VALIDITY AND RELIABILITY OF THE JPS98 FOR UNI-PLANAR JOINT-POSITION-SENSE AT THE ELBOW

THESIS

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DEDICATION

To my husband of eighteen years, Dr. Mark A. Canfield,
who provided inspiration and emotional support
throughout this period of growth.

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TABLE OF CONTENTS

TABLE OF CONTENTS- continued

LIST OF TABLES

Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Background

Proprioception is the awareness of the position of the parts of the body in space.[1] It plays a vital role in all human movement and fulfills a fundamental function in the development of normal postural mechanisms and the components of movement necessary for skilled motor control. Proprioception is a process whereby sensory inputs from cutaneous, joint and muscle mechanoreceptors are integrated into joint-position-sense and kinesthesia.[2] Joint-position-sense is the discernment of the position of musculoskeletal elements around a joint. Kinesthesia is the detection of the movement of the head, trunk and limbs.

Proprioception is an important component in the sensory feedback mechanisms for motor learning. The proprioceptive, visual and vestibular sensory systems help to facilitate and regulate motor function via pathways of the central and peripheral nervous systems.[1] Trunk stability and voluntary motor control, such as in gait and the purposeful reach for food and water, depend on the awareness of the position of the parts of the body in space.

On a cellular level, proprioception is the sensation of changes in length and contractile forces on muscle fibers; the detection of the amplitude, direction and speed of joint movement; and the awareness of the relative compression or distraction of joint tissues.[2] Since mechanoreceptors are found in many different tissues, deficits in proprioception are associated with much orthopedic and neurological pathology, affecting a vast cross-section of patients seeking physical therapy.

Problem

In evaluating the integrity of a patient's proprioception, physical therapists have historically relied on qualitative tests. For example, to test kinesthesia, the blindfolded patient may be asked to identify when, and in what direction the test limb is being moved. Joint-position-sense may be tested by asking the blindfolded patient to actively place the test limb in a position that mirrors the passively-positioned contralateral limb. By these methods, proprioceptive acuity may be qualitatively categorized as absent, impaired or intact.[3] These labels provide broad categories that are of limited use to the interdisciplinary team during the rehabilitation process. In addition, these protocols may not be appropriate for all patient populations, particularly patients with significantly decreased range of motion, loss of motor control, or amputation.

In the clinical setting, objective measures of proprioception are important for monitoring and thus maximizing the outcomes of rehabilitation. The quantification of joint-position-sense and kinesthesia can be used to determine baseline levels, to monitor progress during rehabilitation, to compare the effectiveness of different treatment approaches and to define guidelines for acceptable treatment outcomes. Quantitative measures of proprioception are routinely achieved in the research setting. But, as Du Pont[4] has documented, the preponderance of these protocols are complex, expensive and/or lack documented validity and reliability and are therefore not practical in most clinical settings.

Purpose

The purpose of this study was to assess the validity and reliability of the JPS98, an instrument designed to quantify joint-position-sense in humans. Du Pont[4] created the JPS98 and documented the inter-rater reliability for measuring tri-planar, multiple-joint joint-position-sense of the upper and lower extremities. This instrument is a set of three clear plastic grids, hinged together, that can be used to record the position of a joint along x-, y- and z-axes. The coordinates, (x, y, z), of the joints of a limb define the static position of the entire limb as a unit.

In Du Pont's[4] JPS98 protocol for testing static joint-position-sense, the blindfolded patient attempts to move the test limb to a position that matches a pre-determined target position. First, the therapist establishes the target position by passively placing the patient's limb and holding the limb in a static position for a few seconds. After a brief rest period, the patient is asked to find the target position by actively moving the test limb to the same point in space. The procedure is videotaped with the test limb behind the clear-acrylic JPS98 grid, through which markers on the bony landmarks of the test joints can be visualized. From the videotape, the therapist records the x-, y- and z-coordinates of the joints of the test limb, first at the passive position (the target position) and then at the active position (end-point of the limb as a result of the subject's attempt to reproduce the target). By comparing the two sets of coordinates, the difference in the two positions can be quantified. This difference, the joint-position-error, is calculated using the Euclidean distance formula.[5] The joint-position-error is expressed in units of linear distance and is thus a quantitative measure of the patient's proprioceptive accuracy, or joint-position-sense.

Research Questions

1. The JPS98 system possesses face validity in that it documents the static position of a joint as bi-axial coordinate data within a single plane, or tri-axial coordinate data in three-dimensional space. When comparing the position of a joint at two discreet moments in time, the comparison of the two sets of coordinates can indeed conclude the sameness or difference of the two positions.

Du Pont's system measures the degree of sameness or difference of the passive and active positions of the test limb by computing the linear distance between the coordinates of these two positions. If the computed linear distance is equal to zero, then the two positions are the same by definition. If the passive and active positions are not identical, the linear distance, X, between the coordinates of the distal landmark on the limb is geometrically related to the angle, θ, at the reference joint by the formula

$$\frac{X}{r} = \tan \theta$$

where, r is the radius from the fulcrum of the joint to the distal landmark (Figure #1).[6]

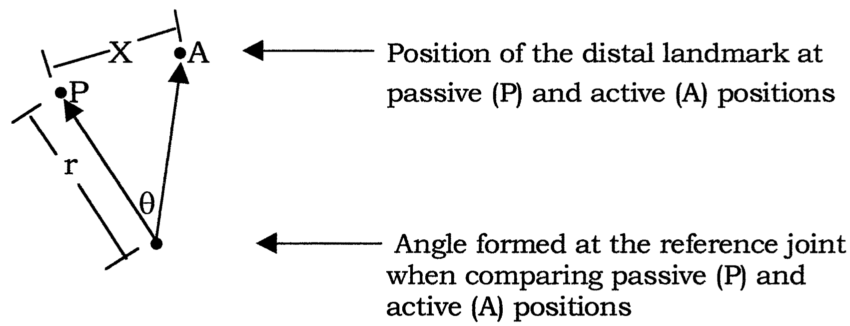


Figure #1. Geometric relationship of two alternative measures of joint-position-error. The linear distance, X, between the coordinates of the distal landmark at the passive and active positions, is geometrically related to the angle of the reference joint, θ. The linear distance is computed from JPS98 coordinate data at the passive and active positions during each trial. The angle of the reference joint is computed from Biodex data recorded at the passive and active positions.

Thus, the construct validity of the JPS98 coordinate system lies in the mathematical proofs of the Euclidean linear distance formula used to calculate the distance between two points of known coordinates. These proofs are beyond the scope of this study.

Although Du Pont addressed face and construct validity, she did not report a measure of concurrent or predictive validity for the JPS98. This study assessed the concurrent validity of the JPS98 for quantifying static joint-position-sense compared to the Biodex B-2000 Isokinetic Dynamometer, for which validity[7] and reliability[8] have been documented. Since the Biodex provides measurements in just one plane, Du Pont's[4]

JPS98 protocol was modified to assess the validity of the JPS98 for the measurement of joint-position-error in a single plane.

Research question #1.

Is the JPS98 a valid instrument for measuring uni-planar, single-joint, joint-position-error when compared to the Biodex B-2000 Dynamometer?

2. Du Pont demonstrated that the JPS98 coordinate grid system can be used to document positional deviations of a limb in three-dimensional space. In her study she tested the inter-rater reliability of physical therapists using the JPS98 based on Pearson's product-moment coefficient of correlation (r), a frequently used but relatively weak statistical test of reliability.[9] In the present study, inter-rater reliability was tested using the more rigorous statistical test, the intra-class coefficient of correlation (ICC). Although no changes were made in the JPS98 hardware, the current study protocol modifies slightly, Du Pont's coordinate scoring system in order to enhance the precision of the data. Therefore, the inter-rater reliability must be established for the modified methodology.

Research question #2.

What is the inter-rater reliability of physical therapists using the JPS98 for measuring uni-planar, single joint, joint-position-error?

3. Continuity of care by the same physical therapist throughout the rehabilitation period is the ideal situation, especially when recording and documenting objective parameters for the determination of the patient's level of recovery. Therefore, the intra-rater reliability of the physical therapist is a critical component of any methodology or instrument used to measure outcomes of rehabilitative therapies. In this study, the scores of a single rater, the principal investigator, were used to calculate the concurrent validity of the JPS98. Consequently, the principal investigator's intra-rater reliability had to be documented in order for the validity data to be credible. The ICC was the statistical measure used to assess the intra-rater reliability of the investigator.

Research question #3.

What is the intra-rater reliability of a physical therapist using the JPS98 for measuring uni-planar, single joint, joint-position-error?

Definitions

Proprioception can be defined as a specialized variation of the sensory modality of touch that encompasses the sensation of joint movement (kinesthesia) and joint position (joint-position-sense).[10]

Joint-position-sense refers to the conscious awareness of the static position of the joint.[2]

Kinesthesia refers to the conscious awareness of joint motion.[2]

Reliability is the degree of consistency [reproducibility] with which an instrument or rater measures a variable.[9]

Validity is the degree to which an instrument measures what it is intended to measure.[9]

Concurrent validity is the degree to which the outcomes on one test correlate with outcomes on a criterion test when both tests are given at relatively the same time.[9]

Predictive validity is a form of instrument validity in which an instrument is used to predict some future performance.[9]

Face validity is the assumption of validity of a measuring instrument based on its appearance as a reasonable measure of a given variable.[9]

Construct validity is the degree to which a theoretical construct is measured by an instrument.[9]

Pearson product-moment coefficient of correlation, (r), is a measure of the strength of association between two variables of interval or ratio type data.[9]

Intra-class correlation coefficient is an index of reliability that provides a measure of both agreement and consistency of ranks among ratings data.[9]

Active position is the position of the subject's test limb when the subject attempts to move the limb to a point that is identical to the target position.

Passive position, or target position, is the position of the subject's test limb determined by the tester moving the limb to a random point in space at the beginning of the trial.

CHAPTER II

REVIEW OF THE LITERATURE

Proprioception in human movement

In order for the human body to maintain stable postures and perform successful motor skills, the neural centers that plan, initiate and regulate movement require feedback as to the positions of the trunk, head and limbs relative to one another and relative to the environment. Proprioception is the collective term for the somatosensory mechanisms by which body position and movements are monitored. There are two component processes of proprioception: joint-position-sense (awareness of static position) and kinesthesia (awareness of movement). A review of the literature reveals a great deal of study on the role of proprioception in functional human movement. Much of the published research concerns proprioception in the lower extremities. However, upper extremity functions, such as bringing food to the mouth and interactions with the environment, are greatly important to the survival of the organism and a full understanding of upper limb proprioception is required as well. From a physiological perspective, what is known about proprioception is that mechanoreceptors in the skin, joints and muscles are specialized to respond to a variety of internal and external physical stimuli, in order to perform complementary roles in influencing movement. Such responses vary among cell types and in different ranges of motion. Damage to these sensory tissues may lead to deficits in proprioception possibly resulting in functional limitations of the individual. Although there are clinical implications necessitating the quantification of joint-position-sense and kinesthesia, assessments made in the physical therapy clinic are more likely to be of a qualitative nature. Currently there is no standard quantitative system for measuring proprioception in the clinical setting.

Neuroanatomy and physiology

Though scientific inquiry into the nature of joint position sense was first recorded in the sixteenth century,[11] complete agreement and understanding of this complex phenomenon is still lacking. Lephart, et al[12] equate proprioception with the somatosensory system (the detection of pain, pressure, touch, and sensation of joint distraction). They have defined proprioception as a specialized variation of the sensory modality of touch that encompasses the sensation of joint movement (kinesthesia) and joint position (joint position sense). Lattanzio and Petrella[1] have simplified the concept of proprioception by defining it as the conscious perception of limb position in space. This definition may not adequately define proprioception because somatosensory feedback is not limited to receptors in the limbs (the neuromuscular system receives sensory data about position and motion from mechanoreceptors in the trunk, head and neck as well[13,14,15]) and subcortical reflexive pathways are an important albeit subconscious component of proprioception.

The visual, vestibular, and proprioceptive sensory networks work interactively to provide information to the central nervous system (CNS) for regulating postural stability and motor control.[12] The visual and vestibular systems function to maintain an upright orientation of the head, and to provide conscious awareness of body position and balance for optimal interaction with the environment.[12,13] Vestibular sensory mechanisms detect linear and rotational motions of the head and assist in maintaining visual cues of position by influencing the control of eye musculature. Visual sensory input aids in the maintenance of balance by tracking visual reference points in the environment.[12,13] And proprioceptive input provides the basis for head, trunk and limb position relative to one another.

Proprioceptive sensory impulses leading toward the brain originate in mechanoreceptors in the skin, joints and muscles. These signals influence motor control on three levels: spinal reflexes, brainstem regulatory pathways and cortical motor programming.[12] Spinal reflexes facilitate muscle tone, co-contraction and reciprocal inhibition of agonist/antagonist muscle groups partly in response to the stimuli sensed by mechanoreceptors in muscles and tendons. Afferent signals from these sensory receptors synapse on motor neurons in the spinal cord and can modulate movements programmed in higher cortical motor centers.[13] Other afferent signals reach the brainstem and are communicated between the basal ganglia and cerebellar nuclei as part of feedback loops to the cerebral cortex to regulate and refine movement. The cerebral cortex is the center for control of voluntary movements and learned motor patterns. Initiation of voluntary movement begins in the sensorimotor and supplementary motor cortex but is influenced by afferent sensory signals.

Positron emission tomography (PET) has been used to produce images of enhanced regional blood flow to parts of the brainstem, cortex and cerebellum.[16,17] Active elbow flexion and extension resulted in increased blood flow to contralateral sensorimotor and supplementary motor cortex, ipsilateral cerebellum, basal ganglia and cingulate gyrus.[17] Passive elbow flexion and extension enhanced blood flow to the identical regions of the contralateral sensorimotor and supplementary motor cortex, although in slightly less amounts than seen with active motion. Blood flow to the basal ganglia and cingulate gyrus was not increased following passive motions of the elbow. Even imagined motions of the hand moving a joystick produced increased blood flow to areas of the ipsilateral cerebellar hemisphere and vermis of the posterior lobe.[16]

There are several types of mechanoreceptors present in the joint capsule, ligaments, bone, muscle and tendons.[13] In the joint capsule and its' supporting structures, free nerve endings, Pacinian corpuscles, Ruffini endings and Golgi tendon-type receptors are thought to be responsible for the sensation of joint position and motion.[1,11] The Pacinian receptors are fast adapting (FA) sensory cells. Once these cells fire, the action potential diminishes very rapidly and in this way they remain sensitive to changes in position. These cells are capable of detecting dynamic joint position or motion. The other joint mechanoreceptors mentioned above are slow adapting (SA) sensory cells. When SA receptors fire, the action potential is maintained in response to continuous stimuli. Thus these cells are well adapted to sensing maintained or static joint position.[2,13]

Muscle spindles are encapsulated intrafusal muscle fibers embedded in the extrafusal fibers of the muscle belly. The group Ia afferent sensory receptors of muscle spindles monitor dynamic stretch and static length of the muscle fiber. The group IIa afferents sense only static length of stretched muscle fibers. This information is shared at the spinal cord reflex level and higher up in the CNS for coordination of movement and maintenance of joint stability. The Golgi tendon organs are found at the musculotendinous junction. Group Ib afferent fibers sense tension on the muscle and function to inhibit excessive stretch of the muscle and excite the antagonist muscle in a protective mode.[13]

Until the 1970s, joint receptors were thought to be the primary sensory cells for joint position sense.[11] Currently the scientific evidence seems to indicate that muscle mechanoreceptors are the primary sensory cells and joint receptors play a more secondary role.[11,18] In his review of the evolution of thought on joint position sense, Marks[11] cites several studies in which the investigator(s) showed a decrease in joint-position-sense after having applied vibration to the muscle fibers to confuse the muscle spindles. Other investigators have reported decreases in joint-position-sense following fatigue of the agonist muscles of the test limbs.[8,14,19,20] However, removing joint receptor sensory input by intra-articular injection of anesthesia[21] or total joint replacement [22-24] did not consistently result in diminished joint-position-sense. The various joint mechanoreceptors seem to be more sensitive in specific ranges of motion.[10,13] This has been called range fractionation.[13] This is partly a protective system whereby at the end of range of motion, near the physiological limit, reflexive pathways are activated to inhibit further deformation of the joint.

The CNS may also integrate information about which receptors are activated and not activated at any given time to determine joint position.[13] Bosco et al,[25] showed that about half of all second order neurons in the dorsal spinocerebellar tract of cats encoded information about the reference frame, or position of the test-limb as a unit, rather than parameters of the individual joints of the limb. Neurons associated with storing limb-length and limb-axis data remained quiet under conditions of joint co-variances. This may help to explain the simplified control of limbs of multiple degrees of freedom.[25]

Khabie et al[21] and Voight et al[8] found no significant differences in joint-position-sense between the dominant and non-dominant limbs. Khabie's group,[21] using a Biodex dynamometer, reported mean joint-position inaccuracy of the angle of the elbow of 3.2° ± 1.6° and 2.6 ° ± 0.8° for the dominant versus non-dominant elbows respectively; no *p*-value was reported. In their study ten subjects (n = 20 elbows) were tested using a passive-reproduction of passive-positioning protocol. Voight et al[8], reported similar findings, also using a Biodex dynamometer but using a protocol of active-reproduction of passive pre-positioning studying the effect of limb dominance on joint-position-sense. No significant difference was found between the dominant and non-dominant shoulder. The lack of significant difference between dominant and non-dominant limb proprioception is relevant to the validity of joint-position-sense studies because clinical assessments of joint-position-sense frequently rely on comparisons of the left and right limbs.

Clinical Implications

Impairments of the joints and muscles due to age,[26-29] injury [30-32] or disease [33-36] have been associated with deficits in proprioception resulting in functional limitations. Pathologies in the joints of the lower extremities may result in a loss of balance, postural instability and dysfunctional locomotion. Damage to the joints of the upper extremities may result in a loss of protective reactions and fine motor skills. Interventions for these pathologies should include strategies that improve impaired somatosensory feedback mechanisms including proprioception.

Skinner et al,[26] Kaplan, et al,[27] and Petrella et al[28] found significantly diminished joint-position-sense at the knee in older compared to younger subjects. Petrella's[28] group found that these deficits were less marked in active older subjects (aged 60-86) than in age-matched subjects that were sedentary. Skinner[26] reported that joint-position-sense decreased with increasing age and may be a useful predictive indicator of age-related degenerative joint disease.

Leanderson's[31] group documented increased postural sway as a measure of decreased proprioception following grade 2 or 3 ankle sprain in ballet dancers. Payne et al,[32] using a Biodex Dynamometer, found joint-position-sense at the ankle, specifically ankle inversion, was predictive of ankle injury in college male and female basketball players, whereas ankle joint muscle strength and flexibility were not predictive of injury.

Neurological pathology such as Parkinson's disease can affect proprioception such as was demonstrated in a study by Zia, et al.[36] Patients with Parkinson's disease, who were taking appropriate medications, had diminished joint-position-sense measured by goniometry compared to controls. The authors suggest that routine neurological testing of this patient population generally fails to diagnose sensory deficits that are related to basal ganglia dysfunction.

Clinically, it is important to quantify joint position sense and kinesthesia in order to maximize rehabilitation at each level of motor control impacted. Assessment of position sense and kinesthesia is important to determine baseline levels of proprioceptive acuity, monitor progress during rehabilitation, compare the effectiveness of various interventions and to define guidelines for acceptable outcomes.

Quantifiable assessment techniques can assist the patient and clinician in understanding the level of impairment and the degree of recovery and can assist third party reimbursers in understanding the basis for treatment approaches.

Current standards of measurements

For many years investigators have studied proprioception by measuring the ability of an individual to reposition a limb to a pre-determined target position (accuracy) or by measuring the ability of the individual to detect movement of a limb (sensitivity).[20] Barrack, et al[6] showed that these two sensory modalities, joint-position-sense and kinesthesia, are closely related but are probably dependent on different neural mechanisms. In their study, professional ballet dancers showed supperior kinesthesia and inferior joint-position-sense when compared to non-dancer controls, indicating parallel but distinctly different neural mechanisms for the two component of proprioception. Thus care must be taken not to generalize proprioceptive deficits when having measured only joint-position-sense or kinesthesia.

As described by Sterner, et al, [20] two common protocols for testing joint-position-sense are active-reproduction of passive-positioning (ARPP) and active-reproduction of active-positioning (ARAP). The subject is blindfolded to remove visual cues when reproducing the target position. In ARPP, the investigator passively places the limb in the target position then, after a brief rest period in the starting position, instructs the subject to place the test limb into the same position. The procedure is similar in ARAP except the subject actively positions the test limb in the target position as well as the reproduced position. Lönn, et al [37] concluded that joint-position-sense testing results were not influenced by the type of protocol (ARPP versus ARAP) in studies of proprioception at the shoulder in horizontal abduction. A question was posed: using target matching protocols, does the concentric muscle contraction during the target positioning phase increase afferent signals from muscle spindles, thus boosting proprioceptive input? When the target was presented passively, they found no difference in joint-position-sense results between active and passive matching.

Much of the research on proprioception has focused on joints of the lower extremity. [6,24,33,38-40] The loss of good balance and locomotion are considered potentially severe functional limitations that may result in disabilities. In addition, many sport- and leisure-related injuries affect the lower extremity; thus there is tremendous interest in the rehabilitation of the ankle and knee, particularly the cruciate ligaments of the knee. However, the importance of upper extremity proprioception has inspired several interesting studies as well.

Verschueren, et al[41] measured proprioception of the upper extremity in a study of the CNS control of spatial and temporal characteristics of unimanual circle drawing. Subjects repeatedly and quickly drew circles with the dominant arm while investigators studied the constancy of hand movements in the x- and y-coordinates. Results indicated that even though the biceps were activated minimally, vibratory impedance of the mechanoreceptors of the biceps diminished circularity of the drawings. The authors suggest that these muscles are acting as sensory transducers independently of motor activity level. Saxton, et al[42] and Brockett, et al[43] have demonstrated the detrimental effects of eccentric exercise on joint position sense. Saxton's group[42] measured the ability of subjects to interpret the position of the elbow following 50 maximal eccentric contractions of the forearm flexors. This study examined the effects of muscle fatigue on proprioception and demonstrated that joint position sense is diminished following maximal eccentric exercise. Brockett's study[43] compared the effect of concentric versus eccentric exercise on joint-position-sense testing. Subjects concentrically contracted the elbow flexors of one arm then eccentrically released the load with the second arm. To assess joint position sense, the subject attempted to match the position of the reference limb with the test limb. A larger absolute error was associated with eccentric exercise. The authors discuss the clinical implications of testing proprioception keeping in mind the relative muscle fiber damage associated with eccentric versus concentric exercise.

Several of the studies cited above have incorporated the use of electronic instrumentation such as the Biodex Dynamometer (Biodex Corporation, Shirley, NY, USA) for quantifying various parameters of human movement. The Biodex can measure limb motion under isometric, isotonic and isokinetic conditions, yielding digital output such as lever-arm angular velocity, linear accelerations and subject-generated torque. One function of the Biodex is to act as an electronic goniometer documenting the angle of the test-joint as a quantitative measure of the position of the test limb. The Biodex has been shown to be a valid[7] and reliable[8] instrument for the purpose of joint-position quantification. The Biodex is ideal for testing the joint-position of a uni-axial, hinge joint such as the elbow, and thus was chosen as the gold standard with which to assess the concurrent validity of the JPS98 for quantification of static joint-position-sense.

Chapter summary

Proprioception is a vital function of the somatosensory system that provides feedback as to the position of the head, trunk and limbs in space for maintaining postural stability and influencing motor control.

Through scientific inquiry, two parallel yet distinct component processes of proprioception, joint-position-sense and kinesthesia, have been identified. Age, injury and disease may interrupt the function of mechanoreceptors in skin, muscle and joint tissues thus impairing proprioception and leading to functional impairments in patients seeking physical therapy for orthopedic or neurological pathologies. Although there are clinical implications for quantifying joint-position-sense, quantitative instrumentation is more likely to be used in the research setting. The JPS98 has been proposed as a simple and inexpensive quantitative tool for use in most physical therapy clinical settings. This study tested the concurrent validity and inter- and intra-reliabilities of the JPS98 for use in the clinic.

CHAPTER III

METHODS

Subject Inclusion/Exclusion Criteria

A sample of convenience consisting of healthy, physically active individuals was recruited from the SWT campus and surrounding communities. Volunteers had to be 18 years of age or older and had to cognitively understand the instructions for the test procedure. The subjects had to have full, pain-free range-of-motion (ROM) in the test limb, no symptoms consistent with UE pathology and a manual muscle test (MMT) score of 3+/5 or greater for the elbow flexors and extensors. Additional requirements were the ability to perform the procedure, including tolerating a blindfold and sitting upright in the Biodex chair for up to five minutes. Males and females over a wide age-range were included. Studies have shown age-related [26-29] and sex-related,[44] differences in proprioceptive acuity.

Rater Inclusion/Exclusion Criteria

Raters had to be physical therapists or physical therapist students in order to participate. This requirement was to ensure that the raters would be a representative sample of the population of individuals who might use the JPS98 in the clinical setting. Volunteer raters also had to be willing to be trained in the scoring procedure for the JPS98 and had to be willing to score all of the videotaped joint-position-sense trials.

Instrumentation

JPS98

The JPS98, created by Du Pont,[4] is a three-sided apparatus constructed of 0.60 cm thick, clear acrylic sheeting with a grid system mapped out on each face. The grid was created with 0.30 cm black vinyl tape evenly distributed every 4.5 cm. Two of the sides measure 92.6 x 78.1 cm and represent x- and y-axes of the sagittal plane. The third grid, which connects the first two, measures 92.6 x 24.5 cm and represents the z- and y-axes of the coronal plane. The three sides are assembled with two, 2-inch, double continuous-style hinges allowing the instrument to be folded for ease of transport and storage. The instrument can be placed around a patient's upper or lower limb for testing. As the patient moves the limb in space, an observer can view the bony landmarks through the clear grid system and document the two-dimensional coordinates of the joint in each of the three planes (Figure 2).

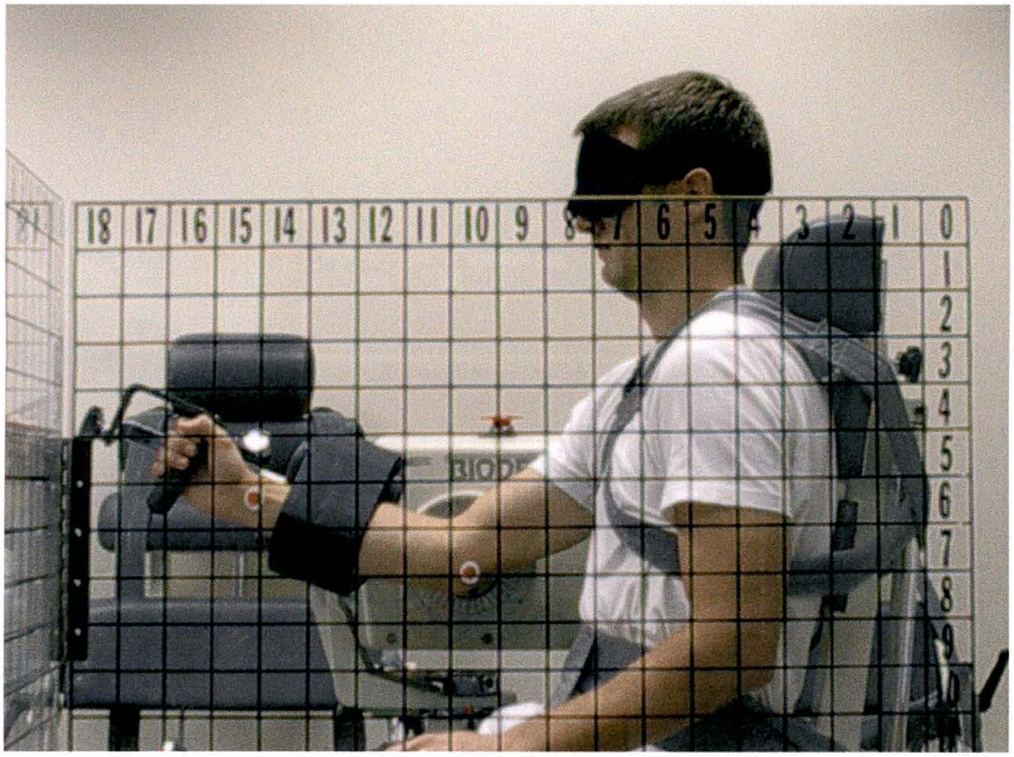


Figure 2. Photograph of a subject from the present study. The JPS98 (clear grid in the foreground) is positioned so that the coordinates of the joints can be documented in various static positions. Only one of the three faces of the JPS98 is pictured here.

In Du Pont's[4] protocol for using the JPS98, a physical therapist passively placed the blindfolded patient's test limb in a target position (passive position). The patient was then asked to actively move the limb to a position that matched the target (active position). Du Pont[4] documented the sagittal (x, y), and coronal (z, y) coordinates of the joints at the passive and active positions. The coordinates for the transverse plane (z, x) were then defined by combining the coronal (z, y) and sagittal (x, y) coordinates. Thus, a single three-dimensional set of coordinates was defined for the passive position (x_p, y_p, z_p) and the active position (x_a, y_a, z_a). Using Euclidean geometry, as suggested by Hair et al,[5] Du Pont[4] calculated the linear difference between the passive and active positions. The absolute value of the difference between these two coordinate points defined the joint-position-error in units of linear distance.

Biodex B-2000 Isokinetic Dynamometer

In this study, the Biodex B-2000 Isokinetic Dynamometer (Biodex Corporation, Shirley, NY, USA) was used as the "gold standard" against which to test the concurrent validity of the JPS98. The Biodex was used to measure the angle of elbow flexion in the passive and active positions. The absolute value of the difference between these two angles defined the joint-position-error in units of angular degrees.

As per the manufacturer's suggested use, the Biodex was used in isokinetic mode, with a sensitivity of 'C' and a soft cushion for the 'stop' at the end of each range of motion. A speed of 450°/sec was selected for direction 1 (elbow moving into flexion) and direction 2 (elbow moving into extension) to allow for resistance-free motion of the test limb. The elbow range-of-motion limits were held constant for each subject and the height of the Biodex powerhead remained constant for all subjects.

Study Design

This study was a quasi-experimental, repeated-measures design whereby joint-position-error was the dependent variable and instrumentation (JPS98 or Biodex) was the independent variable. The same group of subjects was tested with both the JPS98 and the Biodex, simultaneously. Thus, each subject was his own control.

Procedure

The purpose and nature of the study were explained to each subject. Each subject then read and signed the voluntary informed consent (Appendix A) and completed the written eligibility-screening instrument (Appendix A). Basic demographic and other data were collected including sex, age, height, weight, hand dominance, history and current symptoms of right upper extremity pathology, medications taken, vocational and recreational activities, and exercise activities undertaken in the hours prior to testing. Active and passive range-of-motion of the elbow, cutaneous sensation of light touch (using a cotton ball), and manual muscle testing and muscle spindle reactions (MSR) of the biceps and triceps were measured on both upper extremities immediately prior to the trials. The principal investigator, a second-year physical therapy student, performed the physical screening measurements.

Positioning the Subject in the Biodex Apparatus

The Biodex has multiple attachments to accommodate the testing of various limbs. For this study, the right-elbow attachment was used to test right elbows. The lever-arm length (distance from the elbow to the grip-handle) of the right-elbow attachment was adjusted to the length of the subject's right forearm before the attachment was mounted on the Biodex powerhead. The subject was then seated in the Biodex chair with the right shoulder flexed forward in the sagittal plane and the arm placed in the right-elbow-attachment (Figure 2). The subject was asked to firmly grasp the grip-handle and rest the arm in a neutral pronation/supination position. The seat height and position were adjusted until the medial epicondyle of the subject's test elbow was centered at the axis of rotation of the Biodex powerhead. The subject was secured in the chair harness and the test arm was securely strapped in the right-elbow attachment. Finally, the seat wheels were locked to secure the position of the subject's trunk and to prevent movement away from this position during active flexion of the test elbow. The starting positioning of the test arm was with the shoulder forward-flexed to $38.63 \pm 6.08°$ and the elbow flexed to $49.84 \pm 6.61°$ from full extension (Figure 2).

Marking the bony landmarks and positioning the JPS98

Adhesive markers were applied to the subject's right arm at the medial epicondyle of the elbow and midway between the styloid processes of the ulna and radius on the volar aspect of the wrist. The markers were approximately one-inch in diameter with a white outer ring surrounding a red circle one-half inch in diameter. The JPS98 grid was positioned parallel to, and as close as possible to (16.57 ± 1.58 inches) the medial side of the subject's test arm. The videocamera was positioned perpendicular to and as close as possible (91.42 ± 1.46 inches) to the JPS98 grid to optimize the view of the subject and markers throughout the videocamera viewfinder.

Joint-position-sense trials

At the beginning of each day of the trials, the Biodex dynamometer was warmed up for 30 minutes and then calibrated. Before proceeding with the trial, the subject was reminded of the sequence of the protocol and given a final opportunity to ask questions. The weight of the subject's arm was electronically tared and then the subject was blindfolded. The starting position was with the elbow positioned at the end of the range-of-motion in direction 1 (Figure 3).

The protocol was that of active-reproduction-of-passive-positioning (ARPP)[20] of the right elbow joint. This protocol was modified from that used by Khabie et al[21]. The investigator passively positioned the subject's right forearm to a random target angle (passive position) in the sagittal plane and held it there for five seconds before passively returning the forearm to the starting position. After a five second rest, the subject was instructed to "find that angle." The subject then actively reproduced the target position, and held the test arm in this position (active position) for five seconds before the investigator passively returned the forearm to the starting position (figure 3).

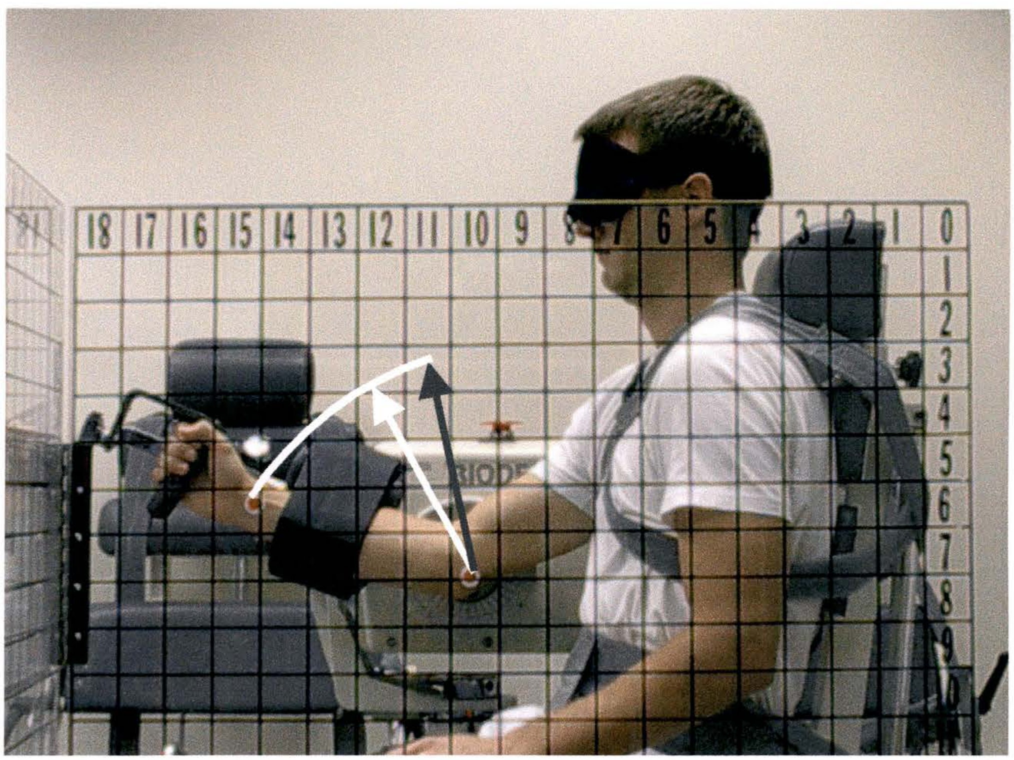


Figure 3. Subject seated at Biodex with arm placed in the right elbow attachment and medial epicondyle centered at the axis of rotation of the Biodex powerhead. The JPS98 grid is positioned to document coordinates of the distal landmark as it rotates through the arc of flexion to the endpoint at the active and passive positions (arbitrarily assigned as the white arrow and black arrow, respectively, in the photo).

Each subject performed three to four cycles of the ARPP sequence. Voight et al[8] and Khabie et al[21] have determined that there is no significant difference in the joint position sense of the dominant and non-dominant shoulder and elbow, respectively. Therefore, for simplicity, only the right arm was tested.

The investigator used a randomly chosen target position for each trial. At the end of the five-second hold in the passive and active positions, the investigator recorded the angular degrees of elbow flexion from the Biodex data output. This raw data was degrees of elbow flexion relative to the starting position. All trials were videotaped with the subject behind the JPS98 and with the markers visible through the clear grid.

Following completion of the trials, all settings on the Biodex, the seat height, and the positions of the test elbow and shoulder joints in the sagittal plane were recorded by the principal investigator before the subject's arm was removed from the apparatus.

Data analysis

Calculation of joint-position-error from JPS98 data

Four volunteers and the principal investigator, all students of the SWT MSPT program, rated the joint-position-error from the JPS-98 data.

Each rater watched the videotaped trials of all of the subjects and recorded on paper the x- and y-coordinate positions of the 1" markers on the elbow and wrist for each passive and active position.

Each rater recorded the x- and y-coordinates of the wrist marker at: 1) the starting position, 2) at the passive position, 3) upon return to the starting position, 4) at the active position and 5) upon return to the starting position at the end of each cycle. The coordinates of the elbow marker were also recorded before and after each excursion of the forearm to document the stability of the elbow joint in the Biodex apparatus.

In Du Pont's original protocol, the coordinates (x, y, z) were whole integers corresponding to the specific window of the grid in which the bony landmark was visualized. To increase the sensitivity of the JPS98 methodology, in the current study, the scale of the coordinate grid was modified to allow for fractions of a grid unit to be recorded. Uniform written instructions were provided to each rater (Appendix B). The rater was instructed to visualize each grid window subdivided into four quadrants, A, B, C, and D. Each of these quadrants were then further subdivided into four quadrants, a, b, c, and d, making a total of sixteen subdivisions. Thus, the rater would record the x- and y-coordinate, the large quadrant (A, B, C, or D) and the small quadrant (a, b, c, or d) for each marker at each stage of the trial. This data was recorded on a uniform data record (Appendix B).

The x- and y-values of the wrist marker at the passive and active positions were entered into a spreadsheet for computation of joint-position-error in linear distance units. Each JPS98 grid unit is 4.5 cm in length. In order that all potential users of the JPS98 system interpret the results similarly, the linear distance data were left in the form of JPS98 units and was not converted to other units for the calculation of joint-position-error. It is not necessary that joint-position-sense be measured in a particular system of units such as centimeters or inches because the displacement of the distal landmark of the test limb is relative to the reference joint.

For each of the three to four attempts per subject, the x- and y-coordinates for the passive position (x_p and y_p) were entered into separate cells of the spreadsheet. Similarly, the coordinates for the active position (x_a and y_a) were entered into separate cells. The spreadsheet was formatted so that the software calculated the absolute error of each attempt, and then calculated the mean error of all attempts for each subject. The non-directional or absolute value of joint-position-error of each individual attempt, (linear error), was calculated by the formula:

$$\text{linear error} = \sqrt{(x_p - x_a)^2 + (y_p - y_a)^2}$$

The mean joint-position-error of all attempts for each subject, (mean linear error) was calculated by the following formula:

$$\text{mean linear error} = \frac{(\text{linear error}_1 + \text{linear error}_2 + \ldots.\text{linear error}_m)}{m}$$

where (m) is the number of attempts performed by the subject.

Calculation of joint position error from Biodex data

The Biodex output was the displacement of the forearm measured in degrees of elbow flexion relative to the starting position. The amount of elbow flexion at the passive and active positions was recorded on paper by the investigator, and then entered into a spreadsheet for computation of joint-position-error. Raw data for each of the three to four attempts were entered into separate cells of the worksheet. The spreadsheet was formatted so that the software calculated the absolute error of each attempt, and then calculated the mean error of all attempts for each subject. The non-directional or absolute value of joint-position-error for each individual attempt, (angular error °), was calculated by the formula:

$$\text{angular error}^\circ = [\text{passive position}^\circ - \text{active position}^\circ]$$

The mean joint-position-error of all attempts for each subject, (mean angular error °), was calculated by the following formula:

$$\text{mean angular error}° = \frac{(\text{angular error}_1° + \text{angular error}_2° + ..\text{angular error}_m°)}{m}$$

where (m) is the number of attempts performed by the subject.

Statistical analysis

Validity of the JPS98

In this study, joint-position-sense at the elbow was defined as the ability to proprioceptively "memorize" and then actively reproduce a passively determined position of the forearm around the axis of the elbow joint in the sagittal plane. The subject's accuracy in attempting to find this target position was quantified in two parameters, angular degrees at the elbow and linear distance of the wrist marker. Concurrent validity was tested by simultaneously measuring static joint-position-sense using the JPS-98 and the Biodex dynamometer.

First, the joint-position-error was measured directly by the Biodex and documented as the difference between the passive and active positions in angular degrees of elbow flexion. This measure was the reference criterion.

Concurrently, the JPS98 was used to measure the joint-position-error as the linear displacement of the wrist marker as recorded on videotape and scored by the principal investigator. The difference between the passive and active positions was calculated by applying the Euclidean distance formula to the x- and y-coordinate values of the marker placed on the wrist. The principal investigator scored the videotaped trials on three separate occasions at one-month intervals.

The validity of the JPS98 was determined by assessing the correlation of each of the three JPS98 datasets scored by the investigator with the Biodex dataset. Correlation was determined using Pearson's product-moment coefficient of correlation (r). Throughout this study, all statistical tests were performed using SPSS ver. 10.0 statistical software.

Inter-rater reliability of the JPS-98

In this study the inter- and intra-rater reliabilities of the JPS98 were measured using intra-class coefficients (ICC). The intra-class coefficient provides a precise and comprehensive statistical test of reliability.[9] The ICC satisfies the concept of the generalizability theory that proposes that differences among data can be attributed to factors other than true variance and random error. In this study, such factors may have been the temperature of the room, the mood of the subjects, the noise level of the testing room and so forth.

The ICC was calculated using variance estimates derived from a repeated measures analysis of variance (ANOVA). The ANOVA partitions the variance in the data that is due to the subjects, the five raters and random error, thus providing for a measure of correspondence and agreement among the data. Portney and Watkins[9] cite Shrout and Fleiss' three models for using the ICC for reliability testing based on the nature of the study, and the number of scores per subject (k). In this study the investigator employed ICC model (2, k), used most frequently for inter-rater reliability studies in which all n subjects are rated by all of the raters.[9] It is useful when several scores for each subject are averaged for use in the reliability statistic:

$$\text{ICC}\,(2,k) = \frac{\text{BMS} - \text{EMS}}{\text{BMS} + \dfrac{(\text{RMS} - \text{EMS})}{n}}$$

where BMS is the between-subjects mean square, RMS is the between-raters mean square, EMS is the error mean square and n is the number of subjects tested. The mean-squares values are reported in the repeated-measures ANOVA table performed on the JPS98 data recorded by several raters.

Intra-rater reliability of the JPS-98

As described above, the investigator watched the videotaped trials and scored all of the subjects' performances three times. The investigator's intra-rater reliability was assessed by calculating the intra-class coefficient of correlation of these three sets of scores. The ICC was chosen for the same reasons as described for the inter-rater reliability section. Portney and Watkins[9] recommend Shrout and Fleiss' model three, ICC (3, *k*), for intra-rater reliability. It can be used for measuring the reliability of data when it is not the intent to generalize the outcome to a larger population. Such is the case in this study, where a single rater's scores have been used to determine the validity of an instrument and beyond that purpose this rater's reliability is not to be generalized to a larger population. The ICC (3, *k*) formula is given:

$$\text{ICC }(3,k) = \frac{\text{BMS - EMS}}{\text{BMS}}$$

where BMS is the between-subjects mean square and EMS is the error mean square. Again, these mean-squares values are reported in the repeated-measures ANOVA table performed on the three datasets scored by the principal investigator.

CHAPTER IV

RESULTS

Description of the sample population

Demographics of the sample population are presented in Table #1. Fifteen males and twenty-eight females (n=43) participated in the study. Participants were screened for signs and symptoms of injury or other pathology involving the right upper extremity or cervical spine. None of the subjects were receiving physical therapy or other treatment for the right upper extremity. One male subject had a history of right shoulder subluxation eight years prior to the study but had not experienced symptoms in several years. Three subjects had a history of symptoms involving the cervical spine or chronic back pain, but that did not include symptoms of the right upper extremity.

Candidates for the study were asked about medications they were currently taking as an indirect way of determining general health status. Nineteen subjects (44.2%) had taken some medication on the day of the trials that may or may not have affected joint-position-sense. Seven of the female subjects (25%) were taking oral birth control. One male was taking Monopril for the control of blood pressure and one female was taking Vasotec for the treatment of renal insufficiency. A total of one person each was taking the one of following medications: Paxil, Celebrex, Aleve, Tylenol, or Advil none of which were indicated for right upper extremity pathology. Four subjects (9.3%) were currently taking a nasal decongestant or asthma-related medications.

Table #1. Demographics of sample population.

Total Subjects, n= 43					
Sex			Dominant Arm		
Male	15	35%	Right	42	98%
Female	28	65%	Left	1	2%
Age in years			Physical Activity		
Range	22-46		0 hr/wk	4	9%
Mean	28		1-3 hr/wk	15	35%
Median	24		3+ hr/wk	24	56%

Results for Research Question #1.

To determine if the JPS98 is a valid instrument for measuring joint-position-sense at the elbow, the principal investigator viewed the JPS98 videotaped trials on three separate occasions, with one-month intervals between each scoring. Each JPS98 joint-position-error dataset (labeled score_1, score_2, and score_3, respectively) was correlated with the Biodex joint-position-error data set.

The average absolute joint-position-error scores for all subjects from the three JPS98 data sets (score_1, score_2, and score_3) and the Biodex dataset are presented in Appendix C. Table #2 below, presents the mean, standard deviation (SD), minimum and maximum joint-position-error values of all n = 43 subjects for each of the three JPS98 data sets and the Biodex data set. A plot of the frequency of the joint-position-error scores for all n = 43 subjects for each data set is presented in Figures #4 through #7.

Table #2. Concurrent Validity: Joint-position-error scores. Three JPS98 datasets scored by the investigator and the Biodex dataset.

Data set	n	Mean (SD)	Min	Max
JPS98 score_1	43	0.406 (0.176)	0.083	0.943
JPS98 score_2	43	0.415 (0.182)	0.083	0.943
JPS98 score_3	43	0.420 (0.177)	0.083	0.943
Biodex	43	4.770 (2.369)	1.00	11.00

Joint-position-error is represented as linear distance units (JPS98 data) or angular degrees (Biodex data).

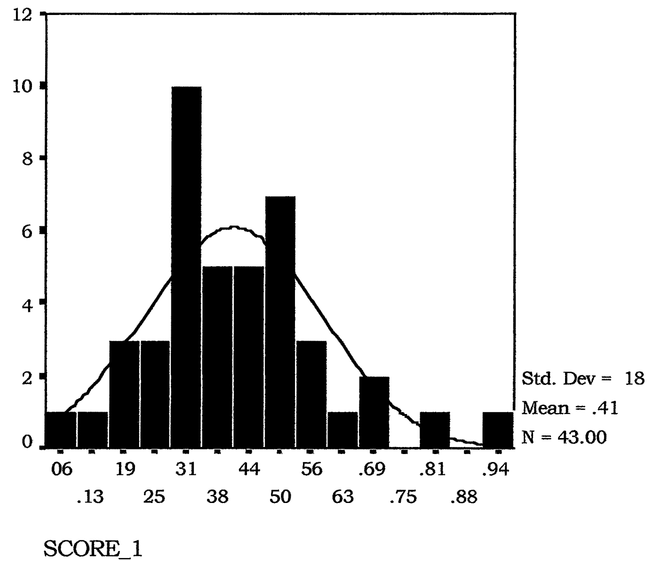


Figure #4. Frequency of JPS98 joint-position-error values for all n=43 subjects from first JPS98 data set (score_1), with normal curve superimposed. Values are linear distance units.

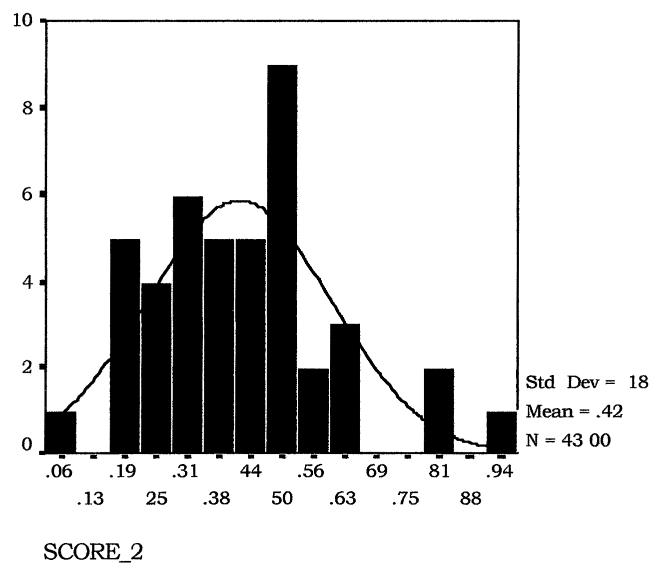


Figure #5. Frequency of JPS98 joint-position-error values for all n=43 subjects from second JPS98 data set (score_2), with normal curve superimposed. Values are linear distance units.

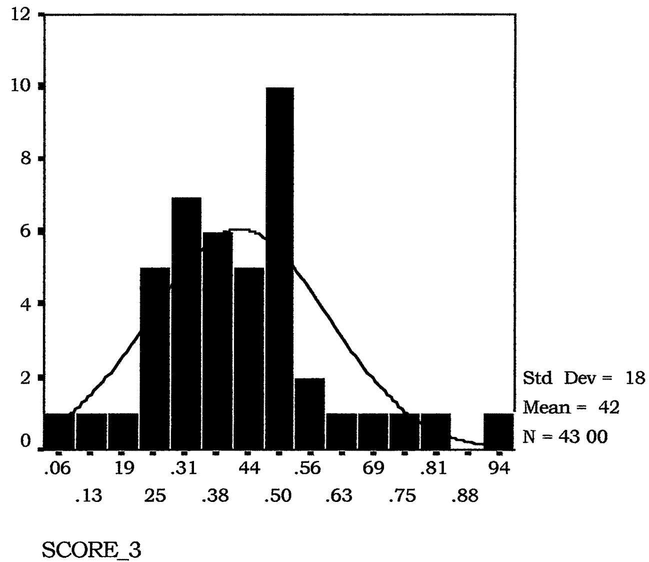


Figure #6. Frequency of JPS98 joint-position-error values for all n=43 subjects from third JPS98 data set (score_3), with normal curve superimposed. Values are linear distance units.

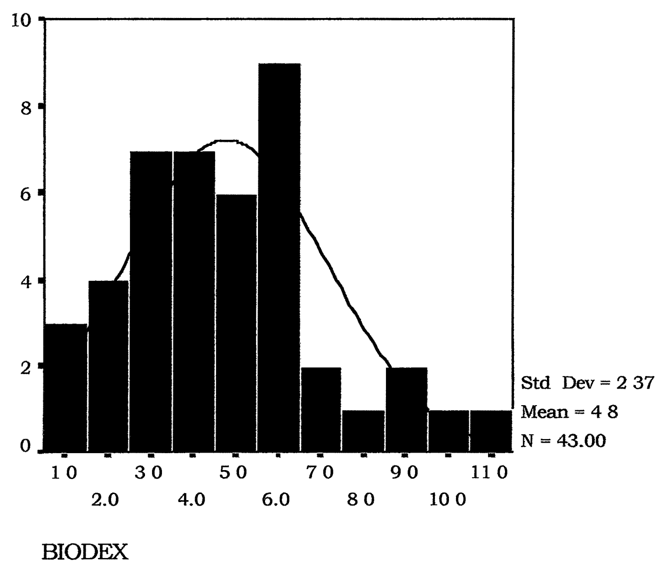


Figure #7. Frequency plot of Biodex joint-position-error values for all n=43 subjects with normal curve superimposed. Values are angular degrees.

Comparison of each of the three sets of JPS98 scores (score_1, score_2, and score_3) with the Biodex scores resulted in Pearson product-moment coefficients of correlation, [r_{score_1}] = 0.89, [r_{score_2}] = 0.87 and [r_{score_3}] = 0.90, respectively, indicating good to excellent concurrent validity,[9] Table #3. Correlation values were significant to the .01 level. (Graphic representations of the correlation of each of the three JPS98 datasets versus the Biodex dataset are presented in Appendix C.)

Table #3. Concurrent Validity: Correlation of joint-position-error scores, JPS98 datasets and Biodex dataset. Pearson product-moment correlation, (r).

	JPS98 score_1	JPS98 score_2	JPS98 score_3
Biodex	0.890	0.869	0.903
Sig.(2-tailed)	0.000	0.000	0.000
n	43	43	43

Correlation is significant at the 0.01 level (2-tailed)

Results of research question #2.

To determine the inter-rater reliability of physical therapists using the JPS98 grid system, five raters viewed the videotaped trials and scored the joint-position-error of all n=43 subjects. The average absolute joint-position-error scores for all subjects recorded by the five raters (Rater#1, Rater#2, Rater3#, Rater#4 and Rater#5) are summarized in Appendix D.

Table #4 below, presents the mean, standard deviation (SD), and minimum and maximum joint-position-error values of all n = 43 subjects scored by the five raters (JPS98 datasets, Rater#1, Rater#2, Rater3#, Rater#4 and Rater#5) and the Biodex dataset. A plot of the frequency of the joint-position-error scores for all subjects recorded by each of the five raters is presented in Figure #8 through Figure #12.

Table #4. Inter-rater reliability: Joint-position-error scores. Five JPS98 datasets scored by the five raters and the Biodex dataset.

Data set	n	Mean (SD)	Min	Max
Rater#1	43	0.406 (0.176)	0.083	0.943
Rater#2	43	0.410 (0.212)	0.083	0.875
Rater#3	43	0.420 (0.217)	0.000	0.951
Rater#4	43	0.407 (0.206)	0.118	0.943
Rater#5	43	0.454 (0.212)	0.083	1.030
Biodex	43	4.770 (2.369)	1.00	11.00

Joint-position-error is represented as linear distance units (JPS98 data) or angular degrees (Biodex data).

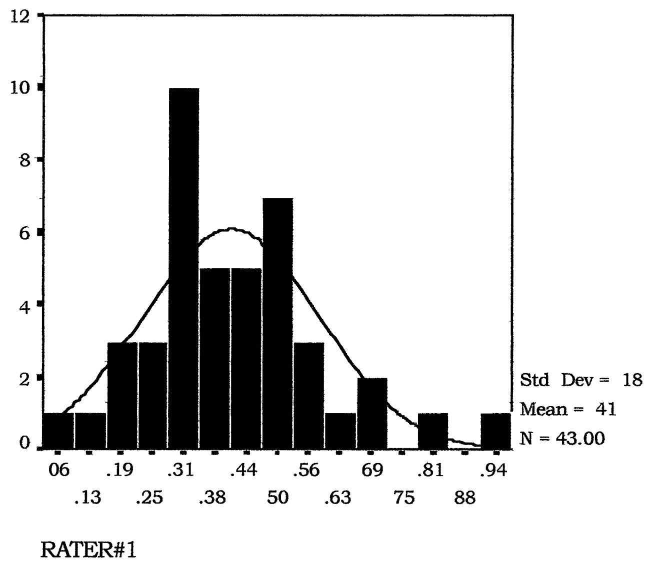


Figure #8. Frequency of JPS98 joint-position-error values for all n=43 subjects scored by Rater#1, with normal curve superimposed. Values are linear distance units. (Data set is the same as JPS98 score_1 scored by principal investigator used for concurrent validity.)

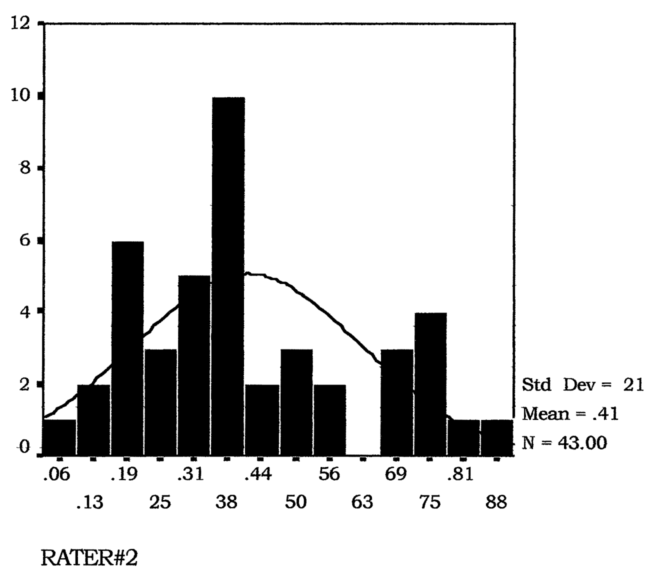


Figure #9. Frequency of JPS98 joint-position-error values for all n=43 subjects scored by Rater#2, with normal curve superimposed. Values are linear distance units.

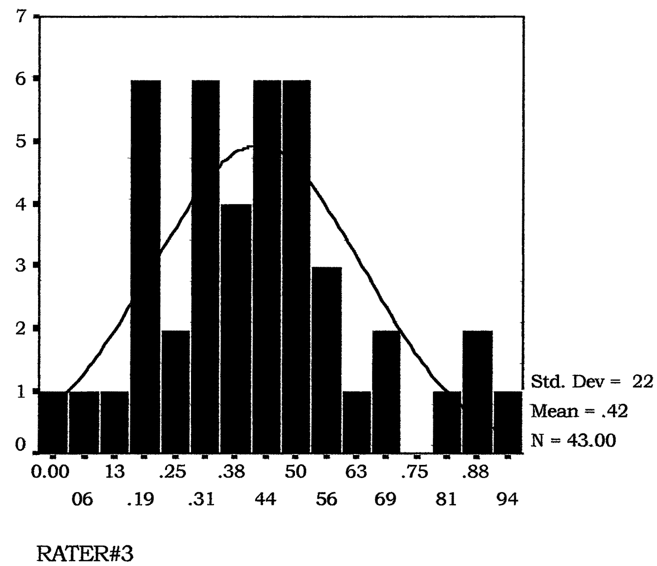


Figure #10. Frequency of JPS98 joint-position-error values for all n=43 subjects scored by Rater#3, with normal curve superimposed. Values are linear distance units.

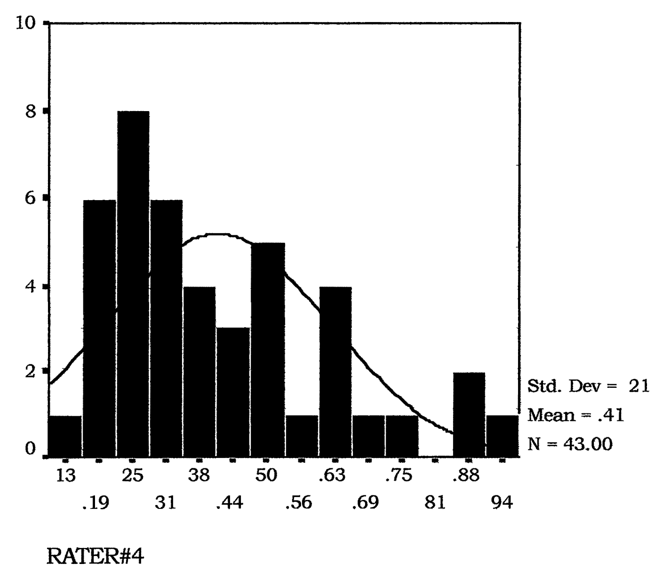


Figure #11. Frequency of JPS98 joint-position-error values for all n=43 subjects scored by Rater#4, with normal curve superimposed. Values are linear distance units.

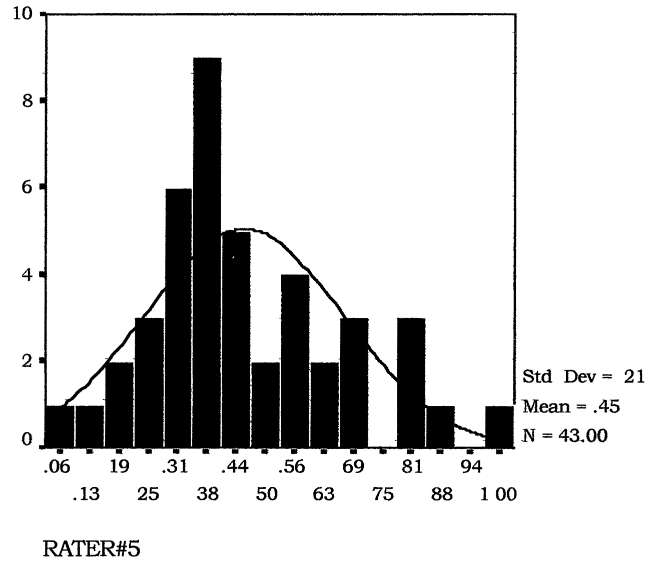


Figure #12. Frequency of JPS98 joint-position-error values for all n=43 subjects scored by Rater#5, with normal curve superimposed. Values are linear distance units.

Though not used for reliability measures, the Pearson product-moment coefficients of correlation, (r) for all possible combinations among the five raters' JPS98 joint-position-error datasets and the Biodex dataset, as well as a graphic representation of each correlation, are presented in Appendix D.

Correlations of the JPS98 scores of Rater#1, Rater#2, Rater#3, Rater#4 and Rater#5 with the Biodex scores resulted in Pearson product-moment coefficients of [$r_{\text{Rater\#1}}$] = 0.89, [$r_{\text{Rater\#2}}$] = 0.80, [$r_{\text{Rater\#3}}$] = 0.73, [r Rater#4] = 0.84, and [r Rater#5] = 0.75. Correlation values were significant to the .01 level. Four of the five rater's scores were in good to excellent agreement [9] with the Biodex data ($r \geq 0.75$) with only Rater#3 demonstrating fair to good agreement, ($r = 0.73$), with the Biodex.

The joint-position-error data was analyzed by a repeated measures analysis of variance (ANOVA), with raters as the independent variable. The variance in the data due to differences between subjects, due to differences between raters and due to error was partitioned by the ANOVA. In this analysis, the rater effect, the variance due to raters, was not significant, F-ratio = 1.6936, ($p = 0.1538$). The results indicate a good reliability [9] among the five raters' scores, ICC (2, k) = 0.9382, (95% lower confidence level = 0.9035). The ANOVA results and the ICC (2,k) calculation are presented in Table # 5, below.

Table #5. Inter-rater reliability: Analysis of Variance Table (ANOVA) for joint-position-error scores by k = 5 raters for n = 43 subjects.

Source of Variance	df	SS	MS	F	p
Between Subjects	42	7.1052	0.1692		
Within Subjects					
Between raters	4	0.06967	0.01742	1.6936	0.1538
Error	168	1.7278	0.0103		

Note: df, degrees-of-freedom; SS, sums of squares; MS, mean squares; F, F-ratio; p, p-value.

$$\text{ICC }(2, k) = \frac{\text{BMS} - \text{EMS}}{\text{BMS} + \dfrac{(\text{RMS} - \text{EMS})}{n}}$$

$$\text{ICC }(2, k) = \frac{(0.1692 - 0.0103)}{(0.1692) + \dfrac{(0.01742 - 0.0103)}{43}}$$

$$\text{ICC }(2, k) = 0.9382 \text{ (95\% LCL = 0 9035)}$$

Computation of ICC model (2, k) based on a repeated measures analysis of variance of several raters across n = 43 subjects. Note: BMS indicates between-subjects mean squares; EMS, error mean square; RMS, between-raters mean square, n, number of subjects tested.

Results of research question #3.

To determine the intra-rater reliability of the JPS98 grid system, the intraclass correlation coefficient (ICC) was computed for the same three JPS98 data sets (score_1, score_2, and score_3) scored by the principal investigator and analyzed for the validity portion of the study. The joint-position-error data (Appendix C) were analyzed using a repeated measures analysis of variance (ANOVA), with ratings (data sets scored on different dates) as the independent variable. In this analysis, the variance due to the three ratings performed on three different occasions, was not significant, F-ratio = 1.1166, (p = 0.3322). The results indicate good reliability among the three sets of scores, ICC (3, k) = 0.9808, (95% lower confidence level = 0.9682).[9] The ANOVA results and the ICC (3, k) calculation are presented in Table # 6, below.

Table #6. Intra-rater reliability: Analysis of Variance Table (ANOVA) for joint-position-error scores for k = 3 ratings for n = 43 subjects.

Source of Variance	df	SS	MS	F	p
Between Subjects	42	3.8537	0.0918		
Within Subjects					
Between ratings	2	0.0039	0.0020	1.1166	0.3322
Error	84	0.1479	0.0018		

Note: df, degrees-of-freedom; SS, sums of squares; MS, mean squares; F, F-ratio; p, p-value.

$$\text{ICC }(3, k) = \frac{\text{BMS - EMS}}{\text{BMS}}$$

$$\text{ICC }(3, k) = \frac{(0.0918 - 0.0018)}{(0.0918)}$$

ICC (3, k) = 0.9808 (95% LCL = 0.9682)

Computation of ICC model 3 based on a repeated measures analysis of variance of several ratings across n = 43 subjects. Note: BMS indicates between-subjects mean squares; EMS, error mean square.

CHAPTER V

DISCUSSION AND CONCLUSIONS

Discussion Overview

In the research setting many methodologies have been used to quantify proprioception as either joint-position-sense or kinesthesia. As Du Pont[4] has illustrated, most of these methods are excessively complex and expensive, or lack proof of validity and reliability. As a result of this absence of a standard, reliable and inexpensive quantitative technique, physical therapists rely on subjective qualitative assessment techniques or fail to test proprioception at all.

The JPS98 was designed to be an inexpensive and practical system for quantifying joint-position-sense that could serve as a standard tool suitable for the clinical setting. The results of this study demonstrated that the JPS98 provided joint-position-error measurements of the elbow statistically similar to measurements obtained by the Biodex B-2000 Isokinetic Dynamometer. The results also indicate that there were no statistically significant differences among or between the JPS98 data recorded by the raters, as intra- and inter-rater reliability measures, respectively, when scoring the subjects' joint-position-error from the videotaped trials.

The Biodex B-2000 Isokinetic Dynamometer was chosen as the "gold standard" for quantifying joint-position-sense because it has been used in many published studies and has been shown to be a valid[7] and reliable[8] instrument. There were advantages and disadvantages inherent in the selection of the Biodex as the criterion instrument. The configuration of the Biodex apparatus allowed the positioning of the video camera (as part of the JPS98 instrumentation) along the axis of rotation and perpendicular to the arc-of-flexion of the subject's elbow in the sagittal plane. This configuration made it possible to measure the subjects' proprioception with both the JPS98 and Biodex at the same time with each subject serving as his own control. The fact that the two protocols could be executed simultaneously was an advantage over other study designs yielding measurements from each instrument at different points in time. A disadvantage of using the Biodex was that the raw data (angular degrees of the test elbow at the passive and active positions) had to be read from the Biodex monitor and manually recorded on paper by the investigator. Although the Biodex read-out was digital integer data, the available version of Biodex software did not allow for direct print-outs of the elbow angle.

Sample characteristics

Although the volunteers were self-selected from among young, healthy physically active individuals representing a relatively homogeneous sample population, the joint-position-sense data recorded for the sample was sufficiently heterogeneous to provide a measurable level of variance with which to compare the two instruments. The JPS98 and Biodex scores for the 43 subjects approached the normal distribution as seen in the frequency plots of joint-position-error scores (Figures 4-7).

As previous studies have shown, deficits in proprioception are associated with increasing age,[26-29] injury [30-32] or disease.[33-36] Because of the lack of injury or disease and the small age range of this sample (range from 22 - 46, with a mean age of 28 years) there existed the danger that the joint-position-sense data could have been of insufficient variability to be useful in demonstrating reliability measures.

Subjects were asked what medications they had taken as part of the screening for upper arm pathology to determine the overall eligibility of the volunteer to participate in the study. This information was also of interest because of the potential for analgesics and other pharmaceuticals to directly or indirectly affect somatosensory neural pathways. In this study no analysis of these potential effects was undertaken, but it was an interesting finding that even in a sample of young, healthy individuals, 44% were taking medications for a variety of conditions.

Biodex joint-position-error data

In this study the mean joint-position-error of the elbow in the sagittal plane was 4.8° ± 2.4° of elbow flexion relative to the starting position. These values are similar to mean joint-position-error scores from previous studies. Khabie et al, [21] studied the joint-position-sense of the dominant elbow of twenty uninjured male volunteers with a mean age of 27.8 years (range 25 to 36 years), and found the mean joint-position-error to be 3.3° ± 1.3° in the control group and 2.8° ± 1.5° after intra-articular anesthesia, ($p < 0.33$). That study differed from the present study in that the protocol was passive-reproduction of the passively-positioned target angle.

Barrack et al,[6] studying joint-position-error of the knee in ballet dancers (five males and seven females average age 25 years) and age-matched controls found the mean error for dancers was 4.8° ± 2.8° and the non-dancer controls was 2.6° ± 1.0° ($p < 0.03$). In this classic study, the dancers had inferior joint-position-sense but superior kinesthesia compared to the non-dancers. These data led the authors to theorize that static joint-position-sense and kinesthesia are facilitated by different neural systems.

Concurrent Validity

In order to assess the concurrent validity of the JPS98, in this study measures of uni-planar, single joint, joint-position-error of all n = 43 subjects were recorded simultaneously with the JPS98 and Biodex and correlated. As can be seen from the frequency plots of joint-position-error scores from the JPS98 and Biodex data (Figures 4-7), the sample data approach a normal distribution. Pearson's (r) correlation coefficient values of 0.89, 0.87 and 0.90 for the first, second and third JPS98 scorings, respectively (Table 3), indicate good to excellent consistency between the JPS98 and the Biodex data. Therefore, the JPS98 yields statistically useful data, and offers the advantages of being less expensive and requiring minimal user training compared to the Biodex B-2000 and similar electronic instrumentation. Thus the JPS98, as modified, may replace the Biodex B-2000 in physical therapy clinics for the quantitative assessment of the joint-position-sense of uni-axial hinge type joints such as the elbow.

Inter-rater reliability

Inter-rater reliability was tested in order to generalize the reliability of the JPS-98 for uni-planar, single-joint measures when used by any physical therapist in the clinical setting. Du Pont[4] documented inter-rater reliability of the JPS98 for three-dimensional, multi-joint, static joint-position-sense. She chose the Pearson product-moment coefficient of correlation, (r) as the statistical test for evaluating correlation between all possible pairs of 19 raters who each scored the videotaped trials of 5 subjects. She then calculated the overall inter-rater reliability using the Spearman-Brown formula for effective reliability (R), citing Rosenthal and Rosnow.[45] Du Pont reported the effective reliability of the JPS98 measurements at the elbow, Spearman-Brown's (R) = 0.806.

Portney and Watkins[9] comment that, although Pearson's (r) is frequently used as a measure of correlation for inter-rater reliability, it is not the best method for doing so. There are at least three weaknesses with basing tests of reliability on the covariance of sets of data. The first weakness is that correlation measures the consistency of ranks and does not measure the level of similarity among data. Second, Pearson's (r) evaluates bi-variate relationships, comparing only two raters' scores at a time rather than all raters' scores simultaneously. And third, this index of correlation does not separate out the variance due to error versus the variance due to rater technique and subject differences. When correlation must be used as a measure of reliability, it is more precise to use a coefficient of determination (r^2) rather than (r). [9]

In this study, the intraclass correlation coefficient (ICC) was used as a single index to describe the agreement and consistency of rank among the JPS98 joint-position-error data scored by the five raters. The statistical analysis was based on Portney and Watkins[9] recommendation of Shrout and Fleiss' model two, ICC (2, *k*), for intra-rater reliability. The strength of the ICC statistic allows the generalization of the reliability to the larger population of similar raters. In this case, the larger population is all physical therapists.

The ICC is calculated using variance estimates derived from a repeated measures analysis of variance (ANOVA).[9] The ANOVA partitions the variance among the data due to the subjects, the raters and random error, thus allowing for the measure of correspondence and agreement among the scores of the raters. In this study, the variance due to the raters was small, F-ratio of 1.69, Table 5, and the rater effect, or the difference in the data due to the raters, was not significant ($p = 0.1538$)

The ICC can take on values ranging from 0.00, representing no reliability, to 1.00 representing perfect agreement and consistency between sets of data. The inter-rater reliability, ICC (2,k) = 0.94, (95% LCL ≥ 0.904), found in the present study, is a strong indication that there is both good agreement and consistency of rank among the scores recorded by the five raters using the JPS98 system, as modified in this study. Thus in the physical therapy clinical setting, several physical therapists scoring the videotaped joint-position-sense trials for the same patient would record essentially the same values. In a typical physical therapy clinic it is not always possible for the same therapist to perform the initial and subsequent evaluations of patient status, so consistency among all physical therapists is crucial.

Intra-rater reliability

For the intra-rater reliability testing, the principal investigator's reliability, for the three sets of scores, was assessed using the intra-class correlation coefficient (ICC). The statistical analysis was based on Portney and Watkins[9] recommendation of Shrout and Fleiss' model three, ICC (3, *k*), for intra-rater reliability. The repeated measures ANOVA, Table 6, partitioned the variance in the three data sets (score_1, score_2 and score_3) due to the rater having scored the trials on three separate occasions.

In this study, the variance due to the rater was small, F-ratio of 1.12 (Table 6). The ratings effect, the difference in the data over the repeated scorings, was not significant ($p = 0.33$). The ICC (3,k) = 0.98, (95% LCL ≥ 0.97) indicates good intra-rater reliability for the principal investigator using the JPS98 system, as modified in this study. Thus, when a single physical therapist were to score the videotaped joint-position-sense trials of a patient on repeated occasions, the resulting scores would be expected to be statistically the same. This is important for the physical therapist when recording changes in patient status throughout the rehabilitation process. It is essential that consistency be carried over from one assessment period to the next.

Delimitations of the study

This study measured only joint-position-sense of one joint, the elbow, in one cardinal plane, the sagittal plane. The JPS98 was not designed to quantify kinesthetic acuity or any other component of proprioception.

Limitations of the study

The statistical, internal and external validity may all have been affected in several ways due to uncontrolled factors. The largest threat to the statistical validity of this study was that the sample was one of convenience rather than a random sample of a larger population. This limits somewhat, the generalizability of the results. The participants also represent only healthy individuals without pain, loss of ROM, loss of muscle strength, or effect of medications. Therefore, the sample did not represent a typical physical therapy patient population. However, the frequency distribution of the joint-position-error scores (Figures 3-6) illustrate that the sample data approaches a normal distribution.

The investigator assumed that each subject performed his or her best effort at each performance and that time-of-day and other environmental factors did not affect the ability of the individual to perform the protocol. Additionally, reliability is most rigorously proven with correlation of data between different trials or sessions over time. It was not the design or the intent of this study to perform reliability measures between repeated sessions.

The internal validity may have been affected by the method of marking the elbow and wrist landmarks. The markings on the joints of the test limb were placed on the subject's skin which is somewhat fluid over connective tissues. The markings may have shifted slightly throughout the excursion of the limb.

The upper arm of the test limb was not directly fixed in place and it was assumed that it remained in a stable position. The shoulder of the test limb was away from the videocamera and therefore it was impossible to document the stability of the right shoulder joint during testing. However, in a study reported by Taylor et al[7] that demonstrated the concurrent validity of measures of joint-position-sense with the Biodex compared to the standard goniometer, the same situation existed with the femur and hip. In that study, the position of the femur was not fixed and no landmark at the hip was visible. The authors addressed the issue of the slight displacement of the joint at the center of rotation of the Biodex and demonstrated statistically that the reliability of the results was not impacted.

The present study removed visual cues to the position of the elbow by the use of blindfolds but did not address the removal of other sensory input that may play a part of proprioception. Other studies [6,8,26] removed cutaneous and cognitive input by using air splints and white noise delivered through earphones. It is possible that cutaneous sensation and the sound of the Biodex apparatus during testing may have supplied sensory input to the subject's proprioceptive system.

It has been theorized that different joint mechanoreceptors are sensitive in specific yet overlapping ranges of joint motion[13]. This study measured position sense in criterion angles only in the mid-range of elbow flexion and thus cannot represent a conclusive assessment of all relevant components that comprise joint position sense.

External validity may have been affected by the study design as well. It was assumed that a lack of subjective signs and symptoms of upper extremity pathology implied complete joint health in each participant. There was no objective effort to prove this assumption such as radiographs or magnetic resonance imagery of synovial, capsular, ligamentous or musculoskeletal integrity. Such objective proof would have been a critical component of the study design if predictive validity had been the focus of the study. However, the determination of concurrent validity was not affected by the presence of subclinical joint pathology. Range of motion (ROM) and manual muscle testing (MMT) was performed only to determine if the subject had the necessary mobility and strength in the test limb to be able to perform the protocol.

Areas for further research

Perhaps the most important area for further research with the JPS98 is the testing of multi-joint, tri-planar movement of a limb that more closely resembles functional motor patterns. In this study, the movement of only one joint (elbow) was tested in only a single plane. In reality, normal human movement does not occur as isolated sequences of motions of individual-joints in the cardinal planes, but rather, movement occurs as the result of the simultaneous combined motions of multiple joints in one or more planes. Indeed, as Bosco et al,[25] have shown, specific groups of second order neurons integrate joint-position-sense input from the individual joints of a limb into limb-based position-sense data making possible the seamless control of limbs of multiple degrees of freedom.

The test-retest reliability of the JPS98 should be assessed as well. The current study had each subject perform joint-position-sense trials on only a single occasion. It would be useful in the clinical setting to know that the JPS98 can be used to record joint-position-error equally well within subjects tested on separate occasions.

Additional research efforts should also focus on testing the JPS98 for assessing joint-position-sense in different age groups and in non-healthy populations, such as those patients with decreased gross motor strength and range-of-motion. This study measured joint-position-error in healthy young male and female subjects (ages 22 to 46 years) that are at risk for a variety of sport-related injuries and neurological conditions that might affect joint-position-sense. However, younger and older individuals are also at risk for conditions in which proprioceptive loss may lead to functional limitations. For instance, Charness[3] cites the research of Bobath et al, that showed that the level of proprioceptive and kinesthetic awareness following stroke or head injury is a highly reliable parameter for predicting recovery of function for the limb.

Lastly, it would be beneficial to determine if the JPS98 has predictive validity. A study of the joint-position-sense of a very large sample population of healthy individuals could be used to determine if there is a correlative relationship between proprioceptive acuity and an increased risk for injury. Such data could be used to identify at-risk individuals and encourage the use of preventative measures to avoid impairment and loss of function.

Conclusions

Proprioception is a fundamental component of the sensory system necessary for all human movement. Impairment of joint-position-sense due to injury or disease may lead to functional limitations for many physical therapy patients. No standard reliable and inexpensive methodology exists for quantifying joint-position-sense in the clinical setting.[4] Research methods for quantifying proprioception are not well suited to the clinic owing to the expense and complexity of the equipment and data collection procedures. Du Pont's instrument, the JPS98, demonstrates good to excellent concurrent validity for measuring joint-position-error at the elbow in a single plane when compared to the Biodex Dynamometer. It also demonstrates high intra- and inter-rater reliability. Further research must be done to show that this system is valid and reliable for the quantification of joint-position-sense for multi-joint motion of a limb across multiple planes.

APPENDIX A

Department of Physical Therapy
School of Health Professions
Southwest Texas State University

VALIDITY AND RELIABILITY OF THE JPS-98 FOR UNI-PLANAR JOINT POSITION SENSE OF THE ELBOW

CONSENT FORM - Subject

You are invited to participate in a research study designed to determine the reproducibility of data using a new instrument that has been proposed to measure joint position sense. This effort will be the primary research topic for a Master's Thesis in physical therapy at Southwest Texas State University. The data obtained will be compared to data simultaneously gathered from a second machine. The potential benefits of this research may help make available a simpler method for assessing neurological problems in physical therapy patients.

In order to participate you must be at least eighteen years of age and in generally good overall health. You must also have no current pain or other symptoms or history of disease or injury in your right arm. The research procedure will require that you be able to fully bend and straighten your right elbow and have adequate strength to hold your elbow in a slightly bent position for up to ten seconds at a time without resting your arm. You will be required to wear a blindfold for up to two minutes at a time while seated at the test apparatus.

During testing the researcher will bend your elbow to a target position for a few seconds and straighten your arm again. You will then be asked to bend your elbow to find the same target position while blindfolded. This procedure will be repeated a total of three times. The entire procedure will be videotaped and may take up to 30 minutes of your time. It may be necessary for you to come back for additional testing one to two weeks later. The procedure is pain-free and involves only minimal risk of muscle fatigue of the right arm. All videotapes will remain in the possession of the student investigator.

You will be asked about your medical history to determine your qualification to participate but this information will not be used in the study and will remain private and confidential. You may withdraw from the study at any time with no repercussions. Southwest Texas State University students, faculty and employees that participate may withdraw at any time without jeopardizing his or her status with the University. You will not be paid for your participation, nor will students receive extra credit.

You may contact Michael Burroughs at (512) 345-3633 or Dr. Diana Hunter (512) 245-3517 for any questions or concerns before, during or after the study. You may obtain a copy of this consent form upon request.

Your signature indicates your understanding of the study requirements and your voluntary decision to participate as a subject in this research. You are also consenting to be videotaped for this purpose. You may withdraw this consent at any time.

______________________________ ______________________________

Signature of Participant Date Signature of Investigator Date

Department of Physical Therapy
School of Health Professions
Southwest Texas State University

VALIDITY AND RELIABILITY OF THE JPS-98 FOR UNI-PLANAR JOINT POSITION SENSE OF THE ELBOW

CONSENT FORM - Rater

You are invited to participate in a research study designed to determine the reproducibility of data using a new instrument that has been proposed to measure joint position sense. This effort will be the primary research topic for a Master's Thesis in physical therapy at Southwest Texas State University. The data obtained will be compared to data simultaneously gathered from a second machine. The potential benefits of this research may help make available a simpler method for assessing neurological problems in physical therapy patients.

In order to participate you must be a physical therapist or a physical therapy student. You must be willing to be trained in scoring the videotaped performances of joint position sense testing of the elbow of human subjects. You must also be willing to maintain the confidentiality of the study participants.

During the test procedure, the researcher will passively place the subject's elbow to a target position for a few seconds and then replace the arm to the starting position. The subject will then actively reproduce the position as a measure of joint position sense. This procedure will be repeated a total of three times. You, as the rater, will view the videotapes and record the position of the elbow and wrist using x- and y-coordinates as indicated on the grid system of the JPS-98. Your participation will require about three hours of your time.

You may withdraw from the study at any time with no repercussions. Southwest Texas State University students, faculty and employees that participate may withdraw at any time without jeopardizing his or her status with the University. You will not be paid for your participation, nor will students receive extra credit.

You may contact Michael Burroughs at (512) 345-3633 or Dr. Diana Hunter at (512) 245-3517 with any questions or concerns before, during or after the study. You may obtain a copy of this consent form upon request.

Your signature indicates your understanding of the study requirements and your voluntary decision to participate as a rater in this research. You may withdraw this consent at any time.

______________________________ ______________________________

Signature of Participant Date Signature of Investigator Date

Eligibility Screening Instrument

First Name____________________ Today's Date______________

Last Name____________________ Date of Birth_______________

Sex_____________ Age____________

What is your occupation?____

What hobbies, exercises, recreational or sports activities do you enjoy?

____

How often do you participate in these activities?_________________________________

What exercises or sports activities did you do today before this research project?

____

Current Health Status: Excellent Good Fair Poor

Please explain Fair or Poor Health Status:_______________________________________

____

Have you ever been diagnosed by a physician with any diseases/injuries or maladies of the head, neck, shoulder, arm, elbow or hand? Yes_____ No______

If so, please state when and describe briefly_______________________________________

____

Was the disease or injury treated successfully and completely? ________________________

Are you currently experiencing any pain, tingling, numbness, muscle weakness or loss of movement in either shoulder, elbow or hand? Yes______ No______

If so, please describe____

	AROM		PROM		MMT	
	Left	Right	Left	Right	Left	Right
Elbow Flexors						
Elbow Extensors						

Sensation (Light Touch)	Left	Right	**MSRs**	Left	Right
			Biceps		
			Triceps		

APPENDIX B

Instructions for Scoring JPS-98 Coordinate Data

Thank you for assisting in this research project The purpose of this effort is to test the validity and reliability of Cynthia Du Pont's JPS-98 instrument for quantifying the joint position sense of the elbow of healthy female and male individuals.

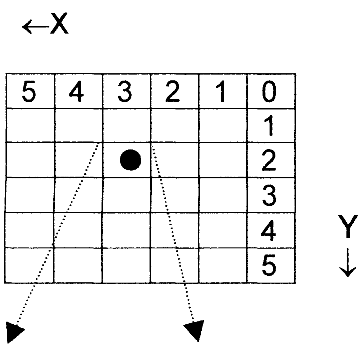
Du Pont's method consists of a clear grid through which the therapist can view and record the x- and y-coordinates of the bony landmarks of the joints being tested. In the current study, blindfolded subjects were asked to flex their elbows to match a target angle passively pre-determined by the investigator. This protocol has been termed active reproduction of passive positioning (ARPP). Three (or four) attempts were recorded on videotape with the JPS-98 grid placed between the subject and the videocamera.

The concurrent validity of the JPS-98 is being tested using the Biodex Dynamometer as the standard. During the three trials, the subject is seated at the Biodex which is concurrently measuring the amount of elbow flexion of the target and reproduced (ARPP) angles. The amount of error in attempting to reproduce the target angle can thus be calculated in angular degrees from the Biodex data and in units of linear distance from the JPS-98 coordinates. These data will be correlated to determine the validity of the JPS-98 grid system. The inter-rater reliability of the JPS-98 will be determined by comparing the outcomes of five raters scoring the trials of 43 subjects.

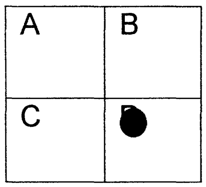
To "score" the subject's accuracy in attempting to find the target angle, the rater will view the videotaped trials for all 43 subjects and record the x- and y-coordinates of the wrist and elbow joints. Both the wrist and the elbow are marked with approximately half-inch markers. The elbow position should remain constant within a certain expected degree of error, but the rater will be required to record the elbow coordinates at both the target and reproduced angles to document the stability of the arm during the trial.

The rater will record the x- and y-coordinates of the wrist and elbow at the starting position, at the target position, again at the start position and then at the position where the subject attempts to match the target position (ARPP). To heighten the sensitivity of the data, each 2 x 2 inch window of the grid must be further subdivided into four quadrants, A, B, C, and D. Each of these quadrants will again be subdivided into quadrants making a total of sixteen subdivisions (much like the window of a house with sixteen panes of glass).

The rater will first record the coordinates of the window in which the marker appears, for example x = 3, and y = 2. Then the rater must judge which of the large quadrants contains the marker (ie large quadrant "D") and finally the smaller quadrant within the larger quadrant (ie small quadrant "a"). Thus, the coordinate score might be (3, 2, D, a). The investigator, not the rater, will then convert these scores to final numerical coordinates of x = 3.25 and y = 2.50.

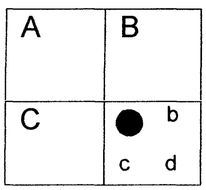


First judge that the marker is in x = 3 and y = 2



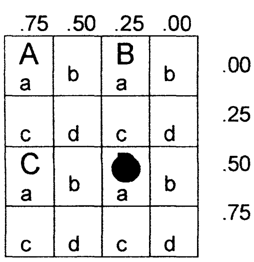
Then judge which large quadrant within window (3, 2) the marker lies.

In this case it would be large quadrant "D".



Then judge within which small quadrant inside larger quadrant D, the marker lies.

In this case it is small quadrant "a"



So overall, the marker appears in window (3, 2, D, a).

The investigator will later convert this score into a final numerical position of (x = 3.25, y = 2.50).

<u>Tips for scoring consistently:</u>

Use the VCR pause function to stop the videotape while you record the coordinates of the markers.

Each position is held for 5 seconds in which to score the coordinates. Wait three or four seconds or until the markers' position stabilizes before pausing the videotape.

When in doubt as to which smaller quadrant the marker lies within or when the marker appears to be exactly centered, use a consistent default such as choosing to score it to the left and/or down. **But always use the same default strategy!!!**

The position of the elbow marker must also be scored for each step although it will only be used to document the stability of the elbow at the fulcrum.

The wrist and elbow marker position coordinates must be scored at the starting position, at the target angle, at the return to the starting position, at the subject's attempt to reproduce the angle and finally upon returning to the starting position.

Subject: ____________ Date scored: ____________ Rater Name: ____________

	WRIST						ELBOW					
	x	y	QUAD	quad	X	Y	x	y	QUAD	quad	X	Y
Start 1												
Target 1												
Return 1												
ARPP 1												
Start 2												
Target 2												
Return 2												
ARPP 2												
Start 3												
Target 3												
Return 3												
ARPP 3												

APPENDIX C

Table C-1. Validity: Average absolute joint-position-error, in linear distance units, calculated from the JPS98 coordinate data recorded on three separate occasions by the principal investigator for all n=43 subjects by all k=5 raters. Biodex data, in angular degrees, recorded at the time of the trials.

Subjects	JPS98 score_1	JPS98 score_2	JPS98 score_3	Biodex
1	0.471	0.471	0.422	3.33
2	0.319	0.236	0.422	4.00
3	0.083	0.083	0.083	1.00
4	0.319	0.319	0.319	5.00
5	0.304	0.422	0.333	1.00
6	0.319	0.319	0.319	4.00
7	0.536	0.555	0.555	6.00
8	0.285	0.236	0.236	3.00
9	0.840	0.840	0.776	11.00
10	0.319	0.304	0.304	2.33
11	0.388	0.304	0.270	2.67
12	0.319	0.201	0.236	1.00
13	0.422	0.422	0.491	5.00
14	0.236	0.354	0.304	4.00
15	0.388	0.354	0.422	4.00
16	0.505	0.505	0.505	6.67
17	0.511	0.514	0.577	6.25
18	0.186	0.285	0.353	3.67
19	0.505	0.505	0.505	6.00
20	0.422	0.422	0.422	5.00
21	0.285	0.201	0.285	2.67
22	0.236	0.236	0.236	4.33
23	0.201	0.201	0.201	2.33
24	0.536	0.487	0.487	6.67
25	0.677	0.797	0.831	9.00
26	0.368	0.422	0.388	2.67
27	0.499	0.437	0.502	6.00
28	0.687	0.640	0.640	9.00
29	0.354	0.354	0.354	5.33
30	0.118	0.201	0.118	1.67
31	0.607	0.630	0.670	8.25
32	0.467	0.596	0.508	5.00
33	0.236	0.236	0.354	3.33
34	0.545	0.530	0.530	6.25
35	0.943	0.943	0.943	9.67
36	0.388	0.388	0.388	4.67
37	0.418	0.555	0.502	6.00
38	0.471	0.471	0.471	6.33
39	0.319	0.402	0.354	3.00
40	0.201	0.285	0.236	2.00
41	0.285	0.201	0.285	3.67
42	0.500	0.500	0.417	6.00
43	0.456	0.491	0.491	6.33

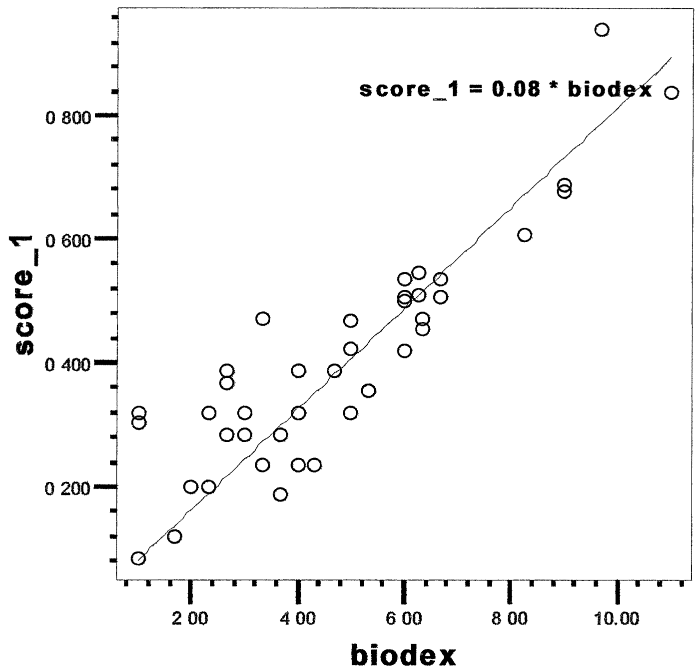


Figure #C-1. Correlation of joint position error for n=43 subjects, first JPS98 data set (score_1) with Biodex data. JPS98 data in units of linear distance; Biodex in angular degrees.

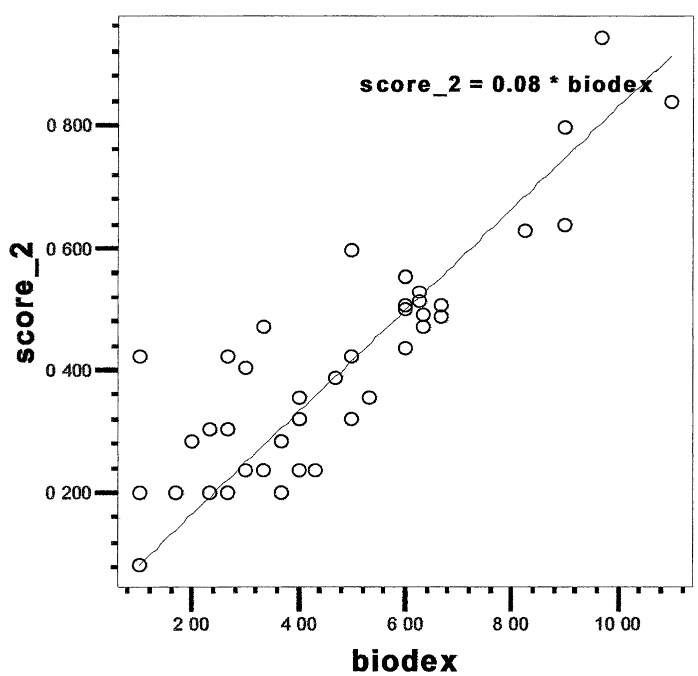


Figure #C-2. Correlation of joint position error for n=43 subjects, second JPS98 data set (score_2) with Biodex data. JPS98 data in units of linear distance; Biodex in angular degrees.

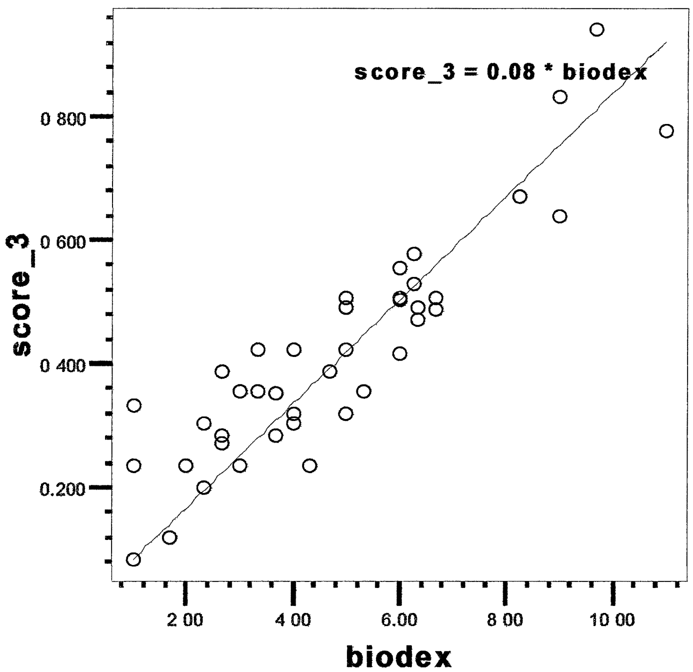


Figure #C-3. Correlation of joint position error for n=43 subjects, third JPS98 data set (score_3) with Biodex data. JPS98 data in units of linear distance; Biodex in angular degrees.

APPENDIX D

Table D-1. Inter-rater reliability: Average absolute joint-position-error, in linear distance units, calculated from the JPS98 coordinate data recorded for all n=43 subjects by all k=5 raters.

Subject #	Rater#1	Rater#2	Rater#3	Rater#4	Rater#5
1	0.471	0.319	0.569	0.201	0.456
2	0.319	0.388	0.319	0.319	0.354
3	0.083	0.285	0.201	0.270	0.381
4	0.319	0.680	0.300	0.236	0.319
5	0.304	0.083	0.167	0.167	0.333
6	0.319	0.201	0.201	0.236	0.319
7	0.536	0.487	0.450	0.654	0.619
8	0.285	0.270	0.201	0.201	0.285
9	0.840	0.707	0.540	0.673	0.658
10	0.319	0.353	0.270	0.319	0.353
11	0.388	0.333	0.319	0.304	0.250
12	0.319	0.167	0.083	0.201	0.083
13	0.422	0.353	0.514	0.430	0.465
14	0.236	0.285	0.304	0.236	0.830
15	0.388	0.402	0.502	0.319	0.422
16	0.505	0.875	0.686	0.605	0.568
17	0.511	0.660	0.608	0.625	0.571
18	0.186	0.118	0.118	0.118	0.186
19	0.505	0.368	0.373	0.354	0.373
20	0.422	0.388	0.437	0.486	0.499
21	0.285	0.285	0.319	0.353	0.388
22	0.236	0.186	0.499	0.236	0.354
23	0.201	0.201	0.491	0.270	0.368
24	0.536	0.520	0.487	0.536	0.418
25	0.677	0.812	0.900	0.846	0.831
26	0.368	0.186	0.418	0.319	0.236
27	0.499	0.533	0.899	0.648	0.617
28	0.687	0.775	0.951	0.775	0.803
29	0.354	0.236	0.236	0.236	0.589
30	0.118	0.236	0.285	0.270	0.285
31	0.607	0.741	0.788	0.872	0.850
32	0.467	0.456	0.453	0.530	0.691
33	0.236	0.373	0.437	0.304	0.354
34	0.545	0.556	0.516	0.493	0.691
35	0.943	0.770	0.707	0.943	1.030
36	0.388	0.721	0.373	0.354	0.354
37	0.418	0.384	0.381	0.437	0.559
38	0.471	0.499	0.533	0.471	0.502
39	0.319	0.354	0.000	0.354	0.285
40	0.201	0.118	0.201	0.201	0.118
41	0.285	0.167	0.201	0.201	0.201
42	0.500	0.354	0.437	0.417	0.264
43	0.456	0.451	0.388	0.491	0.422

Table D-2. Inter-rater reliability: Correlation of JPS98 and Biodex joint-position-error scores, Pearson product-moment coefficient of correlation, (r).

	Rater#1	Rater#2	Rater#3	Rater#4	Rater#5
Rater#1	1.000				
Sig.(2-tailed)	-				
n	43				
Rater#2	0.757	1.000			
Sig.(2-tailed)	0.000	-			
n	43	43			
Rater#3	0.699	0.731	1.000		
Sig.(2-tailed)	0.000	0.000	-		
n	43	43	43		
Rater#4	0.856	0.831	0.808	1.000	
Sig.(2-tailed)	0.000	0.000	0.000	-	
n	43	43	43	43	
Rater#5	0.711	0.691	0.723	0.802	1.000
Sig.(2-tailed)	0.000	0.000	0.000	0.000	-
n	43	43	43	43	43
Biodex	0.890	0.804	0.728	0.843	0.754
Sig.(2-tailed)	0.000	0.000	0.000	0.000	0.000
n	43	43	43	43	43

Correlation is significant at the 0.01 level (2-tailed)

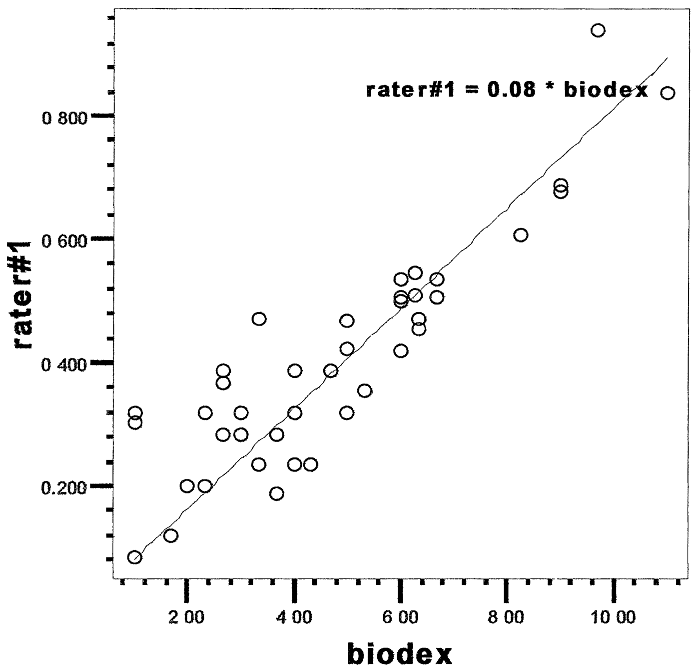


Figure D-1. Correlation of joint position error for n=43 subjects, Rater#1 versus Biodex data. JPS98 data in units of linear distance; Biodex in angular degrees.

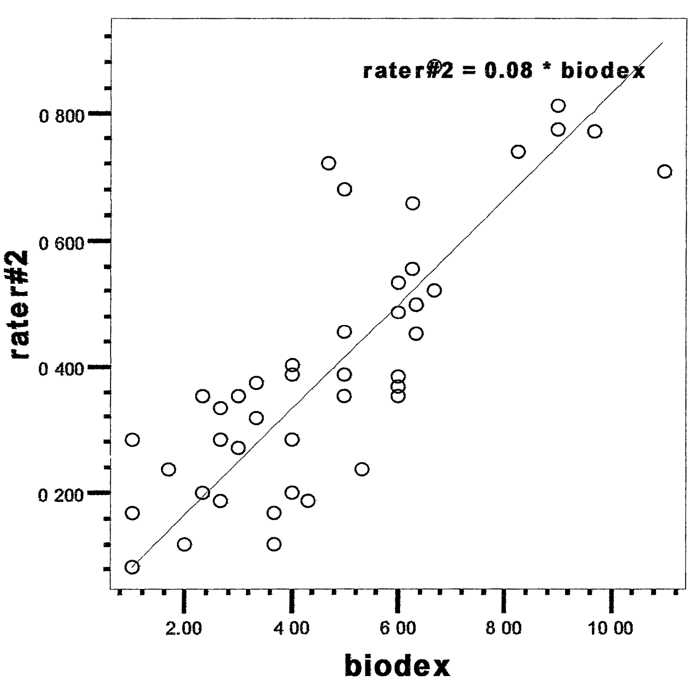


Figure D-2. Correlation of joint position error for n=43 subjects, Rater#2 versus Biodex data. JPS98 data in units of linear distance; Biodex in angular degrees.

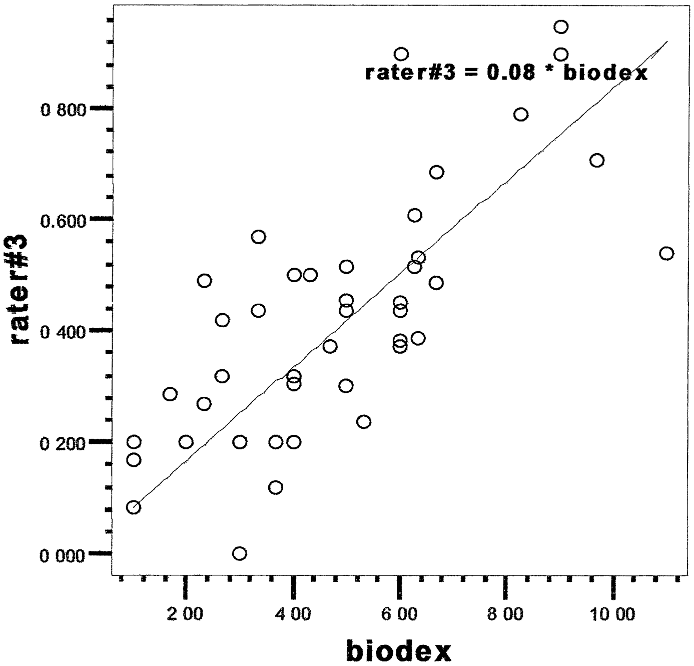


Figure D-3. Correlation of joint position error for n=43 subjects, Rater#3 versus Biodex data. JPS98 data in units of linear distance; Biodex in angular degrees.

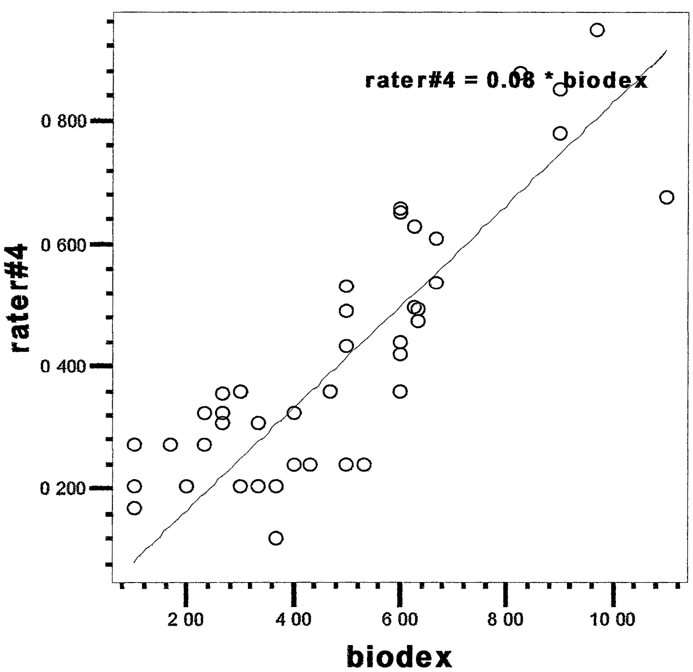


Figure D-4. Correlation of joint position error for n=43 subjects, Rater#4 versus Biodex data. JPS98 data in units of linear distance; Biodex in angular degrees.

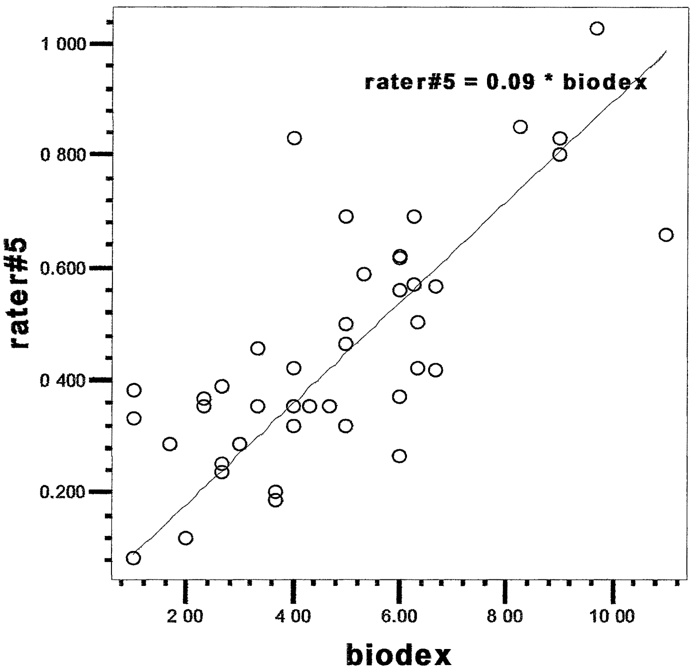


Figure D-5. Correlation of joint position error for n=43 subjects, Rater#5 versus Biodex data. JPS98 data in units of linear distance; Biodex in angular degrees.

REFERENCES

1. Lattanzio P-J, Petrella R. Knee Proprioception: A Review of mechanisms, measurements, and implications of muscular fatigue. *Orthopedics.* April 1998; 21(4): 463-471.

2. Brunnstrom S. *Brunnstrom's Clinical Kinesiology, 4th ed.* Lehmkuhl L, Smith L. eds. Philadelphia: FA Davis Co; 1984: 92-117.

3. Charness A. *Stroke/Head Injury: A Guide to Functional Outcomes in Physical Therapy Management.* Gaithersberg, MD: Aspen Publishers, Inc; 1986. Schneider F, ed. Rehabilitation Institute of Chicago Publication Series.

4. Du Pont C. Interobserver reliability of a new instrument for objectively measuring tri-planar joint position sense. (research project) San Marcos TX: Southwest Texas State University. Located at: Physical Therapy Dept. 1998.

5. Hair J, Anderson R, Ratham R, Black W. *Multivariate Data Analysis.* 4th ed. New Jersey: Prentice Hall Inc. 1995; 422-432.

6. Barrack R, Skinner H, Cook S. Proprioception of the knee joint: paradoxical effect of training. *Am J Phys Med.* 1984; 63(4): 175-181.

7. Taylor N, Sanders R, Howick E, Stanley S. Static and dynamic assessment of the Biodex dynamometer. *Eur J Appl Physiol.* 1991; 62: 180-188.

8. Voight M, Hardin J, Blackburn T, Tippett S, Canner G. Effects of muscle fatigue on and the relationship of arm dominance to shoulder proprioception. *J Orthop Sports Phys Ther.* June 1996; 23(6): 348-352.

9. Portney L, Watkins M. *Foundations of clinical research: Applications to practice.* Norwalk, Connecticut: Appleton & Lange; 1993: 505-528.

10. Lephart S, Pincivero D, Giraldo J, Fu F. The role of proprioception in the management and rehabilitation of athletic injuries. *Am J Sports Med.* Jan 1997; 25(1): 130-137.

11. Marks R. Peripheral mechanisms underlying the signaling of joint position. *NZ J Physiol.* April 1997: 7-13.

12. Lephart S, Pincivero D, Rozzi S. Proprioception of the ankle and knee. *Sports Med.* Mar 1998; 25(3): 149-155.

13. Shumway-Cook A, Woolacott M. *Motor control: Theory and applications.* Baltimore: Williams & Wilkins; 1995: 45-83.

14. Taimela S, Kankaanpaa M, Luoto S. The effect of lumbar fatigue on the ability to sense a change in lumbar position: a controlled study. *Spine.* 1999; 24(13): 1322-1327.

15. McNair P, Heine P. Trunk proprioception enhancement through lumbar bracing. *Arch Phys Med Rehabil.* Jan 1999; 80: 96-99.

16. Jueptner M, Ottinger S, Fellows S, et al. The relevance of sensory input for the cerebellar control of movements (abstract). *Neuroimage.* Jan 1997; 5(1): 41-48.

17. Weiller C, Jueptner M, Fellows S, et al. Brain representation of active and passive movements (abstract). *Neuroimage.* Oct 1996; 4(2): 105-110.

18. Lephart S, Swanik B, Boonriong T. Anatomy and physiology of proprioception and neuromuscular control. *Athletic Therapy Today.* Sept 1998: 6-9.

19. Sharpe M, Miles T. Position sense at the elbow after fatiguing contractions. *Exp Brain Res.* 1993; 94(1): 179-182.

20. Sterner R, Pincivero D, Lephart S. The effects of muscle fatigue on shoulder proprioception. *Clin J Sport Med.* 1998; 8(2): 96-101.

21. Khabie V, Schwartz M, Rokito A, et al. The effect of intra-articular anesthesia and elastic bandage on elbow proprioception. *J Shoulder Elbow Surg.* Sept/Oct 1998; 7(5): 501-504.

22. Fuchs S, Thorwestern L, Niewerth S. Proprioceptive function in knees with and without arthroplasty. *Am J Phys Med Rehabil.* Jan/Feb 1999; 78(1): 39-45.

23. Ishii Y, Terajima K, Tershima S, Bechtold J, Laskin R. Comparison of joint position sense after total knee arthroplasty. *J Arthroplasty.* Aug 1997; 12(5): 541-545.

24. Skinner H, Barrack R, Cook S, Haddad R. Joint position sense in total knee arthroplasty. *J Orthop Res.* 1984; 1(3): 276-283.

25. Bosco G, Poppele R, Eian J. Reference frames for spinal proprioception: limb endpoint based or joint-level based? *J Neurophysiol.* May 2000; 83(5): 2931-2945.

26. Skinner H, Barrack R, Cook S. Age-related decline in proprioception. *Clin Orthop Related Res.* April 1984; 184: 208-211.

27. Kaplan F, Nixon J, Reitz M, Rindfleish L, Tucker J. Age-related changes in proprioception and sensation of joint position. *Acta Orthop Scand.* 1985; 56: 72-74.

28. Petrella R, Lattanzio P, Nelson M. Effect of age and activity on knee joint proprioception. *Am J Phys Med Rehab.* May/June 1997; 76(3): 235-241.

29. Robbins S, Waked E, McClaran J. Proprioception and stability: foot position awareness as a function of age and footwear. *Age and Ageing.* 1995; 24: 67-72.

30. Eakin C, Quesada P, Skinner H. Lower-limb proprioception in above-knee amputees. *Clin Orthop Related Res.* Nov 1992, 284: 239-246.

31. Leanderson J, Eriksson E, Nilsson C, Anders W. Proprioception in classical ballet dancers: a prospective study of the influence of an ankle sprain on proprioception in the ankle joint. *Am J Sports Med.* May 1996; 24(3): 370-374.

32. Payne K, Berg K, Latin R. Ankle injuries and ankle strength, flexibility, and proprioception in college basketball players. *J Athl Train.* Jul 1997; 32(3): 221-225.

33. Marks R, Quinney A, Wessel J. Reliability and validity of the measurement of position sense in women with osteoarthritis of the knee. *J Rheumatol.* 1993; 20: 1919-1924.

34. Cook S, Harding A, Burke S, et al. Upper extremity proprioception in idiopathic scoliosis. *Clin Orthop Related Res.* Dec 1996; 213: 118-124.

35. Barrack R, Whitecloud T, Burke S, Cook S, Harding A. Proprioception in idiopathic scoliosis. *Spine.* 1984; 9(7): 681-685.

36. Zia S, Cody F, O'Boyle D. Joint position sense is impaired by Parkinson's disease. *Ann Neurol.* Feb 2000; 47(2): 218-228.

37. Lönn J, Crenshaw A, Djupsjöbacka M, Pedersen J, Johansson H. Position sense testing: influence of starting position and type of displacement. *Arch Phys Med Rehabil.* May 2000; 81(5): 592-597.

38. Roberts D, Friden T, Zatterstrom R, Lindstrand A, Moritz U. Proprioception in people with anterior cruciate ligament-deficient knees: comparison of symptomatic and asymptomatic patients. *J Orthop Sports Phys Ther.* Oct 1999; 29(10):587-594.

39. Bernier J, Perrin D. Effect of coordination training on proprioception of the functionally unstable ankle. *J Orthop Sports Phys Ther.* April 1998; 27(4): 264-275.

40. Borsa P, Lephart S, Irrgang J, Safran M, Fu F. The effects of joint position and direction of joint motion on proprioceptive sensibility in anterior cruciate ligament-deficient athletes. *Am J Sports Med.* 1997; 25(3): 336-340.

41. Verschueren S, Swinnen S, Cordo P, Dounskia N. Proprioceptive control of multijoint movement: unimanual circle drawing. *Exp Brain Res.* Jul 1999; 127(2): 171-181.

42. Saxton J, Clarkson P, James R, et al. Neuromuscular dysfunction following eccentric exercise. *Med Sci Sports Exerc.* Aug 1995; 27(8): 1185-1193.

43. Brockett C, Warren N, Gregory J, Morgan D, Proske U. A comparison of the effects of concentric versus eccentric exercise on force and position sense at the human elbow joint. *Brain Res.* Oct 1997; 771(2): 251-258.

44. Rozzi S, Lephart S, Gear W, Fu F. Knee joint laxity and neuromuscular characteristics of male and female soccer and basketball players. *Am J Sports Med.* May 1999; 27(3): 312-319.

45. Rosenthal R, Rosnow R. *Essentials of Behavioral Research: Methods and Data Analysis.* New York: McGraw-Hill Book Company; 1984: 162-166.

VITA

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Michael Howard Burroughs was born in Coleman, Texas on May 31, 1955, the son of Howard Austin Burroughs and Mary Alice Holtz Burroughs. After graduating from Spring Branch High School in Houston, Texas in 1973, he graduated Magna Cum Laude with the degree Bachelor of Science in Biology from Sam Houston State University in Huntsville, Texas in 1976. He is listed in Who's Who in American Colleges and Universities, was a recipient of the Life Sciences Department Scholarship, was on the Dean's list and a member of the Beta Beta Beta Biological Society. He also served as a teaching assistant in Zoology and Botany at SHSU.

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