Published in final edited form as:

J Hand Ther. 2007 ; 20(4): 345–350.

A device for testing the intrinsic muscles of the hand

Todd C. Pataky, (PhD)¹, Adriana V. Savescu, (PhD)², Mark L. Latash, (PhD)², and Vladimir M. Zatsiorsky, (PhD)²

¹*School of Biomedical Sciences, University of Liverpool*

²*Department of Kinesiology, The Pennsylvania State University*

BACKGROUND

Loss of intrinsic muscle strength and/or coordination can cause a profound decrease in hand function (Ketchum et al., 1978). Functional assessment of the hand's intrinsic muscles has presented clinical challenges in a variety of pathologies including, among others: hand trauma (Prosser and Conolly, 2003), rheumatoid arthritis (Estes et al., 2000), median/ulnar nerve injuries (Lundborg, 1993; Schreuders et al., 2004), scleroderma (Casale et al., 1997), hand-arm vibration syndrome (Necking et al., 2003), and myelopathy hand (Ono et al., 1987).

Even though manual muscle strength testing (Brandsma et al., 1995) and kinematic observation (Buschbacher, 1997) are still employed in the clinical assessment of the intrinsic hand muscles, multiple technological advancements (reviewed in Schreuders, 2004) have improved reliability making instrumented devices indispensable clinical tools (Bohannon, 1995). Acknowledging the difficulty of isolating the intrinsic muscles (Brandsma et al., 1995), two devices were developed to measure the strength of the intrinsic muscles: (i) Intrinsic-o-meter (Mannerfelt, 1997), and (ii) Rotterdam Intrinsic Hand Myometer (RIHM; Schreuders et al., 2000). The devices are modified dynamometers with an interface customized for the lateral surfaces of the fingers.

The main difficulty with these devices is that they are quite bulky, measuring finger forces one at a time, with other fingers interfering and sometimes forcing awkward postures. Additionally, intensive clinician involvement, holding the dynamometers and securing the patient's hand, unavoidably causes substantial interobserver differences (37-52%, Schreuders et al., 2000).

Our goal was to construct a new apparatus that could measure the ab-/adduction forces of all fingers during natural postures while requiring minimal physical involvement from the clinician.

FABRICATION

The completed device is depicted in Figure 1. We caution the reader that force transducers are highly technical pieces of equipment and urge you to seek technical assistance if you are not familiar with either mechanical interfacing or electronic data acquisition. Please also note that interface information reported herein is specific to the transducers that we selected.

Send correspondence to: Todd Pataky, HACB, School of Biomedical Sciences, University of Liverpool, Sherrington Buildings, Ashton Street, Liverpool, L69 3GE, UK, Ph: +44 151 794 6871, Fax: +44 151 794 5517, tpataky@liv.ac.uk.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Materials

1. Data acquisition:
 - a. Multi-axis force transducers ($\times 4$, Figure 2). We selected the commercially available Nano-17 (ATI Industrial Automation, USA).
http://www.ati-ia.com/products/ft/ft_models.aspx?id=Nano17
 - b. Multiplex and conditioning box (Figure 3). This was custom-ordered from the transducer manufacturer.
 - c. Personal computer and data acquisition card.
2. Mechanical interface (Figure 4):
 - a. Aluminium (thickness: 5 mm). Used to construct the apparatus base, interface discs, and finger slots.
 - b. Interfacing screws. Sensor screws: 4mm, ISO M2. Slot screws: 8mm, ISO M4.
 - c. Cloth padding for finger slots.

Instructions

1. Construct the apparatus base (Figure 5). Cut a sheet of aluminium 11 $\times$ 11cm. Bore 9cm long positioning slots staggered every 2-3 cm or as desired to allow for flexible finger spacing. The slot width should correspond to the width of the bottom interface screw (7mm in our case).
2. Construct interface discs ($\times 4$) to attach to the transducer (Figure 6). These should have the same geometry as the transducer face; the Nano-17 transducer face is a circle with a 17 mm diameter. Since the transducer has multiple interface holes, constructing the interface disc(s) with a single external screw hole allows for more convenient transducer positioning along the length of the apparatus base's positioning slots. Countersink the screw holes on the interface disc to hide the screw head and allow for smooth sliding along the apparatus base. Ensure that the screws do not exceed the safety depth of the transducer interface.
3. Construct finger slots ($\times 4$, Figure 7). Cut three square pieces of aluminium (2cm²), and then weld two 'walls' to the third piece. Drill an interface hole for a slot screw.
4. Attach the interface discs and finger slots to the force transducers (Figure 8).
5. Attach the transducer assemblies to the apparatus base, and add padding to the finger slots (Figure 9).
6. Position the finger slots according to your subject's hand size. Use the patient's hand directly for custom transducer positioning along the positioning slots (Figure 10). For wider finger spacing, place transducer assemblies in adjacent finger slots.

Using the device

The device can be used in two ways: as a secured desktop device or as a freely wielded object. In desktop mode (Figure 11a) the posture of the upper limb can be tightly controlled. In free mode (Figure 11b) subjects can hold the object as if they were holding an everyday object, like a glass of water. Because the apparatus is slightly elevated during desktop mode, the apparatus affords control of thumb posture and force direction (not shown), which is known to affect finger force production (Olafsdottir et al. 2005).

Permit the subject to conduct a few submaximal practice trials to ensure that the padding thickness and placement are adequate. During the actual test, the patient should be instructed to ab- or adduct as firmly as possible against the finger slot walls. To prevent potential injury, the subject should be advised to ramp slowly to maximal force over two to three seconds. Since ab-/adduction finger strength tests can vary trial-to-trial on the order of 10% (Pataky et al. 2007), multiple trials (2-5 or more) should be conducted to achieve reliable strength measurements. Finally, adequate rest time (30-60 s) should be given between trials to prevent fatigue.

The data are recorded using a personal computer. Force is computed using a linear calibration supplied by the manufacturer. We developed custom software for data collection and calibration using LabVIEW (National Instruments, USA).

Data interpretation

Since forces are recorded from multiple fingers simultaneously, finger strength can be defined in a number of ways. We suggest that the strength of an individual finger be defined as its maximal force during a single finger task (Figure 12c). We further suggest that the strength of multi-finger opposition be defined by the instantaneous maximal value of the sum of the absolute finger forces (Figure 12a,b).

Equally or perhaps more interesting than strength are multi-finger synergistic phenomena: 'enslaving' and 'deficit'. Enslaving (observable in Figure 12c) refers to non-zero involuntary forces observed in fingers other than those explicitly required to produce force (Kilbreath and Gandevia, 1994; Zatsiorsky et al., 2000). Deficit (observable in the Index finger differences between Figures 12b and 12c) refers to lower forces during maximal multi-finger tasks vs. single finger tasks (Zatsiorsky et al. 2000). These synergistic behaviours are indicative of the complex functional integration of all digits of the hand, and unique clinical indications may reside in these multi-finger phenomena.

Cautions

1. Forces applied high along the finger slot walls could potentially damage the force transducers.
2. Ensure consistent transducer orientation between the transducer's measurement axes and the apparatus base. Measurement axes information can be obtained from the manufacturer.
3. We remind the reader that force transducers are highly technical pieces of equipment. If you are not comfortable with mechanical interfacing and/or data acquisition, please seek technical assistance.

SUMMARY

We present an instrumented device that is relatively easy to construct (with technical assistance) and is capable of simultaneously measuring the intrinsic muscle forces from all fingers during single- or multi-finger opposition tasks. The synergistic nature of the information derived from these multi-finger tasks could prove to highlight important clinical signs.

Acknowledgements

This study was supported, in part, by NIH Grants AR-48563, AG-018751 and NS-35032. The authors would also like to thank James Metzler for his technical assistance.

References

- Brandsma JW, Schreuders TA, Birke JA, Piefer A, Oostendorp R. Manual muscle strength testing: intraobserver and interobserver reliabilities for the intrinsic muscles of the hand. *J Hand Ther* 1995;8:185–90. [PubMed: 8535479]
- Bohannon RW. Measurement, nature, and implications of skeletal muscle strength in patients with neurological disorders. *Clin Biomech (Bristol, Avon)* 1995;10:283–92.
- Buschbacher R. Side-to-side confrontational strength-testing for weakness of the intrinsic muscles of the hand. *J Bone Joint Surg Am* 1997;79(3):401–405. [PubMed: 9070530]
- Casale R, Buonocore M, Matucci-Cerinic M. Systemic sclerosis (scleroderma): an integrated challenge in rehabilitation. *Arch Phys Med Rehabil* 1997;78:767–73. [PubMed: 9228882]
- Conolly, WB.; Prosser, R. *Rehabilitation of the Hand and Upper Limb*. Butterworth-Heinemann; Toronto: 2003.
- Estes JP, Bochenek C, Fassler P. Osteoarthritis of the fingers. *J Hand Ther* 2000;13(2):108–123. [PubMed: 10855746]
- Kilbreath SL, Gandevia SC. Limited independent flexion of the thumb and fingers in human subjects. *J Physiol* 1994;479(3):487–97. [PubMed: 7837104]
- Ketchum LD, Thompson D, Pocock G, Wallingford D. A clinical study of forces generated by the intrinsic muscles of the index finger and the extrinsic flexor and extensor muscles of the hand. *J Hand Surg [Am]* 1978;3:571–8.
- Lundborg G. Peripheral nerve injuries: pathophysiology and strategies for treatment. *J Hand Ther* 1993;6(3):179–188. [PubMed: 8401798]
- Mannerfelt LG. Studies on ulnar nerve compression neuropathies with a new computerised instrument--the intrinsic-o-meter. *Scand J Plast Reconstr Surg Hand Surg* 1997;31:251–60. [PubMed: 9299687]
- Necking LE, Friden J, Lundborg G. Reduced muscle strength in abduction of the index finger: an important clinical sign in hand-arm vibration syndrome. *Scand J Plast Reconstr Surg Hand Surg* 2003;37:365–70. [PubMed: 15328777]
- Olafsdottir H, Zatsiorsky VM, Latash ML. Is the thumb a fifth finger? A study of digit interaction during force production tasks. *Exp Brain Res* 2005;160:203–213. [PubMed: 15322785]
- Ono K, Ebara S, Fuji T, Yonenobu K, Fujiwara K, Yamashita K. Myelopathy hand. New clinical signs of cervical cord damage. *J Bone Joint Surg Br* 1987;69:215–9. [PubMed: 3818752]
- Pataky TC, Latash ML, Zatsiorsky VM. Finger interaction during radial and ulnar deviation: experimental data and neural network modeling. *Exp Brain Res* 2007;179(2):301–312. [PubMed: 17334750]
- Schreuders, TA. Ph.D. dissertation. University of Rotterdam; 2004. Muscle strength measurements of the hand.
- Schreuders TA, Roebroeck ME, Jaquet JB, Hovius SE, Stam HJ. Long-term outcome of muscle strength in ulnar and median nerve injury: comparing manual muscle strength testing, grip and pinch strength dynamometers and a new intrinsic muscle strength dynamometer. *J Rehabil Med* 2004;36(6):273–278. [PubMed: 15841605]
- Schreuders TA, Roebroeck M, van der Kar TJ, Soeters JN, Hovius SE, Stam HJ. Strength of the intrinsic muscles of the hand measured with a hand-held dynamometer: reliability in patients with ulnar and median nerve paralysis. *J Hand Surg [Br]* 2000;25:560–5.
- Zatsiorsky VM, Li ZM, Latash ML. Enslaving effects in multi-finger force production. *Exp Brain Res* 2000;131(2):187–195. [PubMed: 10766271]

Figure 1. Apparatus depiction. Finger slots housed on multi-component force transducers permit measurement of lateral forces independently for each finger. The transducer signals are routed via a conditioning box to a personal computer.

Figure 2.
Multi-component force transducer (Nano 17, ATI Industrial Automation, USA).

Figure 3. Multiplexing (MUX) box. The MUX box receives electric signals from the transducers, conditions them, and then reroutes them to a personal computer.

Figure 4. Apparatus assembly. Refer to Instructions for details regarding component construction.

Figure 5. Apparatus base. The boxed digits indicate 3cm and 2cm spacing, respectively.

Figure 6.
Interface disc.

Figure 7.
Finger slot.

Figure 8.
Assembly of finger slot, force transducer, and interface disc.

Figure 9.
Completed apparatus assembly.

Figure 10. Custom finger slot positioning based on the subject's hand size. Position the DIP joints in the center of the finger slots to prevent joint strain.

Figure 11.

Device usage. (a) In Desktop mode the apparatus can be fixed to a tertiary device (seen below the apparatus base; various designs possible) or clamped to a desk (not shown). The subjects arm can also be restrained as depicted. (b) In Free mode no other devices are necessary; the subject can wield the apparatus freely. For clarity, the transducer wires have been removed from the photographs.

Figure 12.

(a) Multi-finger abduction force time series, example subject. The four fingers (Index – I, Middle – M, Ring – R, and Little – L) and the sum of the absolute forces (ΣF_{IMRL}) are presented. (b) Multi-finger abduction; average maximal forces across five subjects. These forces were determined at the instant of maximal ΣF_{IMRL} . (c) Single-finger (Index) radial deviation strength across five subjects. In this task, only the Index finger was instructed to produce force. The forces of all fingers were recorded at the instant of maximal Index force. Note the non-zero forces in the other three fingers, and note that the single-finger task (c) is associated with greater force than the multi-finger task (b). Forces are reported in newtons in all panels. Error bars in (b) and (c) indicate standard deviations across subjects.