Novel Dexterity Kit Concept Based on a Review of Hand Dexterity Literature

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Abstract Dexterity is commonly defined by the quality of fine, voluntary movements used to manipulate objects during a specific task involving the movement of wrist, hands, arm, and fingers. Dexterity assessment kits are used to determine a person's skilled task abilities through performance parameters such as speed, accuracy, and precision. This study proposes that one parameter that is as critical as the traditionally measured parameters is finger strength which could be measured as the amount of force or effort that a human hand exerts during object manipulation through fingers. In this paper, a detailed literature review was conducted of the traditional dexterity assessment methods and their kits used in the past. Thereafter, a novel dexterity kit has been proposed which incorporates measurement of finger strength data in addition to the traditional dexterity parameters during hand dexterity assessment. An experiment suggested that a significantly greater finger force is required for peg manipulation in the new test kit than in the traditional one.

Keywords Dexterity · Precision · Finger strength · Hand function · Rehabilitation

1 Introduction

Dexterity is the skill in performing precision hand-based tasks. A dexterity test is used to figure out the manual ability of an individual. For a person to perform a precision activity, both dexterity and hand strength are necessary to produce manipulative actions. Some general examples of dexterous activities are picking up objects using thumbs and fingers, writing carefully using a pen, playing sports, playing finger instruments, etc. Dexterity can be broadly divided into two categories [1]:

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1. ***Manual dexterity***: It refers to the overall gross movement of the hand and the ability of the hand to handle objects.
2. ***Fine motor dexterity***: It involves the fine movement exhibited by the different parts of hand like fingers, wrists with precision, and accuracy.

The two main fields in which the dexterity assessments play a major role are in:

1. ***Rehabilitation***: Dexterity is the best predictor of independence in activities of daily living (ADL) [2]. The gross and the fine motor skills can be impaired due to injury, illness, and stroke or development disabilities causing problems like lack of coordination between the hand, fingers, and eyes. An occupational therapist makes use of the suitable dexterity assessment tool to help re-develop, recover, and maintain the meaningful activities or occupation.
2. ***Industrial use***: The dexterity tools are very useful in evaluating employment interests and pursuits, employment seeking and acquisition, job performance, and retirement preparation [3].

Dexterity assessment helps to measure a person's speed, accuracy, and precision, i.e. the quality of movement as the hand manipulate objects and tools in the context of self-care, work, or any other activity of daily life in order to predict the abilities and the disabilities of a person [3].

In the past, a number of studies have been focused on the concerns of hand dexterity and strength that an individual should possess in his day to day working life. Bell et al. [20] demonstrate the importance of hand dexterity and strength in accessing packaging (plastic bottles, jars, and crisp packets) as the persons taking the test faced difficulty in accessing the package if they lacked either of the two parameters. The data obtained from this study were compared with the Purdue Pegboard Test data to highlight the distinction from pegboard test which focuses only on the dexterity of the person and not on finger strength. Therefore, a means to measure and improve both an individual's finger strength and dexterity shall be highly desirable. In the past, hand function skills like control precision have been measured using Grooved Pegboard Test [4]; manual dexterity has been measured by using kits like Minnesota Manual Dexterity test [5], Functional Dexterity Test [6], and Box and Block test [7]; finger tactility has been measured using O'Connor Finger Dexterity Test [8]; speed, i.e. the ability to make repeated hand movements, rapidly has been measured using tapping test [9]; fine motor dexterity has been measured using Moberg Pick-Up Test [10], Nine-Hole Peg Test [21], Jebsen-Taylor Test of Hand Function [11], and Purdue Pegboard Test [12]. Fleishman [13] identified the existence of at least two types of dexterity: arm-and-hand (gross) and wrist-and-finger (fine). Fleishman [13] later investigated the nature of factors responsible for the manipulative performance and identified five factors responsible for the effect on manual dexterity, namely finger dexterity, manual dexterity, wrist-finger speed, aiming, and positioning based on the various variables obtained by Purdue Pegboard, Tapping, and Punch board. The best measure of finger dexterity factors is the Purdue Pegboard Test. The three printed tests, namely square marking, marking accuracy, and tracing, were regarded as better measures of aiming than the two tapping tests [14] have presented a review on the innovative evaluation of dexterity for infants and children. The paper presented the measurement concepts being incorporated in assessment tools for pediatrics such as rate of completion, in-hand manipulation, and dynamic force control. Functional dexterity test (FDT) and strength dexterity test (SDT) were two novel assessment tools used in this paper [15] evaluated hand dexterity, grip, and pinch strength of the children. All these tests have been successfully measuring the skills for which they have been designed. In this study, the authors propose that along with all these "traditional" parameters of hand dexterity measurement, finger strength or force exerted by the human hand is also an important parameter which when measured along with the other "traditionally" measured dexterity skills can offer a more comprehensive hand dexterity test.

2 Methodology

2.1 Discussion on a Proposed Dexterity Kit

From the study of the various available dexterity kits, it is evident that these kits focus chiefly on the speed and accuracy of the user to complete the task. But in the real-world situations for which these tests are targeted, strength is also a very important factor to determine the user's performance and abilities. In this paper, a design of dexterity kit has been proposed to make the use of a layout similar to existing test kits and to introduce a mechanism to fulfil the finger strength criteria that is realized as missing during this review.

A CAD model of the proposed design has been created using SolidWorks 2015 $\times$64 edition [16] as shown in Fig. 1. The board consists of four columns of holes with 12 holes in each row (tentative proposal). The board has radial spring mechanisms within it underneath each hole. The hole diameters are kept decreasing along the width of the board to study the finger force variation with respect to pin diameter. The spring stiffness is kept increasing along the length of the board to study the variation of finger force with respect to the stiffness of the spring. The shape of the holes is circular with rectangular slits on diametrically opposite sides to provide for a locking option. Similar to the mating part, the pins are also cylindrically shaped with two rectangular pins on either side of the diameter. The pegboard is hollow inside where springs are placed beneath each hole. The spring is fixed at the bottom with a plate at the top which covers the hole from inside. A user inserting the pin into the hole will have to unlock by applying a suitable force (according to the stiffness of the spring used) to the correct orientation such that the extensions on the pin mates with the hole extensions. Also, to keep the pin inside the hole after the applied force is removed the user must turn the pin inside the hole to lock. Using such an arrangement, it becomes convenient to estimate the force exerted by the fingers in addition to the hand dexterity. An important parameter for the proposed design of the

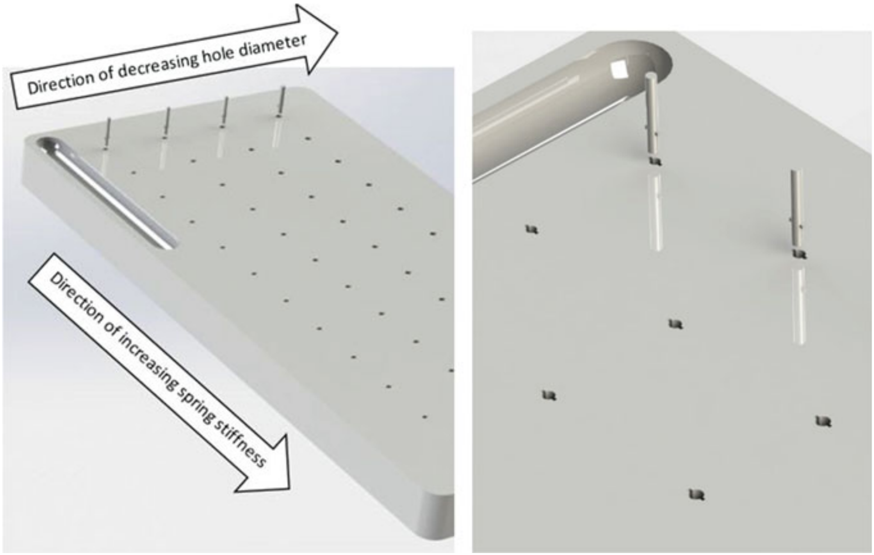

Fig. 1 Proposed kit design

kit is the diameter of the pin and step size with which it will vary. Some previous related works have been helpful in determining the size of the pins. Some of the useful data has been discussed below:

I. 60 Aluminium knobs for determination of torque capacity were used ranging from 12.7 mm (0.5 inch) to 25.4 mm (1 inch) with step size of 3.175 mm, 25.4 mm (1 inch) to 76.2 mm (3 inch) with step size of 6.35 mm, and 76.2 mm (3 inch) to 127 mm (5 inch) with step size of 12.7 mm [17].
II. Cylindrical handles were used for determination of grasping force with diameters ranging from 31 to 116 mm [18].
III. Cylindrical handles were used for determining grip force with diameters ranging from 25 to 50 mm [19].

From the study of these previous works, it can be seen that the diameter measure for which the power gripping or grasping forces has been determined is above 25 mm. Therefore, this test kit is focused on the analysis of pinch (precision) force exerted by a human finger in the smaller dimension range of 5–15 mm with a step size of 2 mm. To validate this range of diameters and the step sizes, a prototype model was developed on which the participants could perform the insertion, twisting, and locking tasks, and the traditional dexterity data along with the finger force data could be recorded.

2.2 Proposed Prototype Design

A CAD model of the prototype of the proposed design is shown in Fig. 2 made using SolidWorks 2015 ×64 edition. The prototype shows only a single hole-spring arrangement. This prototype is proposed to manipulate/vary two important parameters for the kit hole diameter and the spring stiffness by trial and error method, for analysing the observed dexterity and finger force. The prototype was developed using MDF board, plywood board, acrylic fixtures, and an ABS rapid-prototyped peg for preliminary experimentation as can be seen in Fig. 2.

2.3 Working of the Prototype

The pin needs to be inserted in the hole with proper orientation, i.e. when the extensions on both the pin and hole are mating, then the pin is rotated inside the hole to fix it or lock it inside the hole by applying a turning moment.

2.4 Experiment

Eight participants, all post-graduate students of design, were first given a short briefing before the test to ensure that they understood the procedure completely. Participants were requested to comply with the following guidelines:

- Assume a sitting position.
- Ensure the elbow is flexed at a 90° angle.
- Ensure that the forearm is in a neutral position.
- Use the preferred hand to pinch the pin.

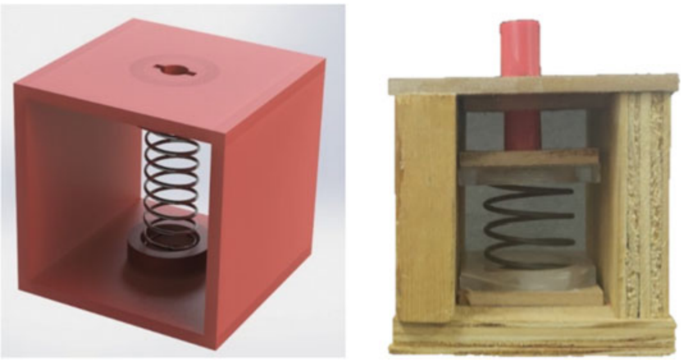

Fig. 2 Proposed prototype model

The following procedure was used for performing the task:

1. On the thumb and index finger of the participants, pressure sensors were attached.
2. The participants were requested to pinch the pin firmly and apply downward force.
3. Then the participants are asked to give a clockwise torque to lock the pin.
4. The pin was to be released.
5. Then a counter-clockwise torque was applied to unlock the pin.
6. Steps 1–5 were repeated for a duration of 60 s.

The fabricated model was used to carry out experiments to estimate the finger strength data from the available test kits. The individuals were asked to insert the pins in the slots, and their reading of force exertion was recorded using is Finger Tactile Pressure Sensing (FingerTPS) system developed by Pressure Profile Systems (PPS). At first, the spring was not loaded into the kit, and the individuals were asked to insert the pin (diameter 7 mm) into the slot. This step was performed to observe the amount of finger force exerted using traditional test kits. Then the spring was loaded into the kits, the individuals perform the same task again, and the readings were recorded. The individuals were made to perform the same task again on the spring-loaded test kit but with varying the pin diameter (11, 15 mm).

3 Results and Discussions

From Fig. 3, we can see that each of the eight participants during the traditional test condition, i.e. without spring-loaded pin, has to exert much lesser force than that in the spring-loaded condition. The reading after the spring was loaded into the kit

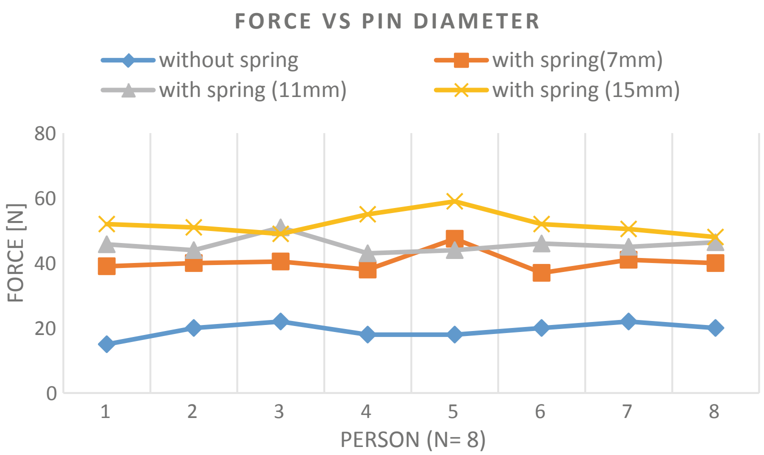

Fig. 3 Variation of finger force under traditional and spring-loaded conditions

Table 1 Comparisons of the various parameters measured using the dexterity kits

References	Control precision	Manual dexterity	Fine dexterity	Finger tactility	Speed	Finger force
Merker and Podell [4]	Measured		Measured			
Berger et al. [8]		Measured		Measured		
Aaron and Jansen [6]		Measured				
Desrosiers et al. [5]		Measured				
Mathiowetz et al. [7]		Measured				
Shimoyama et al. [9]					Measured	
Moberg [10]		Measured	Measured			
Kellor et al. (1971)			Measured			
Jebsen et al. [11]		Measured	Measured			
Tiffin et al. [12]		Measured	Measured			Measured
This study	Measured		Measured			Measured

shows that the finger force also varies with changing pin diameters. These results imply that a significant amount of finger force exertion was demanded in the newly developed test kit as compared to the non-spring-loaded kit. This result verified that the newly designed test kit fulfils the original aim of this work which was to additionally introduce a factor of finger force in the traditional dexterity kit architecture. Traditional ones tend to focus more on parameters such as accuracy, errors, and task time. Table 1 shows a comparative study of the various skill sets measured by the various available dexterity kits.

4 Conclusion

In this work, the design of a new dexterity measurement kit has been proposed which can incorporate concerns of hand dexterity and finger strength parameters during a dexterity test. On comparing the peak force measures obtained from spring-loaded pegs against regular pegs, it can be observed that significant differences do seem to exist in terms of the amount of force applied. Apparently, there exist a number of shortcomings in the work described in this paper; one of them is that the design proposed has only one port for performing the test, but in a professional kit, the test kit should include a battery of ports. An estimation of designing the professional kit could be based on the results obtained from the experiment conducted with a single port model. Also, greater breadth of experiments could be conducted on this single port model, e.g. to study the variation of finger strength with a change in pin diameters or the change in spring stiffness, as well as inputs regarding perceived finger fatigue could be collected. All such data will serve to provide inputs for scaling this test kit into a professional kind with a matrix of several ports to measure speed, accuracy, and precision and finger strength in a single test kit. Another area in which this model needs improvement is the accuracy of construction.

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