Journal of Visualized Experiments

A Standardized Method for Measurement of Elbow Kinesthesia

--Manuscript Draft--

Article Type:	Methods Article - Author Produced Video
Manuscript Number:	JoVE61391R1
Full Title:	A Standardized Method for Measurement of Elbow Kinesthesia
Section/Category:	JoVE Behavior
Keywords:	kinesthesis; proprioception; elbow; upper extremity; measurement; somatosensation; protocol; threshold to detection of passive movement; TDPM
Corresponding Author:	Molly Watkins, DPT College of Saint Scholastica Duluth, Minnesota UNITED STATES
Corresponding Author's Institution:	College of Saint Scholastica
Corresponding Author E-Mail:	mwatkins2@css.edu
Order of Authors:	Molly Watkins, DPT
	Emily Duncanson
	Emma Gartner
	Samantha Paripovich
	Christine Taylor
	Alexandra Borstad
Additional Information:	
Question	**Response**
Please indicate whether this article will be Standard Access or Open Access.	Standard Access (US$1200)

TITLE:
A Standardized Method for Measurement of Elbow Kinesthesia

AUTHORS AND AFFILIATIONS:
Molly Watkins, Emily Duncanson, Emma Gartner, Samantha Paripovich, Christine Taylor, Alexandra Borstad

Department of Physical Therapy, The College of St. Scholastica, Duluth, MN, USA

Email addresses of co-authors:
Molly Watkins (mwatkins2@css.edu)
Emily Duncanson (eduncanson@css.edu)
Emma Gartner (egartner@css.edu)
Samantha Paripovich (sparipovich@css.edu)
Christine Taylor (cmtaylor816@gmail.com)

Corresponding author:
Alexandra Borstad (aborstad@css.edu)

KEYWORDS:
kinesthesis; proprioception; elbow; upper extremity; measurement; protocol; somatosensation; threshold to detection of passive movement; TDPM

SUMMARY:
Here, we present a standardized method for measurement of elbow passive kinesthesia using the threshold to detection of passive movement (TDPM) that is appropriate for a research setting.

ABSTRACT:
Proprioception is an important component of controlled movement. The threshold to detection of passive movement (TDPM) is a commonly used method for quantifying the proprioceptive submodality of kinesthesia in research settings. The TDPM paradigm has been found to be valid and reliable; however, the equipment and methods used for TDPM vary between studies. In particular, the research laboratory apparatuses for producing passive movement of an extremity are often custom designed by individual laboratories or inaccessible due to high cost. There is a need for a standardized, valid, and reliable method for measuring TDPM using readily available equipment. The purpose of this protocol is to provide a standardized method for measurement of TDPM at the elbow that is economical, easy to administer, and that produces quantitative results for measurement purposes in research-based settings. This method was tested on 20 healthy adults without neurological impairment, and eight adults with chronic stroke. The results obtained suggest this method is a reliable way to quantify elbow TDPM in healthy adults, and provides initial support for validity. Researchers seeking a balance between equipment affordability and measurement precision are most likely to find this protocol of benefit.

INTRODUCTION:

Proprioceptive information is an important contributor to the control of human movement. Proprioceptive deficits accompany a wide range of neurologic conditions such as stroke[1-6], Parkinson's disease[7], and sensory neuropathies[8]. Orthopedic injuries such as ligament and muscle tears have also been shown to reduce proprioceptive function[9]. The construct of proprioception is often tested in clinical outcome measures via detection of provider-applied small alterations in finger or toe position[10-14]. Such measures produce relatively coarse measurements: "absent", "impaired", "normal"[12]. While sufficient for detection of gross proprioceptive impairments, laboratory mechanical testing methods are required to precisely measure subtle proprioceptive impairments[14-16].

Researchers and clinicians often divide proprioception into submodalities for measurement. The most commonly investigated submodalities of proprioception are joint position sense (JPS) and kinesthesia, typically defined as the sense of movement[3,16,17]. Joint position sense is often tested via active matching tasks, where individuals replicate a reference joint angle[18,19]. Kinesthesia is commonly measured using the threshold to detection of passive movement (TDPM), whereby a participant's limb is passively moved slowly, with the participant indicating the point at which movement is first detected[16,17,19]. Measurement of TDPM typically requires use of specialized equipment to provide the slow passive movement and denote the point of detection[17].

Valid and reliable results have been found at different joints using TDPM methods[9,16,19-22]. However, there is considerable variation in TDPM equipment and methods, creating a challenge for comparison of findings across studies[16,17]. Laboratories often develop their own limb movement and measurement devices, or use expensive commercial devices and software[16]. Passive movement speeds also vary; movement speed is known to affect detection thresholds[7,16,23]. A standardized, easily reproducible method capable of quantifying TDPM across a range of impairment levels is needed. Because the anatomy and physiology of each joint differs, protocols should be joint specific[19]. The protocol outlined here is specific to the elbow joint. However, the methods of this protocol may be useful to establish protocols for other joints.

To increase generalizability across sensorimotor research laboratories, the preferred apparatus for providing the passive movement for elbow TDPM testing would be commercially available at an affordable cost. To this end, an elbow continuous passive movement (CPM) machine (available speed range 0.23°/s – 2.83°/s) was chosen to produce the motorized, consistent motion. CPM machines are commonly found in rehabilitation hospitals and medical supply stores and can be rented or borrowed to reduce research costs. Additional equipment requirements include items commonly found in sensorimotor laboratories (i.e., electrogoniometer and electromyography (EMG) sensors), and hardware stores (e.g., PVC pipe, string and tape).

Two different groups were tested to explore the measurement properties of this TDPM

protocol: healthy adults and adults with chronic stroke. For the adults with chronic stroke, the ipsilesional (i.e., less affected) arm was tested. Kinesthetic sense in the ipsilesional elbow in adults with chronic stroke may appear normal with clinical testing, but impaired when evaluated using quantitative laboratory methods[5,15]. This example illustrates the importance of developing and using sensitive and precise measures of somatosensory impairment and makes this a useful population for testing purposes. For validation of this protocol, we used the known groups method[24]. We compared TDPM to another quantitative measure of kinesthesia, the Brief Kinesthesia Test (BKT). The BKT has been shown to be sensitive to ipsilesional upper limb impairment post stroke[25]. The tablet-based version (tBKT) was used in this study because it is the same test as the BKT, administered on a tablet with more trials. The tBKT has been shown to be stable in 1-week test re-test measurement and sensitive to proprioceptive knockdown[26]. It was hypothesized that the elbow TDPM and tBKT outcomes would be correlated as sensorimotor control of the elbow contributes to BKT performance[26].

The purpose of this paper is to outline a standardized method of measuring elbow TDPM that is reproducible using common equipment. Data is presented regarding reliability and initial validity testing of the method, as well as feasibility of use for persons with no known pathology, and those who were hypothesized to have mild somatosensory impairment.

PROTOCOL:

The Institutional Review Board at The College of St. Scholastica has approved the study under which this protocol was developed and tested.

1. Fabrication of the visual screen

1.1. Cut the ¾ inch (1.9 cm) diameter PVC pipe into various lengths: two 30 inch (76.2 cm) pieces (screen base); two 8 inch (20.3 cm) pieces (screen base); one 44 inch (111.8 cm) piece (vertical screen support); and one 32 inch (81.3 cm) piece (screen fabric holder).

1.2. Place an end cap on one end of each 30 inch (76.2 cm) piece, and a 90° PVC elbow on the other end. Insert 8 inch (20.3 cm) pieces into the remaining open ends of both elbows. Connect open ends of the two 8 inch (20.3 cm) pieces with a PVC T-piece to create a screen base.

1.3. Insert a 44 inch (111.8 cm) PVC piece into a vertical portion of PVC T-piece to create a vertical support for screen. Place a 45° PVC elbow on an open end of the 44 inch (111.8 cm) pipe. Insert a 32 inch (81.3 cm) pipe into an open end of the 45° PVC elbow to create a screen fabric holder. Place an end cap on an open end of the 32 inch (81.3 cm) pipe.

1.4. Place dishtowels on top of one another to ensure fabric opacity. Secure to a 32 inch (81.3 cm) pipe with athletic tape. The fully assembled screen can be seen in **Figure 1.**

2. Preparation of the testing equipment

2.1. Calibrate electrogoniometer and electromyography (EMG) sensors according to the manufacturers' instructions.

2.2. Turn on the continuous passive motion (CPM) machine and activate **Extension/Flexion** mode. Program the CPM machine to move through 90° to 130° of elbow extension at a speed of 0.23°/s.

3. Preparation of the participant for TDPM testing

3.1. Seat the participant in a standard height chair (46 cm), ensuring sitting with a straight back and feet flat on floor.

3.2. Verbally prepare the participant for the EMG sensor and the electrogoniometer placement using a standardized script: "To begin, I am going to prepare your skin to attach sensors. They will help record movement and ensure your muscles are relaxed during the test. I'm going to mark landmarks on your arm and start attaching the sensors, so you can just relax in the position I place you in."

3.3. Attach the biceps brachii and the triceps brachii EMG sensors.

3.3.1. Manually resist elbow flexion to locate the biceps brachii muscle belly and mark the central point of the muscle belly with a small dot of washable marker to denote the location for the EMG sensor placement. Prepare the skin by removing the dead skin cells followed by scrubbing with an alcohol swab, and then attach the EMG sensor.

3.3.2. Manually resist the elbow extension to locate the muscle belly of the lateral head of the triceps brachii and mark the central point in the bulk of the muscle belly with a small dot of washable marker to denote the location for the EMG sensor placement. Prepare the skin by removing dead skin cells followed by scrubbing with an alcohol swab, and then attach the EMG sensor.

3.3.3. Test the EMG function by evoking an isometric biceps brachii contraction, followed by an isometric triceps brachii contraction, and observing for EMG activation.

3.4. Attach the electrogoniometer to the participant.

3.4.1. Determine the midpoint of the dorsal aspect of the wrist and mark with a washable marker.

3.4.2. Palpate the most prominent aspect of the lateral epicondyle and mark with a washable marker.

3.4.3. Palpate the greater tubercle of the humerus and mark with a washable marker. Verify the greater tubercle location by passively moving the testing arm through passive internal and

external rotation of the humerus as needed.

3.4.4. Attach one end of the string to the lateral epicondyle mark using paper tape. Pull the string taut, connecting it with the dorsal wrist midpoint mark.

3.4.5. Trace the line along the proximal forearm in line with string using a washable marker.

3.4.6. Move the free end of the string to the greater tubercle mark and pull the string taut.

3.4.7. Trace the line along the distal humerus in line with string using a washable marker, and then remove the string.

3.4.8. Place the distal paddle of the electrogoniometer along the path of the traced line, 1.5 inches (3.8 cm) distally from the lateral epicondyle mark.

3.4.9. Place the proximal paddle of electrogoniometer along the path of the traced line, 1.5 inches (3.8 cm) proximally from the lateral epicondyle mark. Secure the remaining components of the electrogoniometer to the skin using paper tape.

3.5. Position the participant's upper extremity comfortably in the CPM machine.

3.5.1. Adjust the height and orientation of the CPM machine to achieve a position of 90° sagittal plane shoulder flexion, 90° elbow flexion, and a neutral forearm. Align the participant's lateral epicondyle with the rotational axis of the CPM machine.

3.5.2. Adjust the CPM machine hand support to fit comfortably with the palm of the participant's hand and secure the forearm via a wrist strap. **Figure 1** shows the final participant setup for TDPM testing.

4. Administration of the TDPM test

4.1. Inform the participant of the testing procedure with the following standardized verbal information: "During this test, the machine is going to move very slowly to either straighten or bend your elbow. We will say "begin" at the start of each trial, there will be eight trials. When I say begin, the machine may or may not move your arm. Please press the button as soon as you feel your arm move, but only when you feel movement. If you don't feel movement, we will stop the trial after a period of time; try to pay attention until we stop the trial. This is the button you'll be using. Please press the button right now to test it."

4.2. Hand the participant the electrogoniometer event marking trigger switch and test the switch.

4.3. Inform the participant of additional aspects of the procedure: "In between each trial, whether your arm moved or not, we will take your arm out of the machine and straighten it,

and then place it back in the machine. Please remain relaxed. Do you have any questions about the test? We will be using this curtain to block your vision during this test and place this hearing protection over your ears to minimize any sounds you might hear during the testing."

4.4. Occlude visual input by blocking the view of the arm being tested and the CPM machine using a visual screen. Drape screen material at the participant's shoulder to avoid sensory input during arm movement. Diminish auditory input by placing noise-cancelling headphones on the participant (see **Figure 1**).

4.5. Loudly state "begin," and wait the corresponding amount of time per trial before initiating movement of the CPM machine to decrease participant guessing when movement will begin[19]. Standardized delay times are shown in **Table 1**. [Place **Table 1** here].

4.6. Observe for activation of biceps brachii and triceps brachii muscles by monitoring EMG sensor feedback readings to ensure that the participant does not attempt to use active movement to assist in movement detection.

4.6.1. If muscle activation is noted, stop the trial and use the following standardized script: "Your muscles are activating. Please try to keep your arm relaxed during the test." This trial should be noted for exclusion from data analysis, with the researcher proceeding with resetting the participant and CPM to start the next trial (protocol step 4.7).

4.7. Between each trial, remove the participant's testing arm from the CPM machine and return the CPM machine to a 90° start position. Passively move the participant's elbow through full extension and then back to 90° flexion to standardize the muscle spindle movement history[27,28]. Place the arm back in the CPM machine for the next trial.

4.8. Complete eight trials, including two "catch" trials where the participant's arm is not moved[19]. Terminate each trial (catch and non-catch) when the participant depresses the trigger switch, or after 15 seconds if the trigger switch is not depressed.

4.9. If during a catch trial a participant verbally reports they cannot feel movement, or depresses the trigger switch, use the following standardized response: "Your arm did not actually move during that trial. I know it's hard to feel, the machine moves very slowly; try to concentrate and push the button as soon as you feel your arm move or that your arm position has changed."

5. Calculation of participant's TDPM score

5.1. Using the electrogoniometer tracing, identify the electrogoniometer angle measurement for the point at which the CPM machine movement started, and for the point at which the participant depressed the trigger switch indicating movement was felt. See **Figure 2** for a representative example.

[Place **Figure 2** here].

5.2. Subtract the starting angle from the final angle, thus identifying the number of degrees the CPM moved; this is the participant's elbow TDPM value for that trial.

5.3. To determine participant's overall TDPM score, remove the smallest and largest TDPM values from the six non-catch trials, and then average the remaining four trial scores[29].

REPRESENTATIVE RESULTS:

Participants:

Using the protocol presented here, elbow TDPM was measured for two different groups of individuals: 20 healthy adults, and eight adults with chronic stroke in an academic research laboratory. Participants for both groups were recruited from the community using fliers, emails, and word-of-mouth. The healthy adults (14 females, six males; mean age (SD) = 28 (7.9) years; 19 right- and one left-handed) were tested to generate representative results for an unimpaired population. Inclusion criteria were: age of 18 to 85 years; ability to follow two-step directions as determined by screening at initial meeting. Exclusion criteria were: history of disease or conditions affecting neuromuscular function the upper limbs based upon self-report; reported allergy to metal or latex. Handedness was assessed using the Edinburgh Handedness Inventory[30]. Half of the healthy adult participants had TDPM of their right elbow tested, and half had their left elbow tested (block randomization). To determine the test-retest reliability of this protocol, healthy adult participant elbow TDPM was measured twice, one week apart. The tBKT was completed on Day 1 following TDPM testing. No adverse events occurred for any participant in the healthy participants group.

The elbow of the ipsilesional (i.e., less affected) upper limb of the individuals with chronic stroke (five males, three females; mean age (SD) = 69 (11.3) years; five right hemisphere stroke, three left hemisphere stroke) was tested to represent the protocol's capability for detecting and quantitatively discriminating TDPM in individuals with suspected mild proprioceptive impairment. Inclusion criteria for this group were the same as for the healthy adult group, with the addition of: history of stroke occurring more than six months prior that impacted upper extremity function. Exclusion criteria were: any history of ipsilesional upper extremity pain or musculoskeletal injury; reported allergy to metal or latex. Participants with chronic stroke completed one elbow TDPM testing session. The tBKT was completed following elbow TDPM testing. One participant with stroke reported mild irritation from the EMG sensor adhesive that precluded participation in follow-up testing; no other adverse events occurred.

Results:

No statistical difference was found between right and left elbow TDPM scores for healthy adults (p = 0.86, two-tailed); the data was combined for subsequent analyses. The average elbow TDPM for healthy adult participants (n = 20) was 1.19 (±1.02) degrees. The Spearman correlation and intraclass correlation coefficient (ICC) were calculated to evaluate test-retest reliability of the TDPM; a positive and statistically significant relationship was found (r = 0.72, p < 0.001), (ICC 2,4 = 0.84), suggesting moderate to good reliability of the measure among

healthy adult participants[24] (**Figure 3**).

The average ipsilesional elbow TDPM for participants with chronic stroke (n = 8) was 8.24 (±4.53) degrees (**Table 2**). Participants with chronic stroke were more variable than healthy adult participants (**Figure 4A**). Using a two-tailed t-test, the TDPM of the healthy adult and chronic stroke groups were found to be statistically different, with the adults with chronic stroke requiring a greater elbow extension excursion prior to movement being detected (t = 4.4, p = 0.003, two-tailed) (**Table 2**). Spearman correlation between elbow TDPM and error in targeted reaching as measured by the tBKT showed a moderate relationship between these two measures (r_s = 0.63, p < 0.001) (**Figure 5**). Participant tBKT scores are shown in **Figure 4B**.

FIGURE AND TABLE LEGENDS:

Figure 1: Participant setup for elbow threshold to detection of passive movement (TDPM) testing. The continuous passive motion (CPM) machine extended the participant's elbow at a constant speed of 0.23°/s. Note the visual screen placed to occlude vision of the testing arm. Not visible are hearing occlusion headphones, and a trigger switch for participant indication of movement detection.

Figure 2: Example electrogoniometer tracing with detection point. The electrogoniometer line tracing (green line), start point of the continuous passive motion (CPM) machine movement, and the point at which participant indicated movement was detected (first blue peak) are shown. The difference between electrogoniometer readings at the start of the trial (pink circle) and at detection point (orange circle) determines the TDPM value for that trial.

Figure 3: Test-retest reliability of elbow threshold to detection of passive movement (TDPM) method in healthy adults. Spearman correlation and intraclass correlation coefficient (ICC) of Day 1 and Day 2 (tested one week apart) were used to compare TDPM scores. Figures show line of fit with 95% confidence interval (shaded area) and a density ellipse. A positive and statistically significant relationship was found (r_s = 0.72, p < 0.003).

Figure 4: Representative results for elbow threshold to detection of passive movement (TDPM) (A) and the tablet version of Brief Kinesthesia Test (B) for healthy adult control subjects versus participants with chronic stroke. Note that one individual with chronic stroke was unable to detect movement on any trial, the maximum specified TDPM value of 15° was assigned. This same individual had the greatest amount of error during tBKT testing.

Figure 5: Elbow threshold to detection of passive movement (TDPM) scores compared to tablet version of the Brief Kinesthesia Test (tBKT) scores in healthy adults and adults with chronic stroke. Spearman correlation between elbow TDPM and error in targeted reaching as measured by the tablet version of the Brief Kinesthesia Test (tBKT) is shown. There was a moderate positive relationship (r_s = 0.63, p < 0.003).

Table 1: Standardized time delays and catch trial locations. Varied trial start time delays are included to prevent participant attempts to guess when movement will begin. Catch trials are

included to test whether or not participant is actually detecting movement[19,31].

Table 2: Participant description, average elbow threshold to detection of passive movement (TDPM) scores (degrees), and average tablet version of the Brief Kinesthesia Test (tBKT) scores. A significant difference was found in average elbow TDPM between healthy controls and adults with chronic stroke, as well as in the average tBKT scores.

DISCUSSION:

The presented protocol describes how to measure elbow TDPM in a standardized fashion using a common CPM machine to provide the passive movement. Across 20 healthy participants the average elbow TDPM measurement was found to be similar to the average value identified in previous studies using other TDPM measuring setups[7,19,32], and produced reliable results across testing sessions. TDPM of the ipsilesional elbow among the eight participants with chronic stroke on average differed significantly, and perhaps clinically meaningfully, from the healthy adult population as has been previously shown[5,15]. It is likely a portion of the difference in TDPM between groups can be attributed to age differences[21,33-35] and to potential reaction time differences[1]. Regardless, the findings indicate this method is able to discriminate between groups that have subtle differences in performance.

Selecting the CPM machine movement speed is a critical protocol step that will affect TDPM scores (protocol step 2.2). Previous studies have shown that TDPM increases with decreasing passive motion velocity[7,16,23]. The speed selected for this protocol, 0.23°/s, is similar to values tested in prior studies[7,22,28], and is near the inflection point where TDPM exponentially increases in difficulty for healthy subjects[7]. As noted in the representative results, one participant with chronic stroke was unable to feel movement in any trial, suggesting the CPM machine movement speed of 0.23°/s has a potential floor effect and may need to be increased for testing of individuals with more severe kinesthetic impairments. The range of available speeds differs across CPM machine manufacturers; researchers should select a model that will meet their study needs. Providing clear participant instruction with verification of understanding is also a critical protocol element to support accurate performance of the TDPM task.

All participants with chronic stroke were able to depress the trigger switch with their more affected extremity, alternative methods of indicating when movement is felt may be needed for participants who are unable to do so. It is possible a larger style of switch could be used. Additional modifications to the protocol may include elimination of the biceps and triceps EMG sensors. EMG use was incorporated into the protocol to confirm muscle contraction did not occur during trials, as active muscle contraction and muscle contraction history have been shown to impact proprioceptive thresholds due to the thixotropic properties of muscle fibers and spindles[27,28]. However, muscle activation was not noted during any trial for any participant, suggesting EMG monitoring may be unnecessary.

A possible limitation of this protocol is the testing position of 90° of shoulder and elbow flexion, as some individuals may be unable to achieve or tolerate this position. Modification of the

testing position is known to change kinesthesia[36]. An aspect of the TDPM paradigm that is not unique to this protocol is the high attentional demand of the task, which limits the appropriateness of this measurement method for individuals with attention deficits. To reduce error due to inattention or fatigue[19], we intentionally designed this protocol to take no more than 15 minutes per limb. This protocol does not control for potential differences in reaction time between participants, which is a potential limitation. The slow passive movement speed used in this protocol decreases the proportional contribution of reaction time error to a participant's TDPM score.

This detailed elbow TDPM protocol provides sensorimotor researchers a sensitive and precise measure of kinesthesia. The data suggest the TDPM's resolution is high affording the possibility of detecting mild impairment or perhaps being sensitive to change if used in a study of recovery of function. Future research could be conducted to determine the minimal clinically important difference in TDPM. Adaptation of this protocol to other joints may also be appropriate.

ACKNOWLEDGMENTS:

The authors would like to thank Dr. Jon Nelson for technical support of EMG and electrogoniometer equipment used here.

DISCLOSURES:

The authors declare they have no competing financial interests.

REFERENCES:

1 Coderre, A. M. et al. Assessment of upper-limb sensorimotor function of subacute stroke patients using visually guided reaching. *Neurorehabilitation and Neural Repair.* **24** (6), 528-541 (2010).

2 Dukelow, S. P. et al. Quantitative assessment of limb position sense following stroke. *Neurorehabilitation and Neural Repair.* **24** (2), 178-187 (2010).

3 Semrau, J. A., Herter, T. M., Scott, S. H., Dukelow, S. P. Robotic identification of kinesthetic deficits after stroke. *Stroke.* **44** (12), 3414-3421 (2013).

4 Meyer, S., Karttunen, A. H., Thijs, V., Feys, H., Verheyden, G. How do somatosensory deficits in the arm and hand relate to upper limb impairment, activity, and participation problems after stroke? A systematic review. *Physical Therapy.* **94** (9), 1220-1231 (2014).

5 Desrosiers, J., Bourbonnais, D., Bravo, G., Roy, P.-M., Guay, M. Performance of the 'unaffected'upper extremity of elderly stroke patients. *Stroke.* **27** (9), 1564-1570 (1996).

6 Carey, L. M., Matyas, T. A. Frequency of discriminative sensory loss in the hand after stroke in a rehabilitation setting. *Journal of Rehabilitation Medicine.* **43** (3), 257-263 (2011).

7 Konczak, J., Krawczewski, K., Tuite, P., Maschke, M. The perception of passive motion in Parkinson's disease. *Journal of Neurology.* **254** (5), 655 (2007).

8 Van Deursen, R. W. M., Simoneau, G. G. Foot and ankle sensory neuropathy, proprioception, and postural stability. *Journal of Orthopaedic & Sports Physical Therapy.* **29** (12), 718-726 (1999).

9 Reider, B. et al. Proprioception of the knee before and after anterior cruciate ligament

reconstruction. *Arthroscopy: The Journal of Arthroscopic & Related Surgery.* **19** (1), 2-12 (2003).
10 Hizli Sayar, G., Unubol, H. Assessing Proprioception. *The Journal of Neurobehavioral Sciences.* **4** (1), 31-35 (2017).
11 Fugl-Meyer, A. R., Jääskö, L., Leyman, I., Olsson, S., Steglind, S. The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance. *Scandinavian journal of Rehabilitation Medicine.* **7** (1), 13-31 (1975).
12 Stolk-Hornsveld, F., Crow, J. L., Hendriks, E., Van Der Baan, R., Harmeling-van Der Wel, B. The Erasmus MC modifications to the (revised) Nottingham Sensory Assessment: a reliable somatosensory assessment measure for patients with intracranial disorders. *Clinical Rehabilitation.* **20** (2), 160-172 (2006).
13 Winward, C. E., Halligan, P. W., Wade, D. T. The Rivermead Assessment of Somatosensory Performance (RASP): standardization and reliability data. *Clinical Rehabilitation.* **16** (5), 523-533 (2002).
14 Lincoln, N. B. et al. The unreliability of sensory assessments. *Clinical rehabilitation.* **5** (4), 273-282 (1991).
15 Sartor-Glittenberg, C. Quantitative measurement of kinesthesia following cerebral vascular accident. *Physiotherapy Canada.* **45** 179-186 (1993).
16 Hillier, S., Immink, M., Thewlis, D. Assessing proprioception: a systematic review of possibilities. *Neurorehabilitation and Neural Repair.* **29** (10), 933-949 (2015).
17 Han, J., Waddington, G., Adams, R., Anson, J., Liu, Y. Assessing proprioception: a critical review of methods. *Journal of Sport and Health Science.* **5** (1), 80-90 (2016).
18 Goble, D. J. Proprioceptive acuity assessment via joint position matching: from basic science to general practice. *Physical Therapy.* **90** (8), 1176-1184 (2010).
19 Juul-Kristensen, B. et al. Test-retest reliability of joint position and kinesthetic sense in the elbow of healthy subjects. *Physiotherapy Theory and Practice.* **24** (1), 65-72 (2008).
20 Deshpande, N., Connelly, D. M., Culham, E. G., Costigan, P. A. Reliability and validity of ankle proprioceptive measures. *Archives of Physical Medicine and Rehabilitation.* **84** (6), 883-889 (2003).
21 Boerboom, A. et al. Validation of a method to measure the proprioception of the knee. *Gait & Posture.* **28** (4), 610-614 (2008).
22 Nagai, T., Sell, T. C., Abt, J. P., Lephart, S. M. Reliability, precision, and gender differences in knee internal/external rotation proprioception measurements. *Physical Therapy in Sport.* **13** (4), 233-237 (2012).
23 Refshauge, K. M., Chan, R., Taylor, J. L., McCloskey, D. Detection of movements imposed on human hip, knee, ankle and toe joints. *The Journal of Physiology.* **488** (1), 231-241 (1995).
24 Portney, L. G., Watkins, M. P. *Foundations of Clinical Research: Applications to Practice*. Vol. 892 (Pearson/Prentice Hall Upper Saddle River, NJ, 2009).
25 Borstad, A., Nichols-Larsen, D. S. The Brief Kinesthesia test is feasible and sensitive: a study in stroke. *Brazilian Journal of Physical Therapy.* **20** (1), 81-86 (2016).
26 Vernoski, J. L. J., Bjorkland, J. R., Kramer, T. J., Oczak, S. T., Borstad, A. L. A Simple Non-invasive Method for Temporary Knockdown of Upper Limb Proprioception. *Journal of Visualized Experiments.* (133), e57218 (2018).

27 Proske, U., Tsay, A., Allen, T. Muscle thixotropy as a tool in the study of proprioception. *Experimental Brain Research.* **232** (11), 3397-3412 (2014).
28 Wise, A. K., Gregory, J. E., Proske, U. Detection of movements of the human forearm during and after co-contractions of muscles acting at the elbow joint. *The Journal of Physiology.* **508** (Pt 1), 325 (1998).
29 Wilcox, R. R., Granger, D. A., Clark, F. Modern robust statistical methods: Basics with illustrations using psychobiological data. *Universal Journal of Psychology.* **1** (2), 21-31 (2013).
30 Oldfield, R. C. The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia.* **9** (1), 97-113 (1971).
31 Piriyaprasarth, P., Morris, M. E., Delany, C., Winter, A., Finch, S. Trials needed to assess knee proprioception following stroke. *Physiotherapy Research International.* **14** (1), 6-16 (2009).
32 Juul-Kristensen, B. et al. Poorer elbow proprioception in patients with lateral epicondylitis than in healthy controls: a cross-sectional study. *Journal of Shoulder and Elbow Surgery.* **17** (1), S72-S81 (2008).
33 Skinner, H. B., Barrack, R. L., Cook, S. D. Age-related decline in proprioception. *Clinical Orthopaedics and Related Research.* (184), 208-211 (1984).
34 Pai, Y. C., Rymer, W. Z., Chang, R. W., Sharma, L. Effect of age and osteoarthritis on knee proprioception. *Arthritis & Rheumatism.* **40** (12), 2260-2265 (1997).
35 Dunn, W. et al. Measuring change in somatosensation across the lifespan. *American Journal of Occupational Therapy.* **69** (3), 6903290020p6903290021-6903290020p6903290029 (2015).
36 Alghadir, A., Zafar, H., Iqbal, Z., Al-Eisa, E. Effect of sitting postures and shoulder position on the cervicocephalic kinesthesia in healthy young males. *Somatosensory & Motor Research.* **33** (2), 93-98 (2016).

Figure 2 Example Electrogoniometer Tracing

Figure 3 Test-retest reliability of elbow TDPM method in healthy adults

Figure 4 Elbow TDPM and tBKT results for healthy adult and chronic stroke participants

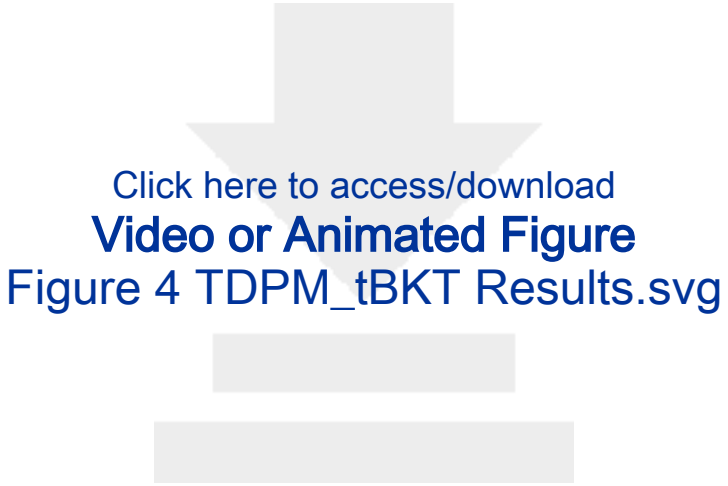
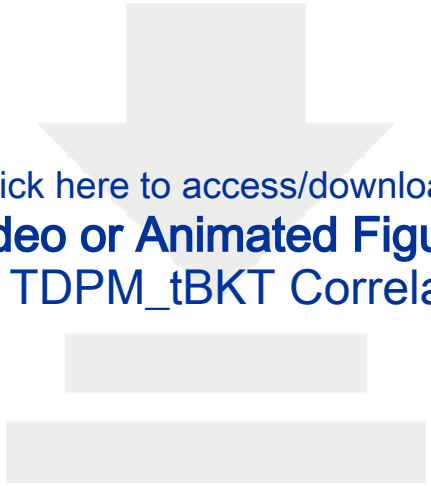


Figure 5 TDPM_tBKT Spearman correlation findings



Click here to access/download

Video or Animated Figure

Figure 5 TDPM_tBKT Correlation.svg

Table 1

Trial Number	1	2	3	4	5	6	7	8
Delay (s)	1	Catch	3	1	2	Catch	3	1

Table 2

Click here to access/download;Table;Revised Table 2 JoVE Participant results comparison values.xlsx

	Age Mean(SD) in years	Sex	Stroke Chronicity Mean(SD) in months	Handedness	Fugl-Meyer Mean (SD) of shoulder-elbow subscore/36
Healthy adults (control) n = 20	28(7.9)	14 F; 6 M	NA	19 - R 1- L	NA
Adults with chronic stroke n = 8	69(11.3)	3 F; 5 M	33(19)	7 - R 1- L	23.9(8.5) 5 - R CVA 3 - L CVA

SD = Standard deviation; F = Female; M = Male; R = Right; L = Left; CVA = Cerebrovascular Accident; NA = Not applicable; cm = centimeter

TDPM Mean (SD) in degrees	tBKT Error Mean (SD) in cm
1.19 (1.02)	1.12 (0.26)
8.24 (4.53)	2.85 (1.16)
t = 4.4, p = 0.003 (two-tailed)	t = 4.15, p = 0.004

Name of Material/ Equipment	Company	Catalog Number
3/4 inch diameter PVC pipe	Charlotte Pipe	
3/4 inch diameter PVC pipe end caps (x3)	Charlotte Pipe	
45° PVC elbow (x1)	Charlotte Pipe	
90° PVC elbows (x2)	Charlotte Pipe	
Athletic tape	3M	
Delsys acquisition software (EMGworks)	Delsys	
Double-sided tape	3M	
Duct tape	3M	
Elbow Continuous Passive Motion (CPM) Machine	Artromot	
Electrogoniometer	Biometrics, Ltd	
Flour sack dishcloths (x2)	Room	
Handheld external trigger switch	Qualisys	
Hearing occlusion headphones	Coby	
Isopropyl alcohol	Mountain Falls	
Paper tape	3M	
Ruler with inch markings	Westcott	
Standard height chair	KI	
String	Quality Park	
Trigno Goniometer Adapter	Delsys	
Trigno Wireless Electromyography Sensors	Delsys	
Washable marker	Crayola	
Washcloth	Aramark	

Comments/Description

Pipe to be cut into lengths of: 30 inches/76.2 cm (x2); 8 inches/20.3 cm (x2); 44 inches/111.8 cm (x1); 32 inches/81.3 cm (x1).

Used to assist in removal of dead skin cells on participant's skin prior to EMG sensor placement.
Chattanooga Artromot E2 Compact Elbow CPM; Model 2038

Fabric used for creation of visual screen.
Trigger switch used for electrogoniometer event marking.

Approximately 15 inches of string needed. String used for standardization of electrogoniometer placement.

Used in combination with isopropyl alcohol for cleaning participant's skin prior to EMG sensor placement.

June 25th, 2020

Thank you for the thoughful reviews of this manuscript. The following response letter includes a point-by-point response to your recommendations and indication of where changes were made in the manuscript.

Reviewer #1:
Major Concerns:
Abstract
- 41: Instructions for creation of visual screen: is it necessary to mention in the abstract?

Response: This portion has been removed from the abstract.

I don't find this part particularly important, as one could easily use e.g. a sleep mask or any other easily-available material to restrict vision.

Response: Visual occlusion, vs. blindfolding, was an intentional choice in the design of this protocol. Absent vision (blindfold or eyes closed) is a different sensory condition than visual occlusion in which the brain receives visual information that does not support completion of the task through integration of vision and somatosensation (Cohen, 1993). Further, in our laboratory, we find participants are more comfortable in the vision occluded condition than with blindfolding.

Cohen, H., Blatchly, C. A. & Gombash, L. L. A study of the clinical test of sensory interaction and balance. Physical therapy. 73 (6), 346-351 (1993).

- 39-41: Generally, last sentence of the abstract is a repetition of what has already been mentioned in lines 36-37. Remove the last sentence but expand line 36-37 ("… provide a standardized method for measurement of TDPM at the elbow, relatively inexpensive and easy to administer. Detailed protocol is provided…"). Instead, last sentence of abstract should contain general impact of this work (benefit for researchers etc..).

Response: The abstract has been reworded to reflect the recommended changes.

Introduction
- 49: It would be necessary to mention Erasmus Modified Nottingham Sensory Assessment or sensory part of Fugl-Meyer, as these are typical clinical measures, which are not mentioned in the cited review paper. I don't think the provided citation is the best choice here.

Response: Citations for the Fugl-Meyer and Erasmus Modified Nottingham Sensory Assessment have been incorporated to more fully encompass common clinical measures [lines 51 - 52]. The purpose of mentioning the commonly-used clinical measures of proprioception here is to draw attention to the relatively coarse, ordinal-type results that most clinical measures of proprioception produce. Such data may be insufficient for detecting (and tracking) small changes in proprioceptive capabilities as would be needed for sensorimotor research purposes, particularly for the proprioceptive submodality of threshold to detection of passive movement (TDPM). Addition of phrasing

that more clearly elucidates this research-focused purpose has been added to the introduction. [lines 77-82]

- 52: I disagree with this statement, especially given your reference number 8 states "Ankle, knee, and shoulder proprioception have been extensively investigated by sports science and medical researchers", which doesn't really suggest upper-limb is investigated less.

Response: Upon review, we agree that this statement may be insufficiently supported by the cited literature; this statement has been removed from the paper.

Protocol

- 177 (Administration of TDPM Test): motivation for some important aspects of the protocol is not provided. Particularly, why is the arm taken out of the machine and straightened after each trial? This seems like a lengthy process, what value does it bring?

Response: The arm was taken out of the machine, straightened, and reset into the test position between each trial in order to provide a consistent state of muscle spindle tension at the start point of each trial. Muscle spindles exhibit thixotropic properties, with sensitivity to stretch depending on prior history of contraction and length changes; this differing stretch sensitivity impacts the threshold for detection of passive movement (Wise, 1998; Proske, 2014). The amount of muscle spindle stretch experienced by each subject during a detection trial was dependent upon when the subject indicated movement was felt. By performing a passive full extension/flexion movement between trials, we attempted to standardize the starting muscle state and muscle spindle stretch history across subjects. A statement has been added to the protocol to indicate the value of this process, lines 236 – 239 now read:

"4.7. Between each trial remove participant's testing arm from CPM machine and return CPM machine to 90° start position. Passively move participant's elbow through full extension then back to 90° flexion to standardize the muscle spindle movement history.26,27 Place arm back in CPM machine for next trial."

Wise, A. K., Gregory, J. E. & Proske, U. Detection of movements of the human forearm during and after co-contractions of muscles acting at the elbow joint. *The Journal of physiology.* **508** (Pt 1), 325 (1998).

Proske, U., Tsay, A. & Allen, T. Muscle thixotropy as a tool in the study of proprioception. *Experimental brain research.* **232** (11), 3397-3412 (2014).

- 177: Do you provide a familiarization trial rounds? What about demonstrating the participants the flexion and extension movements they are going to feel in the familiarization round? No information about this provided.

Response: Familiarization trials were not used in this protocol. The use of 6 trial repetitions was based on Juul-Christenson, 2008.

Juul-Kristensen, B., et al. (2008). "Test-retest reliability of joint position and kinesthetic sense in the elbow of healthy subjects." Physiotherapy theory and practice 24(1): 65-72.

- 192: What happens if active movement is observed with EMG? Is the trial stopped or experiment aborted? What would be the verbal command in such case to the participant? Please clarify.

Response: Thank you for noting this missing step in the original protocol. The trial would be stopped and excluded from analysis, with the subject and researcher then proceeding. This protocol step has been added as step 4.6.1.

"4.6.1. If muscle activation is noted, stop the trial and use the following standardized script: "Your muscles are activating. Please try to keep your arm relaxed during the test." This trial should be noted for exclusion from data analysis, with the researcher proceeding with resetting the patient and CPM to start the next trial (protocol step 4.7)."

- 200: Provide duration of each trial (only catch trials mentioned at this point).

Response: The trial maximum duration is 15 seconds, we added the information to step 4.8:

"4.8. Complete eight trials, including two "catch" trials where participant's arm is not moved. Each trial (catch and non-catch) is terminated when the participant depresses the trigger switch, or after 15 seconds if the trigger switch is not depressed."

- 208: Information missing on how the trials are actually recorded and how to extract the trials. How are the outcome measures extracted? The angle at which subject detects the movement? Outcome measures extraction and calculation not clearly explained. Important point which really needs to be strengthened in this paper.

Response: A full description of electrogoniometric methods seemed beyond the scope of this paper. We added a basic figure (**Figure 2**) and protocol step (5.1, 5.2 and 5.3) to address the methodology we used that could be generalized to any electrogoniometer setup:

*"5.1. Using the electrogoniometer tracing, identify the electrogoniometer angle measurement for the point at which CPM machine movement started, and for the point at which the participant depressed the trigger switch indicating movement was felt. See **Figure 2** for a representative example. [Place **Figure 2** here]."*

"5.2. Subtract the starting angle from the final angle, thus identifying the number of degrees the CPM moved; this is the participant's elbow TDPM value for that trial."

"5.3. To determine participant's overall TDPM score, remove the smallest and largest TDPM values from the six non-catch trials, then average the remaining four trial scores[28]."

Results

- 225: Why the elbow of the less-affected side was measured? Wouldn't you hypothesize that it is the affected side that will have impaired proprioception while the less-affected side should behave in a comparable way as control participants?

Response: People with stroke are known to have varying degrees of bilateral changes in proprioceptive function (Quaney, 2005; Carey, 2011; Borstad, 2016; Lima, 2015; Desrosiers, 1996; Sartor-Glittenberg, 1993). This is not commonly understood, perhaps, because clinical measures are not sensitive to subtle impairments (Meyer, 2014). This conundrum underscores a purpose of this study which was to make more readily available a measure that is sensitive to mild impairment. For this reason we tested the less affected limb of persons with stroke, which may be more mildly impaired. We added this rational to the introduction of the manuscript, lines 87-100.

Quaney, B. M., Perera, S., Maletsky, R., Luchies, C. W. & Nudo, R. J. Impaired grip force modulation in the ipsilesional hand after unilateral middle cerebral artery stroke. *Neurorehabilitation and neural repair.* **19** (4), 338-349 (2005).

Carey, L. M. & Matyas, T. A. Frequency of discriminative sensory loss in the hand after stroke in a rehabilitation setting. *Journal of rehabilitation medicine.* **43** (3), 257-263 (2011).

Borstad, A. & Nichols-Larsen, D. S. The Brief Kinesthesia test is feasible and sensitive: a study in stroke. *Brazilian journal of physical therapy.* **20** (1), 81-86 (2016).

Lima, N. M. F. V. *et al.* Sensory deficits in ipsilesional upper-extremity in chronic stroke patients. *Arquivos de neuro-psiquiatria.* **73** (10), 834-839 (2015).

Desrosiers, J., Bourbonnais, D., Bravo, G., Roy, P.-M. & Guay, M. Performance of the 'unaffected'upper extremity of elderly stroke patients. *Stroke.* **27** (9), 1564-1570 (1996).

Sartor-Glittenberg, C. Quantitative measurement of kinesthesia following cerebral vascular accident. *Physiotherapy Canada.* **45** 179-186 (1993).

Meyer, S., Karttunen, A. H., Thijs, V., Feys, H. & Verheyden, G. How do somatosensory deficits in the arm and hand relate to upper limb impairment, activity, and participation problems after stroke? A systematic review. *Physical therapy.* **94** (9), 1220-1231 (2014).

- 228 & 235 & 240: is your data normally distributed? It needs to be for you to use statistical measures such as Pearson correlation. Please report that or use Spearman rank correlation instead.

Response: We have replaced the Pearson correlations with Spearman rank correlations.

- 288: Comparison of controls and stroke subjects: control subjects are younger than the chronic stroke, can you really compare the two groups?

Response: The inclusion of these two groups was by design, not because we expected them to be similar but because we expected them to be different. This method of determining construct validity is called the known groups method (Portney, 2009, p.

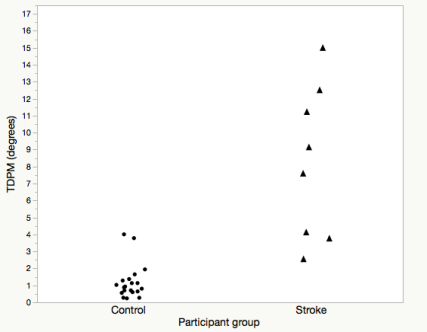
107). As indicated in a previous response [225], people with stroke are known to have bilateral changes in proprioceptive function (Quaney, 2005; Carey, 2011; Borstad, 2016; Lima, 2015; Desrosiers, 1996; Sartor-Glittenberg, 1993) as are the older adults (Dunn, 2015; Goble, 2016). We hypothesized healthy individuals would score similarly (cluster) on the TDPM (as shown below in new Figure 4A). Because the validity of most measures is assessed by taking a correlate of a similar measure, and correlation is dependent upon a distribution of scores, we needed another group of participants whose scores would distribute to have the possibility of observing a correlation. We chose the tBKT because prior published research suggests this method was sensitive to changes in kinesthetic performance in the ipsilesional arm post stroke (Borstad, 2016). And as we acknowledged in the Discussion, lines 358-359, age also results in a difference in performance on some proprioception measures.

Portney, L. G. & Watkins, M. P. *Foundations of clinical research: applications to practice*. Vol. 892 (Pearson/Prentice Hall Upper Saddle River, NJ, 2009)

Dunn, W. et al. Measuring change in somatosensation across the lifespan. American Journal of Occupational Therapy. 69 (3), 6903290020p1-6903290020p9 (2015).

Goble, D. J. Proprioceptive acuity assessment via joint position matching: from basic science to general practice. *Physical therapy.* **90** (8), 1176-1184 (2010)

Borstad, A. & Nichols-Larsen, D. S. The Brief Kinesthesia test is feasible and sensitive: a study in stroke. Brazilian Journal of Physical Therapy. 20 (1), 81-86 (2016).



(Figure 4A revised paper; original Figure 3. Shows similarity of TDPM scores for healthy individuals.)

[-288 continued] Do you have any indication of the chronic stroke subjects actually showing proprioceptive impairment (as measured by standard clinical scales)?

Response: In our experience and based on the literature (Sartor-Glittenberg, 1993), there is no quick clinical screening that reliably detects mild proprioceptive impairment in people with stroke. A common clinical method of proprioception testing is joint position matching; there is little data on the accuracy or validity of this measure and it is not thought to be comparable to movement thresholds (Elangovan, 2014). Clinical scales such as the Nottingham or Fugl-Meyer are also not likely to be sensitive to mild proprioceptive impairment due to the coarseness of their scales. For this reason for

validation of this protocol, we chose to compare TDPM to another quantitative measure of kinesthesia, the Brief Kinesthesia Test (BKT). The BKT has been shown to be sensitive to ipsilesional upper limb impairment post stroke (Borstad, 2016) and in older adults (Dunn, 2015). The tablet-based version (tBKT) was used in this study because it is the same test as the BKT simply administered on a tablet with more trials. The tBKT has been shown to be stable in 1-week test re-test measurement and sensitive to proprioceptive knockdown. (Janz, 2018)

Sartor-Glittenberg, C. Quantitative measurement of kinesthesia following cerebral vascular accident. *Physiotherapy Canada.* **45** 179-186 (1993).

Borstad, A. & Nichols-Larsen, D. S. The Brief Kinesthesia test is feasible and sensitive: a study in stroke. *Brazilian journal of physical therapy.* **20** (1), 81-86 (2016).

Elangovan, N., Herrmann, A. & Konczak, J. Assessing proprioceptive function: evaluating joint position matching methods against psychophysical thresholds. *Physical therapy.* **94** (4), 553-561 (2014).

Janz, J. V., et al. (2018). "A Simple Non-invasive Method for Temporary Knockdown of Upper Limb Proprioception." Journal of visualized experiments: JoVE(133).

- 237: What is ICC 2,4? I don't think this is appropriate notation. Add the type of intraclass correlation used (e.g. two-way random, single measures for absolute agreement, I don't know what is the actual name of the provided ICC 2,4).

Response: We have used a standard, recommended method (Portney, 2009) to report the Model and form of the ICC used in our analysis. The first number 2, indicates Model 2 with random effects for both subjects and raters. The intent of this model is to demonstrate that measurement reliability can be applied to others. The second number, 4, indicates that the TDPM scores were a mean of 4 measurements.

Portney LG, W. M. P. (2009). Foundations of clinical research: applications to practice. Upper Saddle River, New Jersey, USA, Prentice Hall.

- 240: The measure chosen to compare method proposed in this paper to is not at all standard (it is not clear what is the reliability and validity of that measure, especially that you used a modified version of it with a tablet). Using e.g. Erasmus Modified Nottingham Sensory Assessment, which is a standard clinical method, would be much more appropriate to claim validity. With the current choice of non-standard measure of proprioception to compare your novel metric with, you can not really claim construct validity.

Response: See response to line 228, top of page 5 of this letter. In this revision we supply additional rationale in both the introduction and discussion regarding our choice of the tBKT. We believe these rational and data will make the decision and approach to validity apparent. A fundamental challenge in somatosensory measurement is the availability of fine-grained quantitative measures. In publishing this protocol we are attempting to address this problem, in part. Erasmus MC modifications to Nottingham is a screening tool that allows categorization of proprioception(movement detection) on an

ordinal scale of absent, impaired, normal after movement through ¼ of the joint range of motion for 3 trials. We suggest this measure is too coarse to provide a useful comparison to the psychophysical TDPM measure. Thus we chose to use the tablet version of the BKT. The BKT has been studied in healthy individuals (Dunn, 2015) and is known to be sensitive to poststroke proprioception changes (Borstad, 2016).

Dunn, W. et al. Measuring change in somatosensation across the lifespan. American Journal of Occupational Therapy. 69 (3), 6903290020p1-6903290020p9 (2015).

Borstad, A. & Nichols-Larsen, D. S. The Brief Kinesthesia test is feasible and sensitive: a study in stroke. *Brazilian journal of physical therapy.* **20** (1), 81-86 (2016).

Discussion

- 284: It is unclear why for this validation study you are considering the less affected side of stroke subjects, which seems counter intuitive. Moreover, your reference 17 claims "Sensation in the ipsilesional UE appears to be unaffected, or minimally affected after stroke", therefore your claim that the less-affected side has been shown to differ significantly from controls is incorrect, at least according to that reference.

Response: The purpose of this paper is to report the method for a protocol with representative results. Within those results we have an initial look at construct validity, we have not conducted a study of validity. Further we would like to add that reference 17, Pohl et al., 1997, also used coarse measures of proprioception, thus they were unlikely to find impairment. They go on to discuss (p. 63, right column) that “Ispilesional elbow kinesthesia in adults with stroke was found to be normal when evaluated by clinical testing but impaired when evaluated by laboratory mechanical testing.” (Sartor-Gliittenberg,1993) This provides rationale for the approach we used.

- 308: This paragraph nicely discusses several aspects of the protocol. What is missing still is a brief comment on the choice of delay times between trials (why different - as I commented on in methods),

Response: We used a pseudo-random brief delay before each trial to reduce the likelihood participants would use timing from the start of the trial to inform their responses. (Juul-Kristensen, 2008). The italicized portion of the statement below has been added to the manuscript.

*“4.5. Loudly state “begin,” and wait the corresponding amount of time per trial before initiating movement of the CPM machine to decrease participant guessing when movement will begin[19]. Standardized delay times are shown in **Table 1**. [Place **Table 1** here].”*

Juul-Kristensen, B. et al. Test-retest reliability of joint position and kinesthetic sense in the elbow of healthy subjects. Physiotherapy theory and practice. 24 (1), 65-72 (2008).

[-308 continued] as well as the interruption after every trial to straighten the elbow (why is it necessary, what does it add, doesn't it just lengthen the protocol).

Response: Please see our response to this point above (Re: line 177).

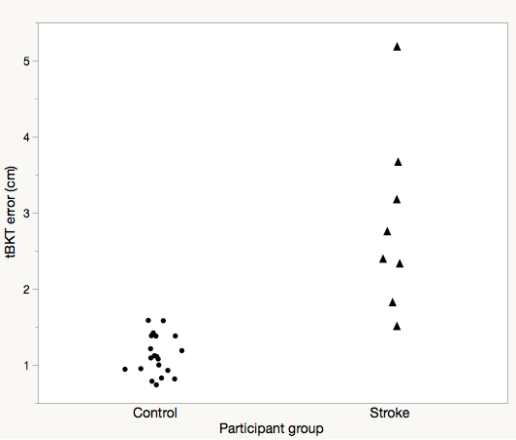
[-308 continued] Moreover, when talking about potential attention artefact, the whole trial duration should be reported to put that problem into perspective (was the attentional demand also coming from the lengthy protocol or just because of the protocol design itself, which requires attention to detect movement).

Response: The session duration was 40-60 minutes per participant including transitions between tests (Edinborough handedness inventory 5 minutes, tBKT 7 minutes (one hand), TDPM ~15 minutes (one hand, 8 trials including instructions, repositioning etc.…) Fugl-Meyer (sections I-V only collected) 10 minutes) The following statement has been added to the paper:

"An aspect of the TDPM paradigm that is not unique to this protocol is the high attentional demand of the task, which limits the appropriateness of this measurement method for individuals who may have deficits in attention. To reduce error due to inattention or fatigue[19] we intentionally designed this protocol to take no more than 15 minutes per limb."

[- 308 continued]: You mention that one participant was not able to feel the movement, was that participant more severely affected than others?

Response: We presumed he was more impaired than the others as he was unable to feel any movement, all others did. He also had more error than the other participants on the tBKT (see figure below, his error on the BKT was the greatest at over 5 centimeters):



More information about your stroke participants needs to be provided by adding a few clinical score results, to deepen reader's understanding of the population in question.

Response: We have added additional information to Table 2.

Minor Concerns:

Introduction

- 45: First sentence missing reference.

Response: Thank you for pointing out that our introduction sentence was more specific than we intended; we modified it to be a more general statement. We do not believe a reference is required.

- 46: Some more diverse literature evidence missing for somatosensory impairments in stroke (e.g. [1])

Response: Additional supporting literature has been added for somatosensory impairments occurring with stroke:

"Proprioceptive information is an important contributor to the control of human movement. Proprioceptive deficits accompany a wide range of neurologic conditions such as stroke1-6, Parkinson's disease7, and sensory neuropathies8."

Coderre, A. M. et al. Assessment of upper-limb sensorimotor function of subacute stroke patients using visually guided reaching. Neurorehabilitation and neural repair. 24 (6), 528-541 (2010).

Dukelow, S. P. et al. Quantitative assessment of limb position sense following stroke. Neurorehabilitation and neural repair. 24 (2), 178-187 (2010).

Semrau, J. A., Herter, T. M., Scott, S. H. & Dukelow, S. P. Robotic identification of kinesthetic deficits after stroke. Stroke. 44 (12), 3414-3421 (2013).

Meyer, S., Karttunen, A. H., Thijs, V., Feys, H. & Verheyden, G. How do somatosensory deficits in the arm and hand relate to upper limb impairment, activity, and participation problems after stroke? A systematic review. Physical therapy. 94 (9), 1220-1231 (2014).

Desrosiers, J., Bourbonnais, D., Bravo, G., Roy, P.-M. & Guay, M. Performance of the 'unaffected'upper extremity of elderly stroke patients. Stroke. 27 (9), 1564-1570 (1996).

Carey, L. M. & Matyas, T. A. Frequency of discriminative sensory loss in the hand after stroke in a rehabilitation setting. Journal of rehabilitation medicine. 43 (3), 257-263 (2011).

Protocol

- 103: are you sure that all CPM machines (from different manufacturers) will allow you to program the machine in the same way (same speed)? Is this really a commonly available equipment at research labs?

Response: CPM machines are not standard equipment within research labs, but are easy to acquire/borrow from hospitals, rehabilitation centers, or medical supply stores. One of the purposes of writing this protocol is to share a more economical, but still precise and quantitative, method for measuring TDPM, which CPM machine use allows for.

A good point is raised with the potential differences in programming options between manufacturers. Additional specifics on the model used have been added to our equipment list for ease of reproduction (Chattanooga Artromot E2 Compact Elbow CPM; Model 2038). This was the model available to us from the local hospital system, and is a common brand. While JoVE style guide indicates company/brand names are to be avoided in the protocol, a comment has been added to the discussion regarding the

need for researchers to check the range of speed options on the CPM in order to determine if it will meet the speed needs for their particular studies. Lines 370-72 read:

"The range of available speeds differs across CPM machine manufacturers. The particular model of CPM machine used for this study is noted in the equipment list. Researchers should select a model that will meet their study needs."

- 117 (Attach biceps branchii and triceps brianchii EMG sensors): I think these steps need to be supported with appropriate images (not always clearly visible on the video, e.g. you can't see the dot of the marker on the biceps)

Response: The exact location of the central point will differ depending upon a participant's unique anatomy; no image could properly convey this location for every individual participant. Rather, we presume a researcher can develop the skill to determine the central point of the muscle belly of the muscle bulk of the biceps and triceps.

- 129 (Attach electrogoniometer to participant): I think these steps also need to be supported by pictures (e.g. the exact location of the dot on the wrist not clearly visible on the video).

Response: The placement of the electrogoniometer (and preceding placement-guiding dots) requires the researcher to palpate common anatomical landmarks on participants in order to standardize electrogoniometer placement. Due to anatomical variation, the exact location of landmarks differs between participants. The necessary landmarks are included in the written protocol, and palpation observable in the video. The exact location for the wrist dot for the participant in the video is observable in later shots at 2:41 - 2:44, and 3:58 - 4:10.

- 203: This point is not clear to me. Is the standardized script used only if participant reported they did not feel the movement or is it provided at every catch trial no matter how the participant reacted? If they report they cannot feel movement that is actually correct, right? What is the purpose of providing this feedback at catch trails? Please clarify.

Response: The standardized script was used only if a participant verbally reported they could not feel movement, or when the participant (erroneously) depressed the trigger switch. The script is written to have a standardized mode of responding to participant verbal reports/questions (if they occur), and to serve as a reminder to prevent guessing. This step of the protocol has been clairified:

"4.9. If during a catch trial a participant verbally reports they cannot feel movement, or depresses the trigger switch, the following standardized response is used: "Your arm did not actually move during that trial. I know it's hard to feel, the machine moves very slowly; try to concentrate and push the button as soon as you feel your arm move or that your arm position has changed."

Discussion

- General point: start discussion with general remarks (few sentences), then move to specific results (e.g. left-right difference). Start with the main points of your paper (standardized protocol using easy-to-set-up equipment).

Response: Thank you, opening paragraph of discussion was revised.

- 280: Did you do this analysis on the right-hand-dominant subjects only (excluding those that are left handed). Results may differ if you redo analysis considering right-handed subjects only.

Response: Handedness of participants was added to Table 2. Because JoVE's Instructions to authors emphasize that the Discussion section should be focused on the protocol rather than the representative results, details like your question were not discussed. Like most studies, we frequently have a group with one or two left handed subjects, when their data is not outlying we include them in the analysis, as we did here. We did not have a hypothesis here to determine the effect of handedness. Perhaps in a future project.

Reviewer #2:

Minor Concerns:

1. Double check journal requirement for reporting methods, results and references.

Response: The relationship between references and closing punctuation has been changed to reflect the JoVE requirements. Information was shifted to and added to the Representative Results section to more fully address the content needs for this area, and to better focus the Discussion on the protocol as opposed to the Representative Results.

2. 'Age range of the healthy adults was 23-58 years, with mean age of 28 years'. Why did authors choose such a vast range in age? Proprioception is known to deteriorate with age. please justify.

Response: A convenience sample of healthy adults was used. The intent of the inclusion of a healthy adult group was to determine if this method could detect differences in groups expected to be more versus less impaired. The inclusion of a wide age range of healthy adults potentially decreased the extent of the difference between the healthy adult group and the chronic stroke groups; however, a statistical difference between groups was still found ($t = 4.4$, $p = 0.003$, two-tailed), providing support for the effectiveness of the method described in the protocol.

3. Why did authors include stroke patients? Stroke patients have various other symptoms including loss of proprioception. Cases, for e.g. peripheral nerve injury, MS injury, etc would would reveal better outcome.

Response: In creation of this protocol we were looking for a method capable of detecting and discriminating amongst those with potential mild proprioceptive impairments, versus identifying gross proprioceptive impairments. The ipsilesional arm of individuals post stroke has been found to have such mild proprioceptive impairments, as noted in our results (**Figure 4A and 4B**), and by other researchers (Quaney, 2005;

Carey, 2011; Borstad, 2016; Desrosiers, 1996, S-G 1993). Individuals with peripheral nerve injuries or musculoskeletal injuries may also have various other sensory or motor impairments (in addition to potential passive movement detection impairments). Additional information regarding our choice of patients post stroke has been added to the Introduction, lines 87-93:

"Two different groups were tested to explore the measurement properties of this TDPM protocol: healthy adults and adults with chronic stroke. For the adults with chronic stroke, the ipsilesional (i.e. less affected) arm was tested. Kinesthetic sense in the ipsilesional elbow in adults with chronic stroke may appear normal with clinical testing, but impaired when evaluated using quantitative laboratory methods[5,15]. This example illustrates the importance of developing and using sensitive and precise measures of somatosensory impairment and makes this a useful population for our testing purposes.

4. 'For protocol standardization, participants were positioned in 90° of shoulder and elbow flexion...' Positioning of proximal and distal joints can affect kinesthesia. Please see following studies
*Effect of sitting postures and shoulder position on the cervicocephalic kinesthesia in healthy young males. Somatosensory & motor research 33 (2), 93-98
*Effect of different head-neck-jaw postures on cervicocephalic kinesthetic sense. Journal of musculoskeletal & neuronal interactions 17 (4), 341

Response: The use of a standardized testing position was included in order to keep the starting proximal and distal joint positioning the same across trials. We include discussion of the potential limitations of this positioning in the Discussion [lines 386-388],

"A possible limitation of this protocol is the testing position of 90° of shoulder and elbow flexion, as some individuals may be unable to achieve or tolerate this position. Modification of testing position is known to change kinesthesia[36]."

5. Future studies: Authors should include how this study can be taken forward

Response: The potential ways in which this protocol could be taken forward have been clarified within the Discussion [lines 400-1]

Reviewer #3:

…safety or participant comfort does not seem to have been monitored in any way.

Response: Participants were monitored throughout the testing process.

I also do not agree with the authors assertion that the equipment they have used is readily available or that this set-up would be generalisable.

Response: The intention of this protocol to be for a research setting has been more clearly stated in the revised manuscript. The equipment accessibility has also been addressed, emphasizing that electrogoniometers and electromyography instrumentation is common to most sensorimotor research laboratories, while elbow continuous passive motion (CPM) machines are commercially available devices that may be rented or

borrowed from medical supply stores or rehabilitation hospitals (or purchased at costs less than other standardized robotic TPDM testing devices). (See Introduction lines 77-85)

The representative results section needs significant work. Insufficient information is available. More information about your setting, who carried out the experiments (same investigator?), your recruitment, selection criteria and statistical analysis is needed. You have a very small sample, and do parametric tests without normality testing. Please justify why you tested the right arm in 50% of your sample and left arm in the other 50% without reference to hand dominance? How did you decide who was right/ who left?

Response: The representative results were substantiall re-written, additional information was added to Table 2. Participants were block randomized to have either right or left elbow tested with the TDPM. (line 275) This was done to reduce the overall protocol time while retaining a portion of dominant and non-dominant arms tested. We reported we found no difference between them in the first line of the results.
"…in an academic research laboratory was added (line 267) Statistical analysis performed are listed in the Representative Results section. (lines 294-309)

Your investigation of validity should be omitted. You need to explore the limitations of your work in much more detail and reduce the certainty of your conclusions - further work is needed before this could be recommended.

Response: Respectfully, we disagree that our initial approach to examining the validity of this measure should be omitted. Please see our response regarding the choice of tBKT in our response to Reviewer 1, top of page 5. Additionally, as this is a paper with the purpose to present a method, we have made no conclusion. We have revised our submission considerably including adding rational for our approach and additional ways to view our the representative results. We demonstrate that this method yields results similar to other, validated, TDPM approaches. We indicate that the data represent an initial look at validity.(line 240)

Major concerns:
a) The premise of this study is that your test has high clinical utility. This is arguable. As a minimum this test needs an electrogoniometer, a continuous passive motion machine (CPM), a purpose built screen and noise cancelling headphones. None of these would be routinely available in the specialist neuro-rehabilitation centre where I work or in many centres. You need to provide information about the costs of all the items that you used. They may be a lot less expensive than a specialist machines but this could be compared.

Response: The intention of this protocol is for research rather than clinical use (indicated in original paper summary statement, line 26). The introduction has been reworked to more clearly indicate that this protocol is intended for research settings.

You also need to give an idea of the time the equipment took to set up, the time the test takes, the level of experience of the clinician carrying out the test and the training required to use this

equipment. These are all important considerations to whether it is clinically useful and whether it could be done.

Response: This protocol was written for research settings, the introduction of the paper has been revised to make this clear. (lines 90-98) As such, details regarding level of necessary clinician experience and training are not included, as the test may be completed by a variety of individuals (clinician and non-clinician). The completion of this TDPM protocol (eight trails) for this study took an average of 15 minutes. A statement regarding this duration has been added to the protocol step 4.8.

In addition not all makes of electrogoniometer, CPM, EMG etc are the same or set up in the same way. You need to be specific about the models of the equipment that you have used for the test to be reproducible. Differences in equipment may also alter the methods for applying and setting-up each element and this is a limitation of your experiment that needs noting. Overall, how generalisable this is to other settings is uncertain.

Response: Per the JoVE Instructions to authors: "Avoid the use of commercial language, including ™/®/© symbols or company brand names before/after an instrument or reagent. Cite these in the Table of Materials instead." The make and model of the devices used in this study has been described in more detail in the Table of Materials, and a statement regarding the variation in CPM machine movement speeds added to the Discussion.

b) I also note you do not discuss safety or seem to have monitored discomfort or any adverse events during testing. Your test requires 90 degrees of shoulder flexion, external rotation to mid-range and full elbow extension. For many people with stroke (and particularly those with acute stroke and flaccidity, shoulder pain, subluxation or upper limb spasticity and joint contractures) this would be a difficult position to obtain, or to spend significant time in. It could be painful, it could provoke spasm. You also use a chair without arms, this may be a safety issue with more dependent patients. Fatigue is also a relevant issue if the test is time-consuming. You seem to have tested this on the non-affected arm in a very small group of people late after stroke with high cognitive function.

Response: The inclusion/exclusion criteria for the study were added to the Participants section of the representative results. (JoVE protocols do not have a traditional 'methods' section) One participant chose not to participate in the second day of testing secondary to mild skin irritation from the adhesive used to attach the EMG sensors and electrogoniometer. We have added this to the manuscript. (lines 457-458) In the Discussion section we acknowledge that the testing position may be uncomfortable or impossible for some individuals, and encourage testing of alternative positions as a future direction for this study. If testing of more dependent patients was desired, we anticipate alterations such as positioning the chair near a wall (with the CPM providing support on the non-wall side) could be made without impacting the study paradigm. However, further research would be needed to verify this. The purpose of the protocol as described is to share a standardized testing methodology that we have found useful for testing those with mild to moderate proprioceptive impairments that could be reproduced using commercially available equipment by other sensorimotor research laboratories.

In addition issues such as infection control need to be considered. The screen you build uses dishcloths - are these removable and washable between patients or should a wipeable fabric be used? These important issues need to be investigated before this test could be used safely in a clinical setting.

Response: This protocol is not currently intended for clinical settings. The material for the visual screen simply needs to be an opaque material of sufficient size; we found dishcloths worked well for this purpose. If desired, the dishcloths could be washed, sanitized, or replaced between participants. Pillowcases attached with wires or clips could also be used and replaced with each patient tested.

c) I agree with you that comparing a healthy young control group with an older group is a limitation. Having age-matched controls would have strengthened your study.

Response: Addition rational for our group choice begin on line 100 of the revised manuscript. Because the purpose of this study was to present a standardized protocol and representative results for the TDPM we believe these two groups are appropriate. If the purpose of this study was to make generalizations about ipsilesional proprioception impairment poststroke, we agree, a different design would be required. We would like to emphasize that we are not suggest to know whether the difference between our groups is age or stroke related, rather they are simply groups which provide a contrast in performance.

d) I am not certain about your scoring method. Was this something you developed independently? Is it based on other systems? Why did you decide to take an average rather than the best performance? Please discuss.

Response: This method was adapted from the methods used by Juul-Kristensen and Wilcox. While we took steps to reduce guessing such as using catch trials and pseudorandomizing the start of each trial, because when conducting TDPM it is impossible to rule out the possibility of guessing. Therefore users of TDPM, and many other similar measures, believe an average is more stable and more likely reflects performance than one 'best' trial.

Juul-Kristensen, B. *et al.* Test-retest reliability of joint position and kinesthetic sense in the elbow of healthy subjects. *Physiotherapy theory and practice.* **24** (1), 65-72 (2008).

Wilcox, R. R., Granger, D. A. & Clark, F. Modern robust statistical methods: Basics with illustrations using psychobiological data. *Universal Journal of Psychology.* **1** (2), 21-31 (2013).

Minor Concerns:

The use of inches is difficult for a non-American reader, please use standard scientific units of measurement i.e.; centimetres.

Response: Centimetres measurements have been added to the manuscript.

Table 2 could be more informative; please include hand dominance for each group, and if possible indicate how many years post-stroke your patient group were. (did you screen for any other UL pathology?)

> **Response**: Thanks for this suggestion, handedness, chronicity, Fugl-Meyer, and tBKT have been added to Table 2. Yes, an inclusion criteria for this study was no other condition affecting upper limb function so all participants healthy or post stroke were screened to rule this out. The inclusion criteria were also added to the Participants section of the representative results.

Did your stroke patients all have hemiplegia following middle cerebral artery strokes? If you can give more detail this would be helpful

> **Response**: We do not have information regarding the lesion location or distribution of the participants in this study. They all experienced hemiparesis, we have added upper limb Fugl-Meyer scores and chronicity to Table 2 improve the description of these participants.

jove
1 Alewife Center, #200
Cambridge, MA 02140
tel. 617.945.9051
www.jove.com

ARTICLE AND VIDEO LICENSE AGREEMENT

Title of Article:	An Accessible Standardized Method for Measurement of Elbow Kinesthesia
Author(s):	Molly Watkins

Item 1: The Author elects to have the Materials be made available (as described at http://www.jove.com/publish) via:

☑ Standard Access ☐ Open Access

Item 2: Please select one of the following items:

☑ The Author is **NOT** a United States government employee.

☐ The Author is a United States government employee and the Materials were prepared in the course of his or her duties as a United States government employee.

☐ The Author is a United States government employee but the Materials were NOT prepared in the course of his or her duties as a United States government employee.

ARTICLE AND VIDEO LICENSE AGREEMENT

1. **Defined Terms.** As used in this Article and Video License Agreement, the following terms shall have the following meanings: "**Agreement**" means this Article and Video License Agreement; "**Article**" means the article specified on the last page of this Agreement, including any associated materials such as texts, figures, tables, artwork, abstracts, or summaries contained therein; "**Author**" means the author who is a signatory to this Agreement; "**Collective Work**" means a work, such as a periodical issue, anthology or encyclopedia, in which the Materials in their entirety in unmodified form, along with a number of other contributions, constituting separate and independent works in themselves, are assembled into a collective whole; "**CRC License**" means the Creative Commons Attribution-Non Commercial-No Derivs 3.0 Unported Agreement, the terms and conditions of which can be found at: http://creativecommons.org/licenses/by-nc-nd/3.0/legalcode; "**Derivative Work**" means a work based upon the Materials or upon the Materials and other pre-existing works, such as a translation, musical arrangement, dramatization, fictionalization, motion picture version, sound recording, art reproduction, abridgment, condensation, or any other form in which the Materials may be recast, transformed, or adapted; "**Institution**" means the institution, listed on the last page of this Agreement, by which the Author was employed at the time of the creation of the Materials; "**JoVE**" means MyJove Corporation, a Massachusetts corporation and the publisher of The Journal of Visualized Experiments; "**Materials**" means the Article and / or the Video; "**Parties**" means the Author and JoVE; "**Video**" means any video(s) made by the Author, alone or in conjunction with any other parties, or by JoVE or its affiliates or agents, individually or in collaboration with the Author or any other parties, incorporating all or any portion of the Article, and in which the Author may or may not appear.

2. **Background.** The Author, who is the author of the Article, in order to ensure the dissemination and protection of the Article, desires to have the JoVE publish the Article and create and transmit videos based on the Article. In furtherance of such goals, the Parties desire to memorialize in this Agreement the respective rights of each Party in and to the Article and the Video.

3. **Grant of Rights in Article.** In consideration of JoVE agreeing to publish the Article, the Author hereby grants to JoVE, subject to **Sections 4** and **7** below, the exclusive, royalty-free, perpetual (for the full term of copyright in the Article, including any extensions thereto) license (a) to publish, reproduce, distribute, display and store the Article in all forms, formats and media whether now known or hereafter developed (including without limitation in print, digital and electronic form) throughout the world, (b) to translate the Article into other languages, create adaptations, summaries or extracts of the Article or other Derivative Works (including, without limitation, the Video) or Collective Works based on all or any portion of the Article and exercise all of the rights set forth in (a) above in such translations, adaptations, summaries, extracts, Derivative Works or Collective Works and(c) to license others to do any or all of the above. The foregoing rights may be exercised in all media and formats, whether now known or hereafter devised, and include the right to make such modifications as are technically necessary to exercise the rights in other media and formats. If the "Open Access" box has been checked in **Item 1** above, JoVE and the Author hereby grant to the public all such rights in the Article as provided in, but subject to all limitations and requirements set forth in, the CRC License.

4. **Retention of Rights in Article.** Notwithstanding the exclusive license granted to JoVE in **Section 3** above, the Author shall, with respect to the Article, retain the non-exclusive right to use all or part of the Article for the non-commercial purpose of giving lectures, presentations or teaching classes, and to post a copy of the Article on the Institution's website or the Author's personal website, in each case provided that a link to the Article on the JoVE website is provided and notice of JoVE's copyright in the Article is included. All non-copyright intellectual property rights in and to the Article, such as patent rights, shall remain with the Author.

5. **Grant of Rights in Video – Standard Access.** This **Section 5** applies if the "Standard Access" box has been checked in **Item 1** above or if no box has been checked in **Item 1** above. In consideration of JoVE agreeing to produce, display or otherwise assist with the Video, the Author hereby acknowledges and agrees that, Subject to **Section 7** below, JoVE is and shall be the sole and exclusive owner of all rights of any nature, including, without limitation, all copyrights, in and to the Video. To the extent that, by law, the Author is deemed, now or at any time in the future, to have any rights of any nature in or to the Video, the Author hereby disclaims all such rights and transfers all such rights to JoVE.

6. **Grant of Rights in Video – Open Access.** This **Section 6** applies only if the "Open Access" box has been checked in **Item 1** above. In consideration of JoVE agreeing to produce, display or otherwise assist with the Video, the Author hereby grants to JoVE, subject to **Section 7** below, the exclusive, royalty-free, perpetual (for the full term of copyright in the Article, including any extensions thereto) license (a) to publish, reproduce, distribute, display and store the Video in all forms, formats and media whether now known or hereafter developed (including without limitation in print, digital and electronic form) throughout the world, (b) to translate the Video into other languages, create adaptations, summaries or extracts of the Video or other Derivative Works or Collective Works based on all or any portion of the Video and exercise all of the rights set forth in (a) above in such translations, adaptations, summaries, extracts, Derivative Works or Collective Works and (c) to license others to do any or all of the above. The foregoing rights may be exercised in all media and formats, whether now known or hereafter devised, and include the right to make such modifications as are technically necessary to exercise the rights in other media and formats. For any Video to which this **Section 6** is applicable, JoVE and the Author hereby grant to the public all such rights in the Video as provided in, but subject to all limitations and requirements set forth in, the CRC License.

7. **Government Employees.** If the Author is a United States government employee and the Article was prepared in the course of his or her duties as a United States government employee, as indicated in **Item 2** above, and any of the licenses or grants granted by the Author hereunder exceed the scope of the 17 U.S.C. 403, then the rights granted hereunder shall be limited to the maximum rights permitted under such statute. In such case, all provisions contained herein that are not in conflict with such statute shall remain in full force and effect, and all provisions contained herein that do so conflict shall be deemed to be amended so as to provide to JoVE the maximum rights permissible within such statute.

8. **Protection of the Work.** The Author(s) authorize JoVE to take steps in the Author(s) name and on their behalf if JoVE believes some third party could be infringing or might infringe the copyright of either the Author's Article and/or Video.

9. **Likeness, Privacy, Personality.** The Author hereby grants JoVE the right to use the Author's name, voice, likeness, picture, photograph, image, biography and performance in any way, commercial or otherwise, in connection with the Materials and the sale, promotion and distribution thereof. The Author hereby waives any and all rights he or she may have, relating to his or her appearance in the Video or otherwise relating to the Materials, under all applicable privacy, likeness, personality or similar laws.

10. **Author Warranties.** The Author represents and warrants that the Article is original, that it has not been published, that the copyright interest is owned by the Author (or, if more than one author is listed at the beginning of this Agreement, by such authors collectively) and has not been assigned, licensed, or otherwise transferred to any other party. The Author represents and warrants that the author(s) listed at the top of this Agreement are the only authors of the Materials. If more than one author is listed at the top of this Agreement and if any such author has not entered into a separate Article and Video License Agreement with JoVE relating to the Materials, the Author represents and warrants that the Author has been authorized by each of the other such authors to execute this Agreement on his or her behalf and to bind him or her with respect to the terms of this Agreement as if each of them had been a party hereto as an Author. The Author warrants that the use, reproduction, distribution, public or private performance or display, and/or modification of all or any portion of the Materials does not and will not violate, infringe and/or misappropriate the patent, trademark, intellectual property or other rights of any third party. The Author represents and warrants that it has and will continue to comply with all government, institutional and other regulations, including, without limitation all institutional, laboratory, hospital, ethical, human and animal treatment, privacy, and all other rules, regulations, laws, procedures or guidelines, applicable to the Materials, and that all research involving human and animal subjects has been approved by the Author's relevant institutional review board.

11. **JoVE Discretion.** If the Author requests the assistance of JoVE in producing the Video in the Author's facility, the Author shall ensure that the presence of JoVE employees, agents or independent contractors is in accordance with the relevant regulations of the Author's institution. If more than one author is listed at the beginning of this Agreement, JoVE may, in its sole

jove
1 Alewife Center #200
Cambridge, MA 02140
tel: 617.945.9051
www.jove.com

ARTICLE AND VIDEO LICENSE AGREEMENT

discretion, elect not take any action with respect to the Article until such time as it has received complete, executed Article and Video License Agreements from each such author. JoVE reserves the right, in its absolute and sole discretion and without giving any reason therefore, to accept or decline any work submitted to JoVE. JoVE and its employees, agents and independent contractors shall have full, unfettered access to the facilities of the Author or of the Author's institution as necessary to make the Video, whether actually published or not. JoVE has sole discretion as to the method of making and publishing the Materials, including, without limitation, to all decisions regarding editing, lighting, filming, timing of publication, if any, length, quality, content and the like.

12. **Indemnification.** The Author agrees to indemnify JoVE and/or its successors and assigns from and against any and all claims, costs, and expenses, including attorney's fees, arising out of any breach of any warranty or other representations contained herein. The Author further agrees to indemnify and hold harmless JoVE from and against any and all claims, costs, and expenses, including attorney's fees, resulting from the breach by the Author of any representation or warranty contained herein or from allegations or instances of violation of intellectual property rights, damage to the Author's or the Author's institution's facilities, fraud, libel, defamation, research, equipment, experiments, property damage, personal injury, violations of institutional, laboratory, hospital, ethical, human and animal treatment, privacy or other rules, regulations, laws, procedures or guidelines, liabilities and other losses or damages related in any way to the submission of work to JoVE, making of videos by JoVE, or publication in JoVE or elsewhere by JoVE. The Author shall be responsible for, and shall hold JoVE harmless from, damages caused by lack of sterilization, lack of cleanliness or by contamination due to the making of a video by JoVE its employees, agents or independent contractors. All sterilization, cleanliness or decontamination procedures shall be solely the responsibility of the Author and shall be undertaken at the Author's expense. All indemnifications provided herein shall include JoVE's attorney's fees and costs related to said losses or damages. Such indemnification and holding harmless shall include such losses or damages incurred by, or in connection with, acts or omissions of JoVE, its employees, agents or independent contractors.

13. **Fees.** To cover the cost incurred for publication, JoVE must receive payment before production and publication the Materials. Payment is due in 21 days of invoice. Should the Materials not be published due to an editorial or production decision, these funds will be returned to the Author. Withdrawal by the Author of any submitted Materials after final peer review approval will result in a US$1,200 fee to cover pre-production expenses incurred by JoVE. If payment is not received by the completion of filming, production and publication of the Materials will be suspended until payment is received.

14. **Transfer, Governing Law.** This Agreement may be assigned by JoVE and shall inure to the benefits of any of JoVE's successors and assignees. This Agreement shall be governed and construed by the internal laws of the Commonwealth of Massachusetts without giving effect to any conflict of law provision thereunder. This Agreement may be executed in counterparts, each of which shall be deemed an original, but all of which together shall be deemed to me one and the same agreement. A signed copy of this Agreement delivered by facsimile, e-mail or other means of electronic transmission shall be deemed to have the same legal effect as delivery of an original signed copy of this Agreement.

A signed copy of this document must be sent with all new submissions. Only one Agreement is required per submission.

CORRESPONDING AUTHOR

Name:	Molly Watkins
Department:	Physical Therapy
Institution:	The College of St. Scholastica
Title:	DPT
Signature:	Molly Watkins
Date:	02/25/2020

Please submit a **signed** and **dated** copy of this license by one of the following three methods:

1. Upload an electronic version on the JoVE submission site
2. Fax the document to +1.866.381.2236
3. Mail the document to JoVE / Attn: JoVE Editorial / 1 Alewife Center #200 / Cambridge, MA 02140