Psychophysical thresholds are more precise measures of proprioceptive sensitivity than matching error values at the elbow joint

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Dedication

This Master’s thesis is dedicated to my family. At a very young age my parents, Mark and Julie, instilled upon me the significance of earning a higher education. They have endlessly made sacrifices in order for me to obtain a Bachelor of Science degree and now a Master of Science degree. They made every effort to provide for my siblings and me an education that they never had the opportunity to experience. Words cannot express my gratitude for my parents and my brothers, Aaron and Kyle, who challenge me to succeed, assist me while making difficult decisions, and support me along every path I choose.

Abstract

To assess proprioceptive function, clinicians employ joint position matching tasks. However, the reliability and validity of matching tasks are infrequently considered. Laboratory tests of proprioceptive sensitivity include more controlled matching methods that yield position error measures or psychophysical methods that yield a perceptual threshold. Psychophysical methods have been shown to be both valid and reliable.

In this study, proprioceptive sensitivity of the elbow joint was assessed in 24 healthy adult volunteers using an ipsilateral matching method and a psychophysical method. The aims of the study were: 1) to determine if threshold measures obtained by psychophysical testing yield more precise measures of position sense than error measures obtained by an ipsilateral joint position matching method and 2) to determine if the two methods are linearly correlated with each other. The results indicated that the psychophysical method provided more precise measurements than the ipsilateral matching method. Despite both assessments measuring position sense sensitivity of the elbow, they were poorly linearly correlated with each other. Based on the findings, the study demonstrated that the psychophysical method provided a more precise measure of proprioceptive sensitivity at the elbow than the ipsilateral matching method.

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Introduction

Proprioception is the term used to describe the sensory processes that contribute to a sense of self-position and movement (Sherrington, 1906). Proprioception is based on afferent feedback from muscle spindles to the central nervous system (Goble et al., 2009; Proske et al., 2000). Additionally, mechanoreceptors in the joints, ligaments, muscles, tendons, and skin play a critical role in establishing the location of body limbs and responding to rapid fluctuations in direction and velocity (Goble, et al., 2009; Grob et al., 2002). Two forms of proprioception are joint position sense and joint movement sense. Joint position sense is the perception of the location of a limb in space, and joint movement sense is the perception of limb motion (Grob et al., 2002). In general, proprioception is an unconscious awareness of one's body in space. Proprioception is essential for voluntary movement; therefore it is important to understand the effects of proprioceptive deficits.

Proprioceptive deficits can occur due to a variety of disease states, for example deafferentation and Parkinson's disease. Deafferented individuals, with undamaged efferent pathways, have been known to display pronounced motor control deficits. These deficits include reduced endpoint precision (Ghez, et al., 1990) and failure to execute extensive sequential movements (Rothwell, et al., 1982). Patients with large-fiber sensory neuropathies displayed notable errors during a voluntary, multi-joint movement (Sainburg et al., 1995). Additionally, individuals suffering from Parkinson's disease perform poorly when estimating limb positions during passive motion testing (Konczak et al., 2007). In a study on patients with Parkinson's disease, the patients were reported as having significantly higher postural sway scores than their age-matched controls (Waterston et al., 1993). Consequently, proprioceptive feedback is necessary for controlling voluntary movement and maintaining postural stability (Huang, Gillespie, Kuo, 2007; Konczak et al., 2007; Riemann and Lephart, 2002).

Proprioception is frequently examined by assessing the measurements of several proprioceptive sensitivity tests. A commonly implemented method is a test for joint position sense (Westlake et al., 2007). The test measures the error between a pre-established joint position and a reproduced position. The replicated position is performed by means of active or passive movement, and is executed by the same (ipsilateral) or different (contralateral) joint (Westlake et al., 2007). A passive movement is a joint movement where there is no effort or contribution by the participant. An active movement is a joint movement executed by the participant. Tests with a replicated movement are often referred to as a joint position matching method. Joint position matching methods are traditionally used within the clinic as a test of proprioceptive sensitivity. During an exam, a trained professional observes an individual's matching error, or position error, in order to determine his or her overall proprioceptive sensitivity.

<u>Matching methods are used frequently in clinical and laboratory settings to measure proprioceptive sensitivity</u>. Although this method is widely accepted within the clinic as a test of proprioceptive sensitivity, the reliability and validity of joint position matching methods are infrequently considered (Goble, 2010). Furthermore, the quantity of the results of clinical matching methods is not generally expressed. Additional issues, such as memory in ipsilateral matching, interhempispheric transfer in contralateral matching, and the source of the measurement error (from which arm the error is occurring) in contralateral matching may contribute to measurement inaccuracy (Goble, 2010). Although clinical matching methods present issues of concern, matching methods performed in a laboratory setting quantify the resulting error from the reproduced movement in degrees. However, researchers often use psychophysical methods to test somatosensory sensitivity in a laboratory setting.

<u>An alternative to the joint position matching method is the use of psychophysical methods to measure proprioceptive sensitivity</u>. Psychophysical methods were introduced by German physicist Fechner (1860/1966) and examine the connection between the body and the mind. There are two types of psychophysical tests that are also frequently used for proprioceptive sensitivity testing: a test for a detection threshold and a test for a discrimination threshold (Ehrenstein and Ehrenstein, 1966). A detection threshold is defined as the smallest stimulus that can be perceived. A discrimination threshold, also

called the just noticeable difference (JND) threshold, indicates the smallest amount by which a changing comparison stimulus must diverge from a fixed reference stimulus to generate a noticeable perceptual difference. The comparison stimulus diverges from the reference stimulus based on a step sequence. An ascending sequence begins with a weaker comparison and moves closer to the reference stimulus. A descending sequence begins with a stronger comparison and moves away from the reference stimulus. The difference threshold is defined as the difference between the two stimuli, of the first trial, in which a participant changes his or her response from a previous trial. A JND threshold can be obtained for both position and motion sense; however, this study will focus on a JND threshold of position sense.

Different measures of proprioceptive sensitivity have been used within clinic and laboratory settings; however, the relationship between matching methods and psychophysical methods remains unclear. The aims of this study are to determine whether the two methods yield measures of sensitivity that are significantly different from each other and if the two methods are linearly correlated with each other. Understanding the relationship between the two methods will provide useful insight to professionals who commonly utilize matching methods as a form of proprioceptive sensitivity testing.

Specific Aims

1. To test the hypothesis that threshold measures obtained by psychophysical testing yields more precise measures of position sense than error measures obtained by an ipsilateral joint position matching method.

A statistical significant difference between these two measures at the sample level with the mean threshold being significantly smaller than the position sense error would verify the hypothesis.

2. To test the hypothesis that the ipsilateral joint position matching method and the psychophysical method are linearly correlated with each other.

In order to determine the relationship between the two sensitivity measurements, a simple linear regression of the position error values from the ipsilateral joint position matching method and psychophysical thresholds from the psychophysical method was performed. A correlation that reaches statistical significance at the sample level would verify the hypothesis.

Methods

Participants

Twenty-seven healthy subjects ranging in age from 18-35 years (Mean age = 25.7 ± 4.1 years; 15 males) participated in the study. Recruitment for the study occurred through posters displayed around the University of Minnesota campus and an e-mail sent to the kinesiology department faculty and graduate student staff. Participants were informed about the study and signed the consent and evaluation form. They also completed the Edinburgh Handedness Inventory (Oldfield, 1971) to determine their hand dominance. There were 26 right-handed participants and 1 left-handed participant. The participants also completed the subject information form, which screened for a history of any associated neural or muscular deficits in the upper extremities. If deficits existed, the participants were excluded from the study. All participants gave voluntary written consent as stipulated by the University of Minnesota Internal Review Board (IRB).

Experimental Design

Proprioceptive sensitivity was assessed using two methods in a single group by two-treatment study design. All participants were assessed using both methods: an ipsilateral joint position matching method and a psychophysical threshold method. In order to control for an order effect, every participant performed the two assessments, which were part of a larger study that was counterbalanced using a Latin square design. With this design, each participant performed the methods in different orders, which allowed for order to be controlled for by having equal effects in all conditions. As a result, the order in which the participants performed each method had no effect on the results of the study.

Instrumentation

1. Psychophysical Method

A passive-motion apparatus was used to passively rotate the elbow joint. The participants sat on an immovable stool, which was raised by a wooden box for appropriate seating height. The participants placed their dominant arm at a 90° angle in relation to the splint apparatus (Figure 1). A goniometer was used to confirm the 90° elbow joint angle. The splint apparatus consisted of a metal rectangular bar (9 cm wide x 60 cm long). Padding on the splint eliminated vibrational cues. During testing, the participants' vision was occluded and the potential motor noise was masked by pink noise transmitted through headphones to eliminate visual and audio cues. In addition, this further accentuated the dependence on elbow joint proprioception to discriminate between the two angular stimuli. The splint was moved by a torque motor (precision: 5466 steps per 1° = 0.00018°/step; Nyden Inc., San Jose, USA) and tested 10° for the reference stimulus and a range of degrees (<10°) for the comparison stimulus. The order of the stimuli is described in the procedure. The movement of the splint occurred in a horizontal plane and allowed for flexion and extension at the elbow, with no movement at the wrist or shoulder.

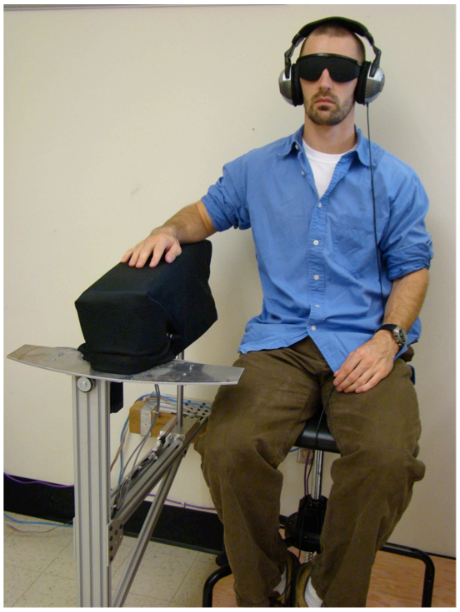

Figure 1. Passive Motion Apparatus

2. Ipsilateral Joint Position Matching Method

For the ipsilateral joint position matching method, a single-plane manipulandum was used (Figure 2). The participants were seated with their dominant arm at a 90° angle over the pivot point of the apparatus. All participants' vision was occluded for the ipsilateral method. The manipulandum measured absolute joint angular deviation via an inbuilt potentiometer (Novotechnik P4500, 0.008° resolution). The manipulandum recorded the potentiometer's shaft position in voltage and the algorithm in BASIC digitally sampled the analog signal and displayed the participants' angular positions in real time on the personal computer. BASIC was also used to record the participants' response data. For our experiment, rotation occurred at the elbow joint only. The manipulandum allowed for flexion and extension of the elbow in the horizontal plane, while maintaining stabilization at the wrist and shoulder. In order to provide a reference stimulus for the participants, we measured the 10° position with the potentiometer and then marked it by placing tape on the table. An L-shaped wooden block was used as a stopping device placed at a 10° position to indicate the reference position.

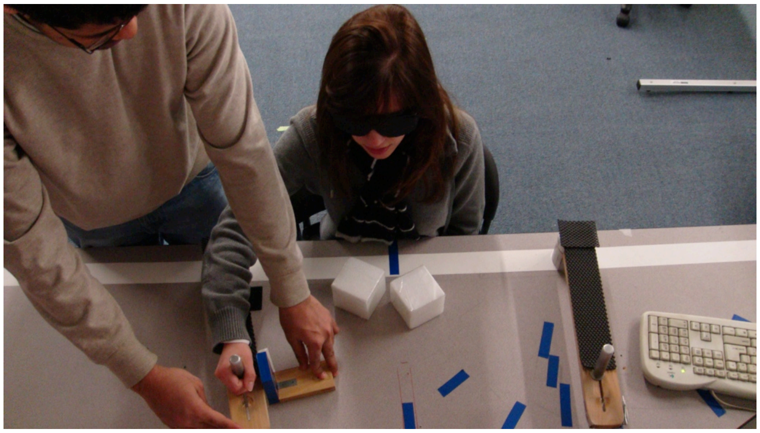

Figure 2. Single-Plane Manipulandum

Procedure

1. Psychophysical Method

The psychophysical procedure consisted of 40 trials. The total number of trials could be increased to 60 trials, if participant responses did not converge after the initial set of 40 trials. Each trial consisted of two passive movements to defined locations: a reference position and a comparison position. The reference joint angular position was 80° (10° amplitude). The comparison angle was always a joint angle between 80°-90° (<10° amplitude). At the beginning of a trial, the first passive movement occurred, followed by a pause, and then the armrest returned to the starting position. Next, the second passive movement occurred, followed by a pause, and then the armrest returned to the starting position. Using a forced-choice paradigm participants were asked, “which movement came closer to the body, the first movement or the second movement?” The participants’ verbal responses were recorded through a software program based on MATLAB Technical Programming Language (Mathworks Inc., Natick, MA). Based on the response data, the magnitude of the comparison angle for each consecutive trial was determined by QUEST, an adaptive algorithm (Watson and Pelli, 1983). If the participant answered the first trial correctly, the algorithm chose a comparison value that was closer to the reference angle. If the person answered incorrectly, the algorithm chose a comparison value that was further from the reference angle.

2. Ipsilateral Joint Position Matching Method

The participants placed their dominant arm on the manipulandum with their elbow centered over the pivot point of the apparatus (Figure 2). Each individual completed a total of 20 trials. The starting position was defined by the 90° position of the manipulandum. A stopping device prevented their forearm from moving further than the starting target in one direction, but allowed movement in the other direction to the desired 80° target (10° amplitude). To begin each trial, the participants’ dominant forearm was passively moved by the experimenter to the 80° reference target, marked by the wooden stopping device. The experimenter verbally informed them when the desired target was reached, but they were not provided any other indication of the location, other than proprioceptive feedback. Their forearm was then passively moved back to the starting position. Next, the participants were directed to complete active self-paced movement of their forearm as efficiently and precisely as possible. They were instructed to stop their movement and provide verbal notification when they felt they had reached the same forearm position as the reference target. The participants were asked keep their forearm stationary until the position of the potentiometer was recorded. When they heard a “beep” sound, they were allowed to move their forearm back to the starting position to prepare for a new trial. This sequence of events denoted a single trial and occurred for a total of 20 trials. All 20 trials had the same 80° reference target.

Measurements

1. Psychophysical Method

From the response data, the percentage of correct responses for each stimulus level was computed and a cumulative Gaussian function was fitted to yield a psychometric sensitivity function. Based on that sensitivity function, the 75% correct response was determined and defined as the participants’ JND threshold. The value of 75% correct response was chosen, because it is half way between guessing (correct 50% of the time) and knowing (correct 100% of the time).

2. Ipsilateral Joint Position Matching Method

A software program based on MATLAB Technical Programming Language was used to calculate position error for each trial, which was the target angle minus the participants’ angular displacement (or matching position). The software program was then used to calculate the absolute error value for each trial. The mean position error value was computed using the software program, which was the mean of the absolute error values of all trials for each participant.

Design & Data Analysis

Preceding data analysis, the absolute mean error value for each participant was calculated from the ipsilateral joint position matching method. The JND threshold value from each participant was also computed from the psychophysical method. The absolute mean error values and the respective JND thresholds were stored in a comma separated values (csv) file. All subsequent statistical analysis was performed using software program The R Foundation for Statistical Computing (R Development Core Team, 2011).

The data were analyzed after removing three outliers (see *Outlier Analysis* for details). A paired t-test was performed to determine if there was a statistically significant difference between the mean error values from the ipsilateral joint matching method and the JND threshold values from the psychophysical method. In addition, a simple linear regression was fitted, modeling the effects of mean error values of the ipsilateral joint position matching method on JND threshold values. The alpha level of significance was set to 0.05.

Results

Outlier Analysis

The interquartile ranges were computed for the psychophysical thresholds and the mean error values for the whole sample. According to Tukey (1977), any data that fall outside of the interquartile range of 1.5 may be considered outliers (Frigge, 1989). Any data that fell outside this range for one of the two variables (psychophysical thresholds or mean error values), the subject was considered an outlier. Three subjects were considered outliers and their entire data sets were excluded from further analysis.

Descriptive Data Analysis: Single-Subject

1. Psychophysical Method

A sensitivity function and JND threshold were computed for each participant. Figure 3 displays the sensitivity data from a single subject fitted with a Gaussian function. This individual's JND threshold at the 75% correct response level was computed as 0.82° (SD ± 0.27°). The arrow denotes the JND threshold and the shaded area indicates the standard deviation. Thus, for the psychophysical method, this participant could detect a difference between two position stimuli for a difference of 0.82° and greater.

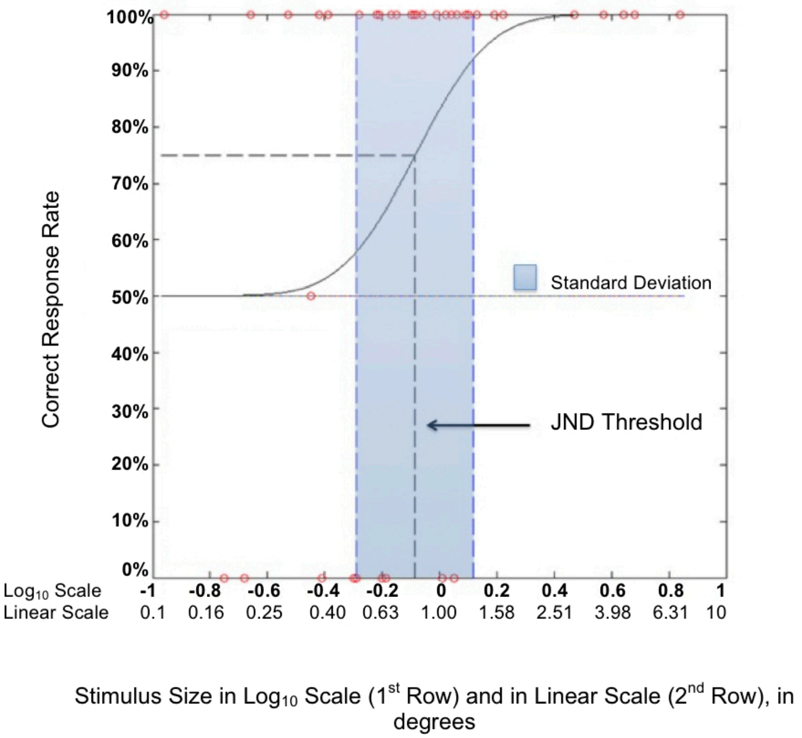

Figure 3. Single subject sensitivity data fitted using a cumulative Gaussian function. The figure depicts the stimulus size in $\log_{10}$ scale. The y-axis displays the translated linear scale. This individual's JND threshold is 0.82° (SD ± 0.27°).

2. Ipsilateral Joint Position Matching Method

The absolute mean error value was calculated for each individual. Figure 4 displays position error values across all 20 trials for a single subject. This individual's mean position error value was 1.25° (SD ± 0.99°), meaning that on average, the individual matched the elbow position with an error rate of 1.25°.

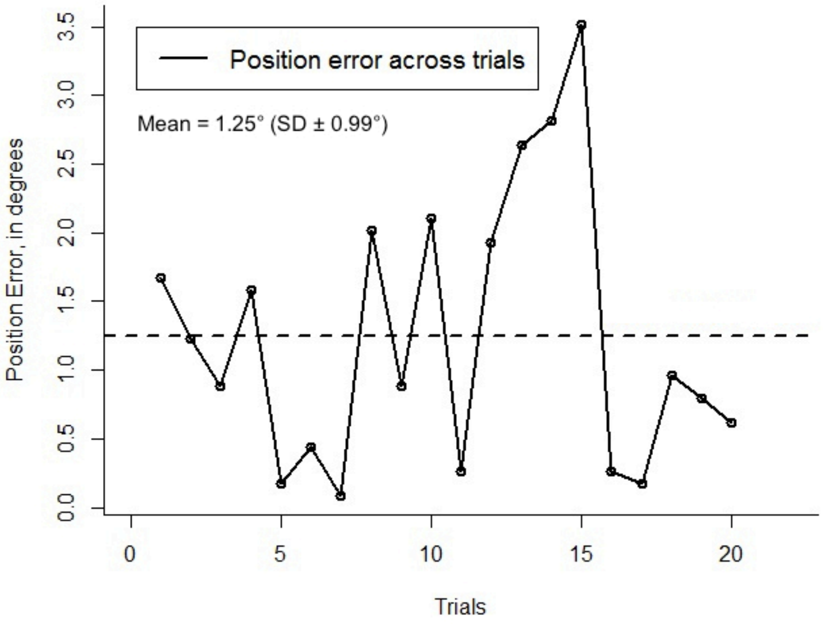

Figure 4. Position error values plotted across all trials for a single subject. This individual's overall absolute mean error value was 1.25° (SD ± 0.99°).

Descriptive Data Analysis: All Subjects

Exploratory analysis of the data indicated that the distribution of the JND threshold values and the mean ipsilateral position error values for all subjects followed a roughly normal distribution (Figure 5). Notable is the JND threshold curve is shifted to the left of the ipsilateral position error curve, indicating a lower proprioceptive sensitivity average. This is also shown in Figure 6, which displays the mean values for the two proprioceptive sensitivity methods. For all subjects, the mean value for the psychophysical method was 1.06° (SD ± 0.48°). The mean value for the ipsilateral matching method was 1.51° (SD ± 0.64°).

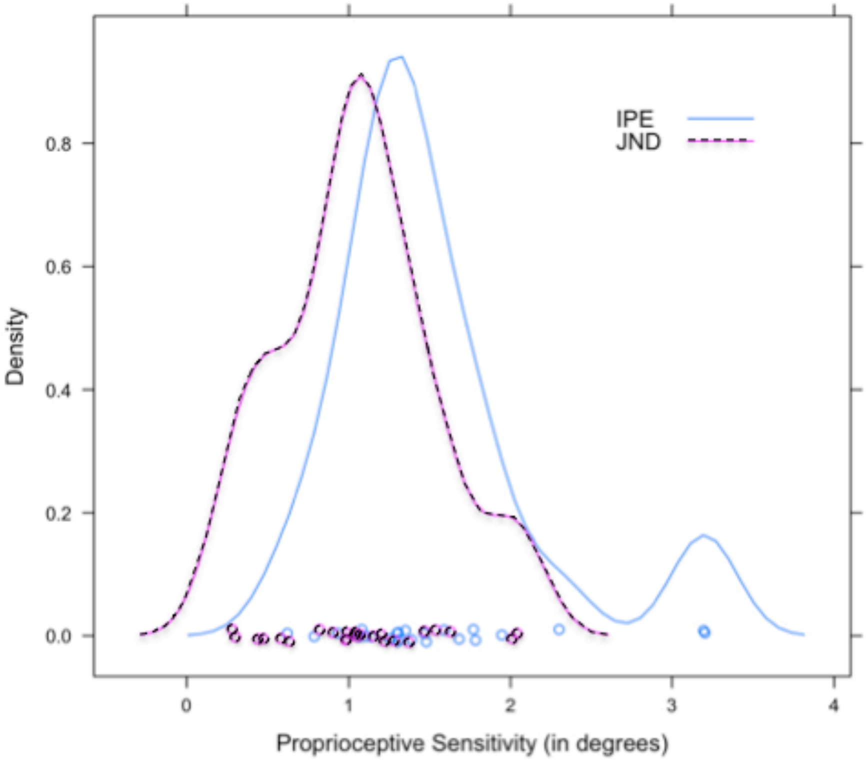

Figure 5. Density distributions of mean ipsilateral position errors (IPE) and just noticeable difference (JND) threshold values for all subjects.

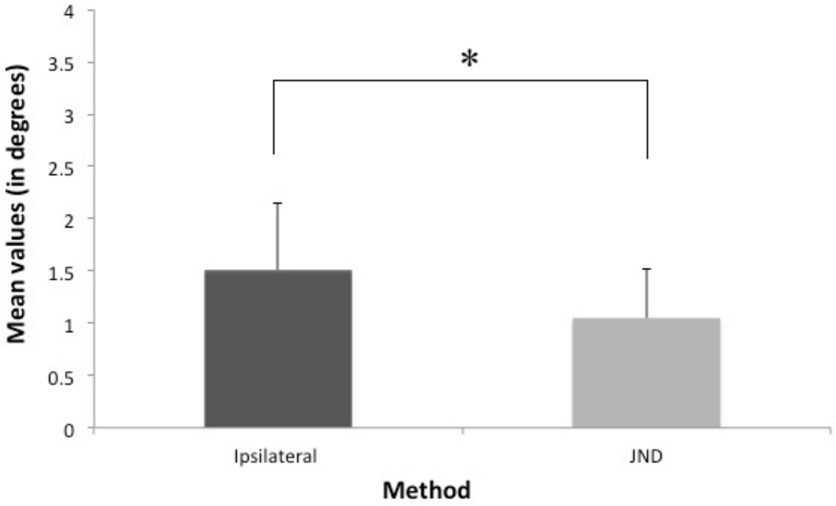

Figure 6. Mean values of the ipsilateral matching method and the psychophysical method for all subjects. The mean value for the ipsilateral matching method was 1.51° (SD ± 0.64°). The mean value for the psychophysical method was 1.06° (SD ± 0.48°).

Analysis to Determine Which of the Two Methods is More Precise

To determine if the ipsilateral joint position matching method and the psychophysical method were significantly different from each other, a paired t-test was performed. The results indicate that there was a statistically significant effect (t = 2.79; *p* = 0.01) between the two groups, indicating the two methods of proprioceptive sensitivity are significantly different from each other. Figure 6 depicts the significant difference between the two mean proprioceptive sensitivity values. In addition, Figure 7 conveys the individual difference between the two methods of proprioceptive sensitivity. For 19 out of the 24 subjects, the JND threshold value was lower than the ipsilateral position error mean value. Therefore, this suggests that the JND threshold values are relatively consistently below the ipsilateral position error values. The result indicates that the psychophysical method may be a more precise measure of proprioceptive sensitivity testing (addressing the first aim of the study).

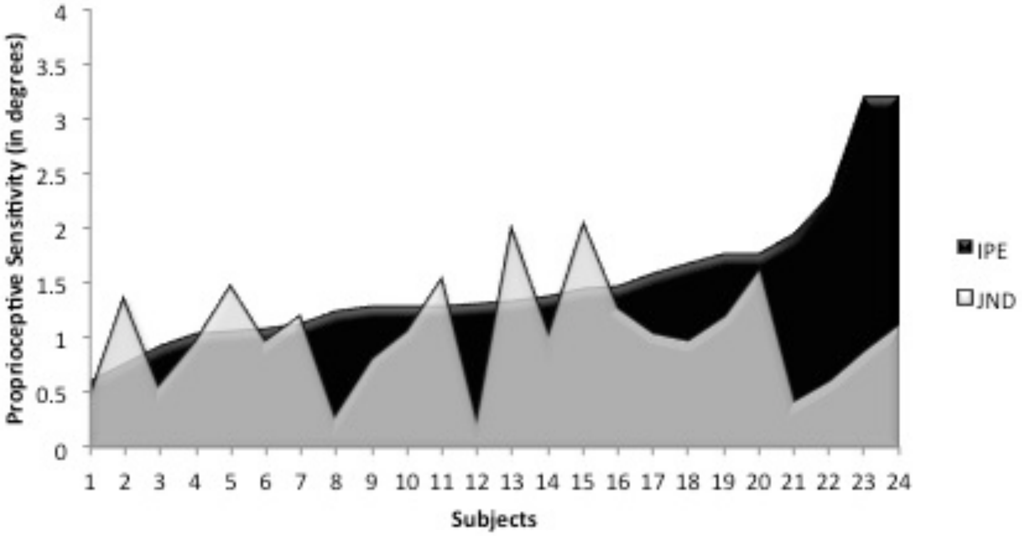

Figure 7. Mean values of the two methods of proprioceptive sensitivity testing for all subjects. Subjects were sorted in ascending order according to their IPE response. IPE = ipsilateral position error; JND = just-noticeable difference threshold.

Analysis for a Linear Correlation Between the Two Methods of Sensitivity

Figure 8 displays mean position error values regressed on JND threshold values. The linear regression analysis revealed a slightly negative correlation of r = -0.004. The coefficient of determination was $r^2 = 1.49e^{-05}$, indicating that the mean position error values explained less than 1% of the variance of the JND threshold values. The simple linear regression failed to reach significance at the 0.05 level. As a result, the two methods of proprioceptive sensitivity were poorly linearly correlated with each other, which rejects the second hypothesis.

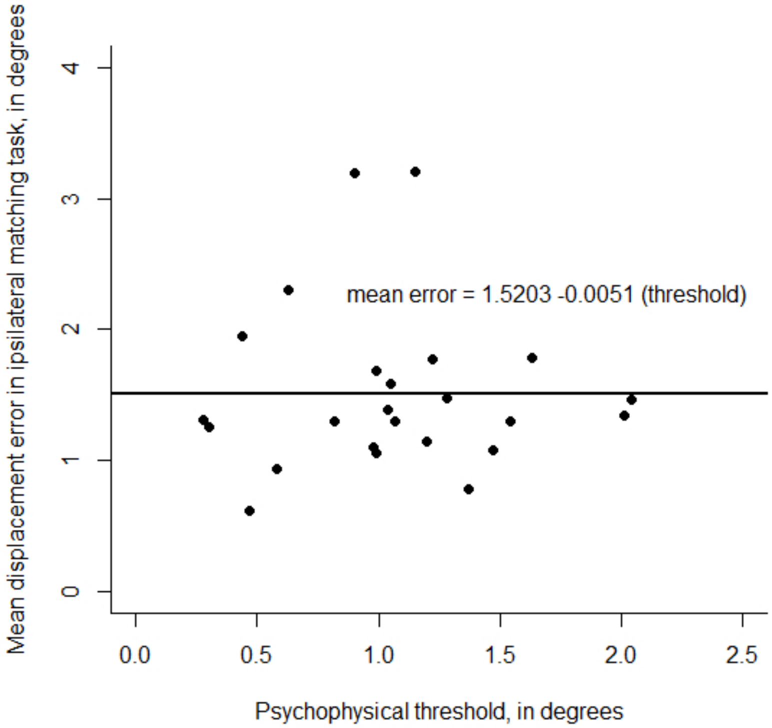

Figure 8. Mean displacement error of the ipsilateral joint position matching method regressed on psychophysical threshold values of the psychophysical method for all subjects.

Discussion

The overall goal of this study was to assess methods that are commonly used for proprioceptive sensitivity testing: a joint position matching method and the psychophysical method. The first aim of the study was to test the hypothesis that thresholds measures obtained by psychophysical testing yield more precise measures of position sense than error measures obtained by an ipsilateral joint position matching method. The second aim of the study was to test the hypothesis that the ipsilateral joint position matching method and the psychophysical method are linearly correlated with each other.

Based on the results, the psychophysical method was 142% (0.45°) more precise than the ipsilateral joint position matching method. The results indicated that the ipsilateral joint position matching method and the psychophysical method yielded measures of proprioceptive sensitivity that were significantly different from one another. Lastly, the two measures of proprioceptive sensitivity were poorly linearly correlated with each other.

Psychophysics has widely been accepted as one measure of proprioceptive sensitivity. Early studies using psychophysics included the work of German neurologist Alfred Goldscheider (1898). Like the current study, he tested elbow position sense at a starting position of 90°. Defining the psychophysical threshold was a 50% correct response rate (where the participant was equally knowledgeable and equally dubious) he reported thresholds in the range between 0.43°-0.76° with a mean value of 0.55°. The current study defined thresholds at the higher 75% correct response rate, which consequently yielded a slightly higher mean threshold of 1.06° for our sample.

Further evidence that the data of this study are consistent with previous reports comes from a study by Maschke and colleagues (2006) that used a similar passive motion apparatus and tested 11 healthy control subjects. They found the threshold value at the 75% correct response rate to be 1.03°, which is nearly identical to the mean threshold of 1.06° at the 75% correct response rate computed for the 24 participant sample in this study. In summary, both early and recent studies using psychophysical methods have shown similar psychophysical thresholds for proprioceptive position sense at the elbow, indicating that the values reported in this study are consistent with previous research.

To date, no prior studies have compared the psychophysical method and the ipsilateral joint position matching method to determine which is more precise. However, previous studies have discussed the reliability and validity of the two methods individually. The use of thresholds for the perception of passive movement, or the psychophysical method, has been shown to be reliable and valid (Deshpande et al., 2003). Psychophysical methods have also been successfully implemented in prior studies with healthy adults and Parkinson's disease patients (Konczak et al., 2007) and children (Pickett and Konczak, 2009). Alternatively, the reliability and validity of the joint position matching method has rarely been assessed, but is still a widely accepted measure of proprioceptive sensitivity (Goble, 2010).

One previous study by Grob and colleagues (2002) analyzed the relationship between the psychophysical method and the joint position matching method, in order to determine if they are linearly correlated with each other. They compared detection thresholds from two psychophysical method tests with mean error values from three position matching tests around the knee joint. They found no correlation between two psychophysical method tests and three joint position matching tests, although they did find a significant correlation between the two tests using the psychophysical method.

Although a significant correlation between the two methods was not found in the present study, the results could not be attributed to measurement error. The resolution of the device used for the ipsilateral joint position matching method was 0.008°. The resolution of the device used for the psychophysical method was 0.00018°/step. Thus, the precisions of both devices were well below the mean JND threshold of the psychophysical method (1.06°) and the mean position error of the ipsilateral joint position matching method (1.51°).

One drawback to the psychophysical method is the length of time it took to reach JND threshold. For this study, it typically took 25-35 minutes and 40 or 60 trials in order to reach a JND threshold value for one participant. Alternatively, the ipsilateral joint position matching method took about 3-5 minutes and only 20 trials. Through continued research, a well-established normative database of healthy individuals and an optimization of the algorithm to converge more quickly could substantially reduce the amount of time it takes to reach a JND threshold.

Conclusion

In summary, this study examined the relationship between the psychophysical method and the ipsilateral joint position matching method. Since the joint position matching method is generally used as a subjective measure of proprioceptive sensitivity testing within a clinical setting, it is crucial to understand its precision and its relationship to other reliable objective evaluations. Based on the results of this study, the psychophysical method provided a more objective and precise measurement of proprioceptive sensitivity compared to the ipsilateral joint position matching method. With further optimization of the testing procedure, the psychophysical evaluation may develop into a clinically accessible tool for testing proprioception.

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Appendix A

Adult Consent Form

University of Minnesota

ADULT CONSENT FORM

The Development of Limb Position Sense Across the Lifespan

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Co-Investigator:	**Naveen Elangovan**	**(612) 625-3313**

Purpose and Background

The Human Sensorimotor Control Laboratory at the University of Minnesota examines the ability of human adults to sense joint position, to determine the differences between active and passive movement on position sense sensitivity, and to investigate if this ability can be trained.

Procedures

If you agree to be in this study, you will be asked to come to the laboratory to complete a sensory and a motor task. Prior to testing, a short assessment of handedness will be completed to determine the dominant hand. The sensory task will require you to sit in a chair with your arm placed on a moving arm rest, while wearing goggles and headphones. The arm rest will support the arm while a motor is used to passively move the forearm. You will then be asked to make a judgment about the movement velocity or movement distance. In a subsequent motor task, you will place your arm on the arm rest of a manipulandum. You will be asked to actively move your forearm as accurately as possible to a specific target position.

Risk and Discomfort

We believe that our study imposes no risks other than fatigue. We work closely with the individuals to find a convenient time for testing. If you do not want to participate in the testing activities, we will stop the assessment, accommodate retesting you on a better day, if desired, or completely stop the investigation.

Benefits
There is no direct benefit to you for participation in this study.

Compensation:
No compensation will be given to subjects.

Research Related Injury:
In the event that this research activity results in an injury, treatment will be available, including first aid, emergency treatment, and follow-up care as needed. Care for such injuries will be billed in the ordinary manner, to you or your insurance company. If you have suffered a research related injury let the study investigators know right away.

Confidentiality:
Regarding confidentiality, you will receive an ID number from the investigators and all data will be analyzed using that number. No individual will be able to be identified. All our data are retained in a locked file cabinet and a password is used with our computerized data files. In any sort of report we might publish, we will not include any information that will make it possible to identify a subject.

Voluntary Nature of the Study:
Participation in this study is entirely voluntary. You may terminate the experiment at any time without penalty. Your decision whether or not to participate will not affect your current or future relations with the University of Minnesota or with the researchers. If you decide to participate, you are free to withdraw at any time without affecting those relationships.

Contacts and Questions:
The researchers conducting this study are Amanda Herrmann, Naveen Elangovan and Dr. Jürgen Konczak. You may ask questions now. If you have questions later, you may contact Amanda Herrmann or Naveen Elangovan at (612) 625-3313.

If you have any questions or concerns regarding the study and would like to talk to someone other than the research(s), contact the Fairview Research Helpline at telephone number 612-672-7692 or toll free at 866-508-6961. You may also contact this office in writing or in person at Fairview University Medical Center – Riverside Campus, #815 Professional Building, 2200 Riverside Avenue, Minneapolis, MN 55454.

HS Code Number 0302M43481

You will be given a copy of this form to keep for your records.

Statement of Consent:
I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

Name: ____ Date:_______________
(PLEASE PRINT)

Signature____ Date:_______________

Signature of Investigator: __________________________________ Date:_______________

Appendix B

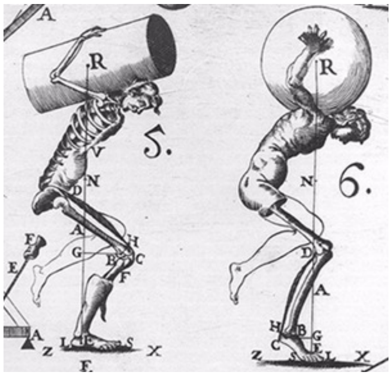
Handedness Questionnaire

Handedness questionnaire

Study name: ____________________

Subject number: ____________________

Date: ____________________



	Which hand do you prefer?			**Do you ever use the other hand?**	
	right	**left**	**no preference**	**yes**	**no**
Writing					
Drawing					
Throwing					
Using scissors					
Using a toothbrush					
Using a knife without a fork					
Using a spoon					
Using a broom (upper hand)					
Opening a box					

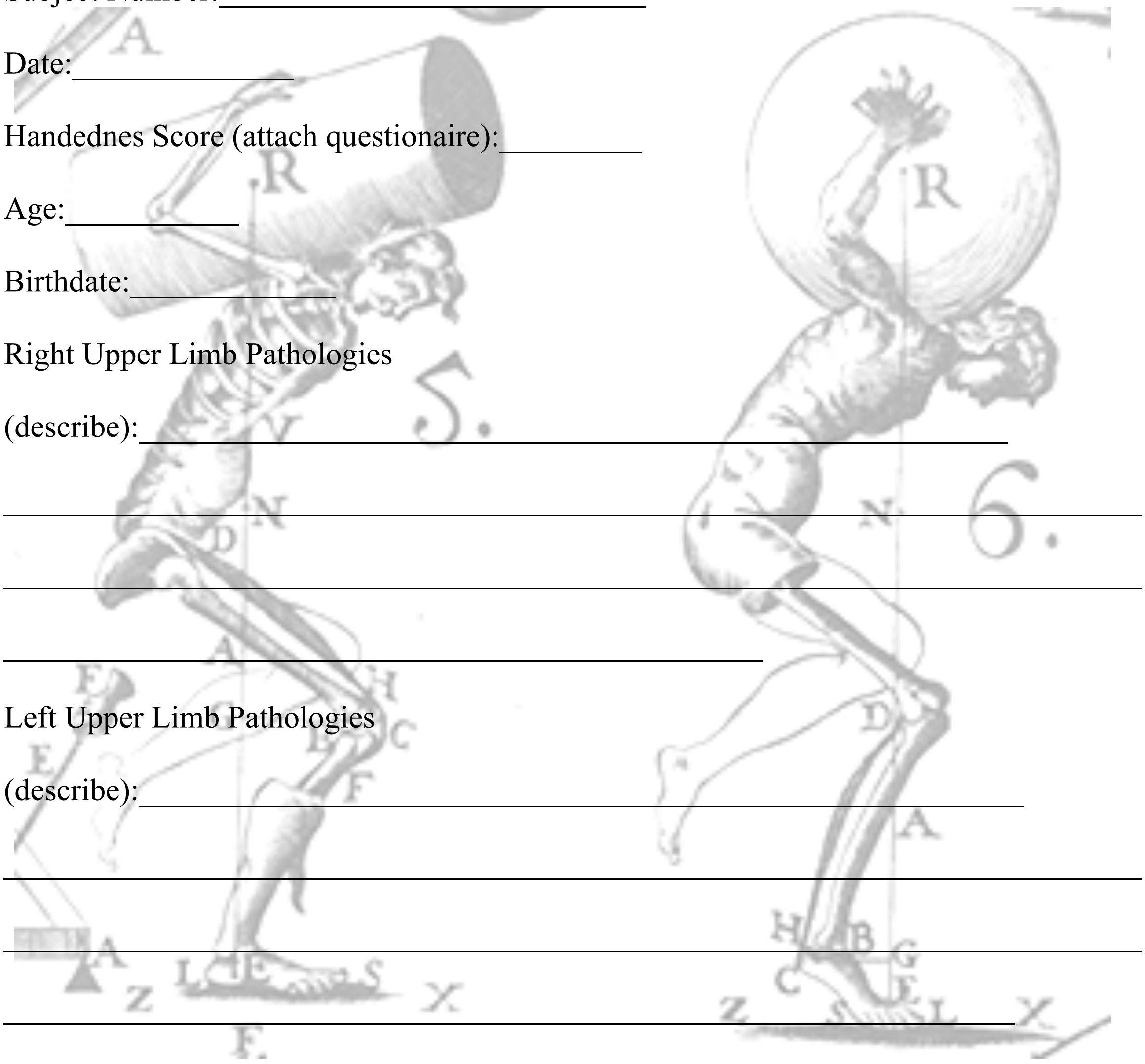
Total score: ______________________________

Appendix C

Subject Information Form

Univerisity of Minnesota
Human Sensorimotor Control Laboritory

Proprioception and Development
Subject Information Form



Subject Number:____________________________

Date:______________

Handednes Score (attach questionaire):_________

Age:___________

Birthdate:_____________

Right Upper Limb Pathologies

(describe):____

____

____

____

Left Upper Limb Pathologies

(describe):____

____

____

____

Subject Accepted for study (investigator's initials):________

Date:____________

HS Code Number 0302M43481