0 (18)	95.0 (21)	0.49
Average total sequences	17.9 $\pm$ 4.5	20.4 $\pm$ 3.9	15.7 $\pm$ 3.8	< 0.01
Average time to 10 completed sequences	12.1 $\pm$ 3.8	10.2 $\pm$ 2.4	13.7 $\pm$ 4.2	< 0.01
Average frequency	1.20 $\pm$ 0.4	1.0 $\pm$ 0.2	1.4 $\pm$ 0.4	< 0.01
Average accuracy (% , n)	74.1 $\pm$ 19.2	80.3 $\pm$ 13.3	68.4 $\pm$ 22.2	0.04

Values shown as mean  $\pm$  standard deviation. Two-sided *t*-tests were used for continuous data and chi-square test was used for categorical data.  $p < 0.05$  was defined as significant.

The average scores for the outcome measures can be found in Table 1. When participants were grouped into high and low dexterity groups based on previous dexterous activities, we found that the high dexterity group had completed significantly more sequences in 20 seconds, had completed 10 dexterity sequences in a shorter amount of time, had a lower average frequency, and had a higher accuracy compared to the low dexterity group.

*Correlation between DIGITS dexterity assessment and NHPT*

The Pearson correlation analyses between the DIGITS dexterity outcomes and the NHPT are shown in Table 3. A significant negative correlation was found between the NHPT and the total number of completed sequences for both dominant and non-dominant hand trials, respectively. In other words, lower scores on the NHPT were associated with less time to complete 10 sequences on the DIGITS task as expected. Additionally, significant positive correlations were found between the NHPT and DIGITS time to complete 10 sequences. Graphical representations for the correlations are shown in Figure 4 for the dominant hand trials and Figure 5 for the non-dominant hand trials.

*Average dexterity assessment values based on age and sex*

Average dexterity outcomes based on hand dominance and sex are shown in Table 4. Average values were taken to compare to other

studies that have utilized the NHPT. The only significant difference was found for the NHPT in the non-dominant hand, where male sex had a significantly faster time to completion compared to female sex.

Pearson correlation analyses based on participant age and dexterity outcomes are shown in Table 5. Older age was associated with greater time to complete 10 sequences, fewer overall completed sequences, and increased average frequency in both dominant and non-dominant hands.

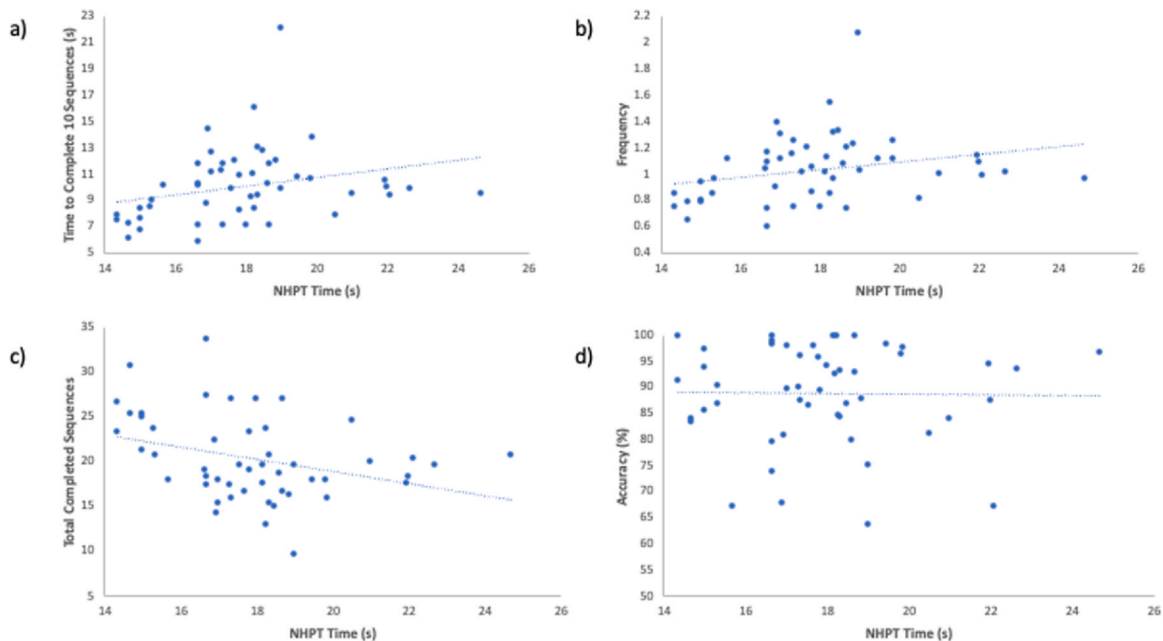
**Discussion**

This pilot study was able to identify four outcome measures that could be obtained using the DIGITS web application and utilize this tool as a remote assessment of hand dexterity. Three of the outcomes: (1) total sequences completed, (2) time to complete 10 sequences, and (3) time to complete each sequence were significantly correlated with participant age with higher age being associated with fewer sequences completed, longer time to complete 10 sequences, and longer overall time to complete each sequence. Additionally, participants in the high dexterity group based on previous musical/artistic and video game experience performed better in these three outcomes compared to the low dexterity group. Part two of the study was able to build on these findings to determine if these outcomes correlated with the NHPT.

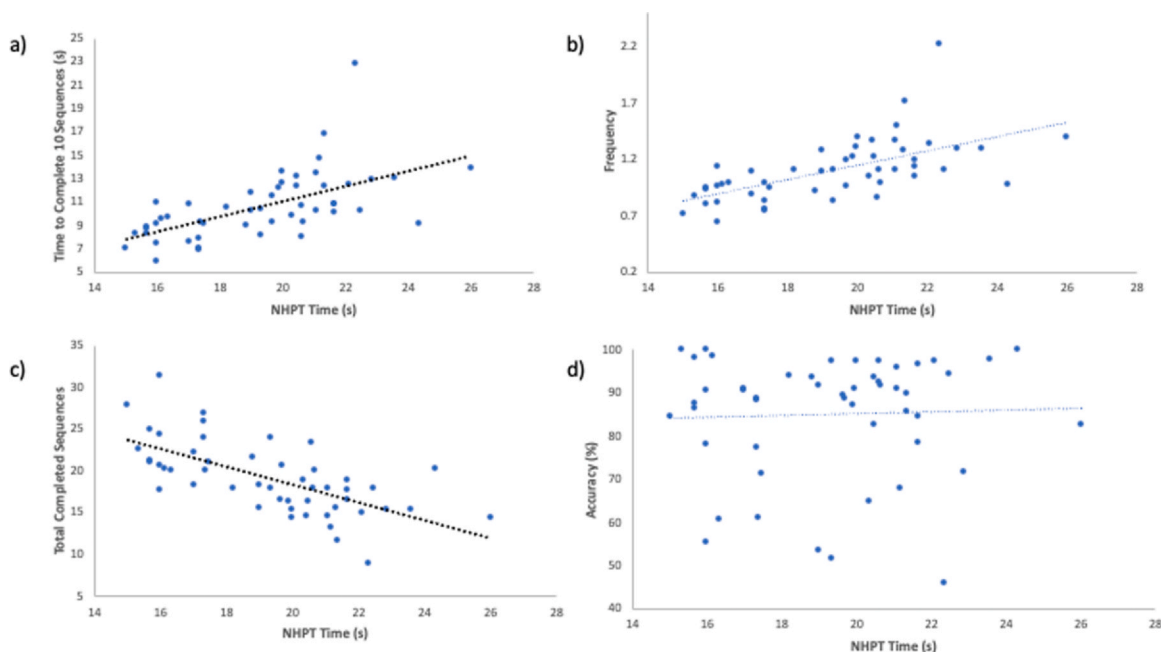
**Table 3**  
Correlational analyses of the NHPT scores compared to the DIGITS dexterity outcomes

Variable	Dominant hand		Non-dominant hand	
	p-value	Pearson correlation coefficient (95% CI)	p-value	Pearson correlation coefficient (95% CI)
Number of completed sequences	<b>0.02</b>	<b>(-0.33 [-0.56-[-0.06])</b>	<b>&lt; 0.01</b>	<b>(-0.65 [-0.79-[-0.46])</b>
Time to complete 10 sequences	0.07	0.26 ([-0.02-0.50])	<b>&lt; 0.01</b>	<b>0.59 (0.37-0.74)</b>
Average frequency	0.07	0.26 ([-0.02-0.50])	<b>&lt; 0.01</b>	<b>0.61 (0.40-0.76)</b>
Accuracy	0.95	(-0.01 [-0.29-0.27])	0.78	0.04 ([-0.24-0.31])

p < 0.05 was defined as significant; significant values are bolded.  
CI = confidence interval; NHPT = nine-hole-pegboard test.



**Fig. 4.** Line plots showing the correlations between pegboard scores in the dominant hand and (A) total sequences completed, (B) time to complete 10 sequences, (C) sequence frequency, and (D) sequence accuracy.



**Fig. 5.** Line plots showing the correlations between pegboard scores in the non-dominant hand and (A) total sequences completed, (B) time to complete 10 sequences, (C) sequence frequency, and (D) sequence accuracy.

**Table 4**  
Average values across the entire population for DIGITS and NHPT based on sex in part 2

Variable	Male (n = 32)	Female (n = 18)	p-value
Nine-Hole Peg Test dominant hand	17.8 ± 2.6	18.2 ± 1.8	0.57
Nine-Hole Peg Test non-dominant hand	18.7 ± 2.7	20.4 ± 2.2	<b>0.03</b>
DIGITS Time to complete 10 sequences dominant hand	9.9 ± 3.1	10.4 ± 2.1	0.55
DIGITS Total sequences completed dominant hand	20.8 ± 4.9	19.6 ± 4.2	0.39
DIGITS average sequence frequency dominant hand	1.0 ± 0.3	1.1 ± 0.2	0.62
DIGITS accuracy dominant hand	87.4 ± 10.6	91.3 ± 6.7	0.17
DIGITS Time to complete 10 sequences non-dominant hand	10.5 ± 3.2	10.9 ± 2.1	0.64
DIGITS Total sequences completed non-dominant hand	19.6 ± 4.7	18.2 ± 3.5	0.28
DIGITS average sequence frequency non-dominant hand	1.2 ± 0.31	1.1 ± 0.2	0.40
DIGITS accuracy non-dominant hand	83.5 ± 16.2	87.7 ± 8.9	0.32

Values shown as mean ± standard deviation; significant values are bolded. NHPT = nine-hole-pegboard test.

**Table 5**  
Correlational analyses of dexterity outcomes and participant age

Variable	Dominant hand		Non-dominant hand	
	p-value	Pearson correlation coefficient (95% CI)	p-value	Pearson correlation coefficient (95% CI)
Nine-Hole Peg Test Time to completion	0.11	0.23 ([-]0.05–0.48)	<b>0.01</b>	<b>0.36 (0.09–0.58)</b>
DIGITS: Number of completed sequences	<b>0.02</b>	<b>(-)0.34 ([-]0.56–[-]0.07)</b>	<b>0.03</b>	<b>(-)0.30 ([-]0.53–[-]0.02)</b>
DIGITS: Time to complete 10 sequences	<b>&lt; 0.01</b>	<b>0.48 (0.23–0.67)</b>	<b>&lt; 0.01</b>	<b>0.40 (0.13–0.61)</b>
DIGITS: Average frequency	<b>&lt; 0.01</b>	<b>0.44 (0.19–0.64)</b>	<b>&lt; 0.01</b>	<b>0.40 (0.13–0.61)</b>
DIGITS: Accuracy	0.96	(-)0.01 ([-]0.29–0.27)	0.61	(-)0.07 ([-]0.35–0.21)

p < 0.05 was defined as significant; significant values are bolded. CI = confidence interval.

In part two of the study, Pearson Correlations comparing the DIGITS outcome measures with the gold standard method of assessing hand dexterity, the NHPT, found that the total number of sequences completed in 20 seconds had a significant negative correlation with the time to complete the NHPT for both dominant and non-dominant hands. In other words, participants on average who completed more DIGITS finger tapping sequences in 20 seconds completed the NHPT in a shorter amount of time. This highlights that the total number of sequences completed in 20 seconds may be

a valid measure of finger dexterity and one that could be used remotely when the NHPT is unavailable.

This study also identified average values for both the DIGITS dexterity outcomes and the NHPT scores based on sex. Values for the NHPT dexterity task were similar to previous studies evaluating adult normative values for both dominant and non-dominant hands.<sup>32,33</sup> This provides baseline normative values for the dexterity outcomes obtained from the DIGITS application as our sample included healthy adults ages 18–65. However, future

studies should utilize larger sample sizes and obtain normative values for age quartiles similar to previous studies that found a significant positive correlation between age and time to complete the NHPT.<sup>33</sup>

It is important to note that the DIGITS web application was able to track finger tapping speed and accuracy, which is one of the three main domains used to assess finger dexterity clinically.<sup>5,6</sup> When reviewing the exercises done by previous studies, the most common finger tapping exercises were either using one finger to tap on a specified area as fast as possible for a certain duration of time or performing a specific task such as the coin rotation task.<sup>5,7,9,15,17</sup> The advantage of our study design is that the finger tapping exercise enables simultaneous speed and accuracy assessments of the index, middle, and ring finger as opposed to any isolated finger, and also allows us to evaluate coordination of the fingers.

In addition to measuring finger tapping speed, the DIGITS web application may also be used to assess hand tremor, another key domain for assessing hand dexterity.<sup>10–12</sup> For example, the web application tracker could be coded to detect a specific deviation of hand movements which can then be used to monitor for both positional and resting hand tremors. The use of DIGITS in assessing hand tremors will be explored in future research. The ability of our technology to measure hand tremor and finger tapping speed indicates that it may have potential uses outside of the field of hand surgery, specifically in assessing patients with neurocognitive disorders.

The cost of the technology is a limiting factor for implementing remote assessment of the third domain of hand dexterity, finger task-based dexterity, which is often done by a validated test such as the NHPT,<sup>1</sup> Minnesota manual dexterity test,<sup>2</sup> or box and block test.<sup>3</sup> Several studies have utilized virtual reality technology to remotely monitor patients using these tests, though they require virtual reality technology such as Kinect sensors and depth-sensing cameras which can be costly to implement in patient's homes.<sup>34,35</sup> While our technology may be limited in the ability to assess task-based dexterity, our tool can be a valuable initial screening tool to identify patients who are not progressing as expected after their hand trauma/surgery and can then be identified to attend an in-person appointment to be assessed with a task-based test.

### Limitations

There were several limitations identified in this study. The first limitation involves the length of time used to analyze outcomes. The 20 seconds time was taken to ensure that we had enough sequence rotations to adequately compare participants, however, we are unable to conclude that this was the optimal amount of time. Participants may have experienced fatigued by 20 seconds which could have impacted the accuracy of the results. Additionally, three measurements were taken and the average of the three trials was taken for outcome measures which may not represent how the technology would be used in clinical practice. Participants may improve with repeated measures and it may be a more reliable tool when only using the first measurement. Another limitation in this study is the small number of participants and average age of participants. Most of the participants were between the ages of 20 and 30, which may skew the average dexterity measurements data as dexterity generally declines with age. Another limitation was that several participants had graphical results that were difficult to interpret due to poor performance on the activity as shown in [Supplemental Content 3](#). This highlights the importance of accurate user training prior to utilizing the technology to assess dexterity. Finally, the DIGITS dexterity exercise was found to be a useful monitor of finger speed and accuracy which are both important domains of hand dexterity. However, we were unable to utilize

DIGITS to assess task-based dexterity which means that additional technologies would need to be used in tandem to obtain a complete assessment of an individual's level of dexterity.

In conclusion, we have identified several outcome measures using the DIGITS web application that can be used to assess hand dexterity and found several significant correlations when compared to the gold standard NHPT. Furthermore, we found that several of the DIGITS dexterity outcomes identified were significantly correlated with participant age and that high dexterity participants had significantly better scores than low dexterity individuals. Finally, we identified average values for the DIGITS dexterity outcomes based on sex. Future directions include using DIGITS to evaluate and compare this dexterity metric between patients with hand pathologies such as trauma and arthritis and healthy controls. With the increasing emphasis on telemedicine in the field of medicine, this application has the potential to improve patient outcomes and patient adherence to rehabilitation exercises by providing a remote tool by which to track their progress.

### Declaration of Competing Interest

We would like to express our sincere interest in publishing this manuscript in the Journal of Hand Therapy. Thank you for your careful consideration.

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### Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.jht.2023.08.013](https://doi.org/10.1016/j.jht.2023.08.013).

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# JHT Read for Credit

## Quiz: # A79

**Record your answers on the Return Answer Form found on the tear-out coupon at the back of this issue. There is only one best answer for each question.**

- #1. Finger tapping involved
- a. thumb to little finger
  - b. thumb to middle finger
  - c. thumb to index finger
  - d. thumb to each of the 4 digits
- #2. What gold-standard did the authors select for comparison with DIGITS
- a. Purdue Peg Board
  - b. Moberg Pick Up Test
  - c. Nine Hole Peg Test
  - d. Mayo Clinic Hand Dexterity Test
- #3. How many finger tapping sequences did each subject perform for DIGIT testing\_\_
- a. 3
  - b. 4
  - c. 5
  - d. 9
- #4. How long was each finger tapping sequence \_\_\_\_\_
- a. 60 seconds
  - b. 20 seconds
  - c. 10 seconds
  - d. 90 seconds
- #5. There was good correlation between the gold-standard and DIGITS
- a. false
  - b. true