A Portable Soft Hand Exerciser With Variable Elastic Resistance for Rehabilitation and Strengthening of Finger, Wrist, and Hand[1]

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1 Background

Stroke is the leading cause of long term disability and has a major impact on societal and healthcare burden [1,2]. The recovery and rehabilitation process, if not well-managed, can lead to aftereffects which will impact on the quality of lives of the patients and their families. It was reported that early rehabilitation management after acute stroke leads to better outcomes and shorter hospitalization stays [3].

However, stroke rehabilitation is both manpower and resource-intensive. Hence, the shortage of skilled expertise and equipment is the primary limiting factor to the amount of rehabilitation each patient can receive. It is also observed that stroke patients spend a large part of their time resting in bed without any activity and this time could be better utilized for bedside therapy at their own convenience [4].

Existing hand exercisers, such as putty, elastic bands, grip strengtheners, soft balls and finger webs, are associated with disadvantages such as portability, durability, limited range of motion, and operational use on one hand only. Most devices also consist of only one elastic resistance in one unit, requiring the user to purchase multiple color-coded units as they progress in their rehabilitation or strength training.

In this study, we aim to develop a portable, lightweight, and intuitively designed multifunctional soft hand exerciser with variable elastic resistances within one unit. The gradient feature of different resistance levels is expected to motivate and hasten user progress up the level of difficulty. This device should support a variety of finger, hand, wrist, and arm exercises in multiple planes of motion. Currently, this device is intended for use by outpatients suffering from hand injuries or disabilities, but with some residual strength in their fingers, hand, and wrist, and are in the stage of recovery toward regaining their strength.

This portable and lightweight device is designed primarily for use at home to facilitate patient's recovery outside of in-clinics therapy. Other user groups such as the elderly could also utilize this device for strength and flexibility training. Eventually, our goal is to make iterations to this device for use as a supplementary therapeutic intervention for stroke in-patients to self-manage a range of hand, finger, and wrist exercises by their bedside.

2 Methods

2.1 Fabrication of Soft Hand Exerciser. First, the mold design of the device was created using the SolidWorks software and subsequently printed using a 3D printer. A volume ratio of 1:1 of the Ecoflex® silicon rubber solution A and solution B were mixed together. After vacuum degassing, the mixture was poured into the 3D printed mold, then cured at 65 °C for 20 min before leaving to cool at room temperature. The process was repeated using silicon rubber of different shore hardnesses, poured into the same mold to create variable elastic resistance within one unit. The cured silicon rubber was removed carefully from the mold, and subsequently named as the soft hand exerciser. The level of resistance along the length of the device will be correlated to the shore hardness of the material, depending on where the user places his fingers. For example, resistance level 1 indicates shore hardness of 0010 and 0010 on the top and bottom of the device, respectively; Resistance level 6 indicates shore hardness of 0050 and 0050, respectively.

2.2 Characterization Setup. Load-extension profile of device was characterized using the Instron machine, which consisted of a 100 N load cell, a vertical moving platform, and a pair of 1- or 3-prong hooks. The load cell was used to measure the tensile load on the device (Fig. 1). The moving platform was controlled at a rate of 1 mm/s and moved from its initial position to a maximum displacement of 50 mm or 100 mm. The hooks, which simulate the human fingers, were fixated at the top (adjacent to load cell) and bottom (at the static base) of the Instron machine before mounting on the exerciser device. The mount distance between the two hooks varies along the device length, depending on the resistance level of interest. The aforementioned setup was used for tensile testing to simulate finger abduction, finger stretch, and grasping and pulling with both hands.

3 Results

Three different sets of tensile testing were performed on the device to mimic actions such as finger abduction, finger stretch, and grasping and pulling with both hands (Fig. 2).

To simulate the action of finger abduction, 1-prong hooks were placed within selected holes of varying shore hardnesses located

Fig. 1 Mechanical testing setup using an Instron machine, fitted with 1- or 3-prong hooks. Both ends of the device were mounted onto the hooks and pulled at a rate of 1 mm/s (far right). The load cell detects the tensile loads.

[1]Accepted and presented at The Design of Medical Devices Conference (DMD2015), April 13–16, 2015, Minneapolis, MN, USA.

DOI: 10.1115/1.4030555
Manuscript received March 3, 2015; final manuscript received March 17, 2015; published online July 16, 2015. Editor: Arthur Erdman.

Fig. 2 Simulated finger abduction, single finger stretching and hand grasping–pulling exercises using the Instron machine fitted with 1- or 3-prong hooks

central to the device and pulled apart. Tensile loading increased linearly with increased extension of the elastic hole within the device. Greater tensile loading was required to extend the device at higher abduction levels, i.e., materials of higher shore hardness. At an extension distance of 50 mm, abduction level 3 required 1.20–2.00 times greater load, compared to abduction levels 1 and 2. This corresponded to 1.18–2.02 times higher stiffness at the location of abduction level 3, compared to abduction levels 1 and 2 (Fig. 3).

To simulate the action of single finger stretch exercises, each hook was placed at the desired central location on either end of the device and pulled from one end. Similarly, tensile loading increased linearly with increased extension of the device. Greater tensile loading was needed to extend the device at higher resistance levels, i.e., materials of higher shore hardness. At an extension distance of 100 mm, resistance level 6 required 1.24–2.95 times larger tensile loading, compared to resistance levels 1–5. This corresponded to 1.22–2.94 times higher stiffness at the location of resistance level 6, compared to resistance levels 1–5 (Fig. 4).

To simulate the use of the hand for grasping and pulling, as well as for wrist flexion/extension exercises, each 3-prong hook was placed at either end of the device and pulled from one end. Tensile loading was found to increase proportionally with increased extension of the device. Larger tensile loading was required to extend the device at higher resistance levels, i.e., materials of higher shore hardness. At an extension distance of

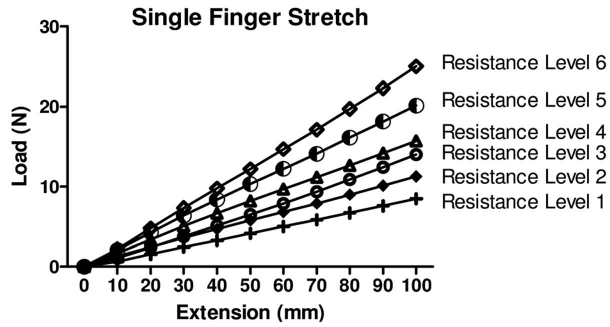

Fig. 4 Changes in tensile load with increasing extension at different resistance levels during simulated finger stretch

100 mm, resistance level 6 required 1.46–3.44 times greater tensile loading, compared to the other resistance levels. This corresponded to 1.42–3.37 times higher stiffness at the location of resistance levels 1–5 (Fig. 5).

All three sets of data showed relatively linear relationship of the loading profile versus extension, indicative of an approximately fixed range of tensile (pulling) forces allowable (∼1–3 times more forces) regardless of the amount of extension. Also, the loading profiles showed a steeper gradient, i.e., increased stiffness at higher resistance levels (Figs. 3–5). For engineering testing and customer validation, the same device underwent >50 times of small and large elastic deformation with no observable tears or material stiffness degradation. It is durable and expected to fulfill user's rehabilitation requirements through repeated stretch cycles.

4 Interpretation

The incorporation of variable elastic resistances into one unit serves to be a useful feature, allowing the user more flexibility as one varies the exercises according to rehabilitation requirements. Results have shown that the device can allow the user to exert a range of tensile forces for the same amount of extension, depending on where the fingers are placed along the device. User can choose to apply greater strength without having to stretch the device over a longer displacement.

This is a first generation prototype for testing the range of tensile loading (pulling forces). Enhancements will be made to accommodate a wider range of motions and other user-centric considerations. Further testing will be performed to investigate any changes in mechanical and material properties of the device under prolonged repetitive cyclical stretching.

Future work will include a stroke-patient trial for clinical evaluation of the device as a supplement intervention to existing

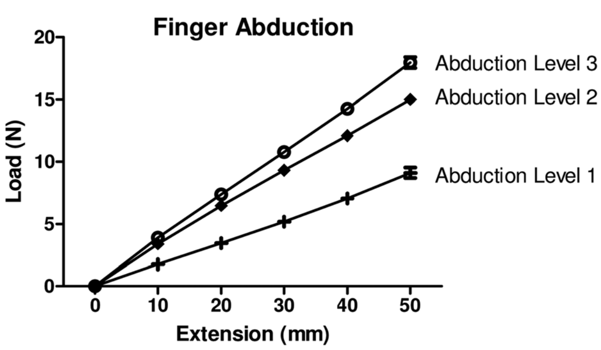

Fig. 3 Changes in tensile load with increasing extension at different abduction levels during simulated finger abduction

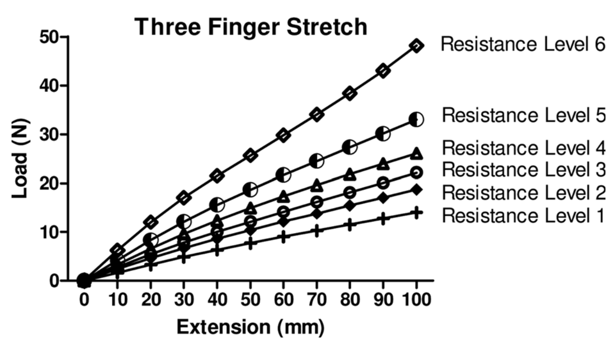

Fig. 5 Changes in tensile load with increasing extension at different resistance levels during simulated hand grasping–pulling

therapy sessions. In the long term, the introduction of this innovative soft hand exercise for bedside use is expected to translate into cost savings for the hospital (enhanced productivity due to optimized therapy time) and shorten patient recovery time and hospitalization stays.

Acknowledgment

This study was supported by the Singapore Millennium Foundation Grant No. R-397-000-164-592.

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