THE USE OF MOBILE TECHNOLOGY TO ASSESS WRIST PROPRIOCEPTION

by

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Andrew R. Karduna

The freedom of multitasking, walking, running, or playing sports requires an unconscious awareness of our limbs locations and movements. Proprioception helps provide this freedom, allowing us to recognize a limb's orientation in space without visual cues. There are a number of sensory receptors located in the skin, muscles, ligaments, tendons and joint capsules that send afferent sensory information to the central nervous system. This information is processed in the sensory-motor cortex, where the brain interprets changes in muscle length and tension to determine a limb's position. The brain sends efferent neural signals down the spinal cord providing motor commands to change limb orientation, velocity or angle. Proprioception is critical for balancing, preventing falls and generating reflexes. Any impairment to this process can indicate disease, aging or injury. Therefore, having an accurate and precise device to quantify proprioception is important for detecting changes in proprioception as well as advancing further research of proprioception. The purpose of this study was two-fold. First, we sought to test the reliability of a Joint Position Sense (JPS) app on assessing wrist proprioception. The second purpose was to test the hypothesis that the angular errors in a joint position sense task would decrease as the degree of wrist flexion increased. In this study, the repositioning errors did not improve with an increase in degree of wrist flexion. However, the JPS app proves a valid and reliable tool for assessing wrist proprioception.

Acknowledgements

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Background

Proprioception is the awareness of a limb's location and movement in space without visual cues (King & Karduna, 2014). This sense helps ensure smooth movement and proper motor control of joints. Proprioceptive information originates from changes in mechanical stimuli on receptors located in the muscles, tendons, fascia, ligaments, skin and joints (Floyd, 2015, pp. 51). These mechanoreceptors respond to changes in tissue status and these changes evoke the sending of sensory information via *afferent signals* to the central nervous system (CNS) (Adachi et al., 2002). The afferent neural signals elicit either a reflexive response at the spinal cord or continue to be processed by the *sensorimotor system* in the brain (Moore, 2014, pp. 57; Myers, Wassinger, & Lephart, 2006). Motor commands sent through *efferent signals* are responsible for changing the length of muscles and producing adjustments in joint angle, resulting in movement (Floyd, 2015, pp. 49). This process is essential maintaining posture, participating in sports and completing daily activities. Joint position sense (JPS) tasks are commonly used to quantify limb proprioception. This study uses a JPS app developed by the University of Oregon's Orthopaedic Biomechanics Laboratory to test subject's wrist proprioception by performing joint position sense tasks. This method has previously been utilized to investigate proprioception of the shoulder, elbow and ankle (Gillespie, 2013; King & Karduna, 2014; Jackson 2015).

The present study aims to expand the ultization of the app and develop a protocol for quantifying wrist proprioception.

This study also aims to observe any trends of wrist proprioception as the subject's reposition to different degrees of wrist flexion. We hypothesize that as the target angles of wrist flexion increase, the subject's active repositioning error will linearly decrease.

Introduction

Proprioception

Proprioception is the ability to perceive a limb's orientation and movement in space without any visual aid (King & Karduna, 2014). Proprioceptive information is mainly provided by mechanoreceptors located in the muscles, joints, fascia, ligaments, tendons and skin (Tsay, Giummarra, Allen, & Proske, 2015). These receptors are activated with movement evoking changes in pressure, motion, velocity, force and stretch (Floyd, 2015, pp. 52). This information is then interpreted and used to make muscular adjustments. Some of the main peripheral proprioceptive receptors include muscle spindle fibers and golgi tendon organs (GTOs) (Hagert, 2010). Muscle spindles are located in the muscle belly and react to stretching of the muscle (Proske & Gandevia, 2012). Golgi tendon organs are located near musculotendinous junctions and provide information pertaining to tension forces in muscles and tendons (Hagert, 2010). When activated, both receptors send afferent signals to the CNS. Both GTOs and muscle spindles are pivotal for the process of generating smooth muscle control.

Proprioception is composed of three subcategories: *kinesthesia*, the awareness of limb movement and *joint position sense (JPS)*, the awareness of limb location and force perception, being able to sense the force applied to a joint or within a joint (Han et al., 2015; King & Karduna, 2014; Myers et al., 2006). Many researchers utilize JPS to evaluate proprioception. There are several ways in which JPS can be measured. In this study, we implemented active limb positioning and active repositioning. This method directs subjects to a specific target angle or position with the aid of visual, tactile or auditory cues. Subjects then attempt to reposition their limb to the target position without any cues. In this testing protocol, the peripheral mechanoreceptors are responsible for providing the sensorimotor system with proprioceptive information. From the sensory information received, the CNS then sends motor commands via efferent pathways to elicit movement or changes in force (Han et al., 2015). There is a strong understanding of the proprioceptive receptors and their functions but the way in which different types proprioceptive information is weighed and integrated in the CNS still requires more research (King & Karduna, 2014; Gillespie, 2015). King et al. (2013), mention how the response of muscle spindles, golgi tendons, cutaneous and joint activation and afferent signals can vary with different degrees of muscle stretch, contributing to changes in proprioceptive acuity across different joint angles. In previous studies, the shoulder and elbow JPS accuracy demonstrated a positive linear relationship with an increase in target angles (King & Karduna, 2014; Gillespie, 2015). We are interested to observe if this positive linear relationship also exists in the wrist joint.

In healthy persons, proprioception is important for coordinated, dynamic movements that are utilized in day-to-day activities (Wright, Adamo, & Brown, 2011). Deficits in proprioception clearly impede daily activities and can result in ataxia or poor, uncoordinated movements and instability (Wright et al., 2011). When an individual experiences an injury resulting in damage to the muscle, tissue or joint, the proprioceptive receptors located in these regions risk impairment (Wise, Gregory, & Proske, 1998). Damage potentially causes gaps in sensory information being sent to the CNS. These gaps may cause problems with motor control and confidence in limb utilization, all of which can result in increased risk of re-injury. Restoration of proprioception permits the CNS to receive and send accurate information, preventing further damage and discomfort. Continual research of proprioception and its mechanisms is important due to its valuable role in daily life (Deshpande, Connelly, Culham, & Costigan, 2003).

Many clinicians use proprioceptive tests to assess injury damage and prescribe rehabilitation exercises to restore normal function (Risberg et al., 2007). The wrist contributes to an individual's quality of life, ability to work and play sports, therefore restoration of function directly impacts improving life and decreasing amount of sick leave (Krischak et al., 2009). Physical therapists use PRWE (patient related wrist evaluation) in order to determine a patient's functional abilities after their injury or illness and throughout their time in therapy (Krischak et al., 2009). Proprioception is a good indicator of a limb functionality by representing the accuracy and efficacy of the afferent and efferent neural pathways (Deshpande et al., 2003). The JPS app has proven reliable for quantifying proprioception of shoulder, elbow and ankle (Gillespie, 2013, King & Karduna, 2014, Jackson 2015). If the app can also be used to measure proprioception of the wrist, this could potentially be added to the PRWE and assist in monitoring wrist injury recovery.

Enhancements in technology have allowed researchers to improve JPS measurements. In the past, technology such as flexible twin axis electrogoniometer (Kim, Choi, & Kim, 2014), dynaomometers, potentiometers, digital anaylsis, goniometers and inclinometers have been utilized to measure passive and active JPS (Gay et al., 2010). However some of these devices and protocols involve wires and various attachments requiring subjects to report to a clinical or research establishment for their measurements. Since the creation of the Joint Position Sense (JPS) app, it has proven statistically reliable in recording dynamic movements of the shoulder, elbow and ankle (Gillespie, 2013; King & Karduna, 2014; Jackson, 2015). Therefore a goal of this study is to expand the utilization of the app and test its reliability of measuring proprioception of the wrist.

Purpose of this study

Assessment of proprioception after an injury, surgery or rehabilitation can be a valuable indication of neuromuscular integrity (Erickson & Karduna, 2012). Therefore obtaining accurate and precise measurements of proprioception requires reliable instrumentation. The JPS app possesses the potential to accurately quantify proprioception and contribute to research as well as clinical treatments. Using an iPod touch with the JPS app rather a goniometer or inclinometer reduces the effect of human error. The goniometer and the inclinometer require clinicians to meticulously locate anatomical landmarks for each measurement. In order to track a patient's progress, measurements require consistency and accuracy (Kolber, Pizzini, Robinson, Yanez, & Hanney, 2013). The way in which these mechanical measuring devices are used can differ from clinician to clinician or researcher to researcher. This could cause variations in measurements resulting inconsistent data and has the potential to negatively affect a patient prognosis.

The JPS app controls for discrepancies in locating anatomical and measuring methods (Kolber et al., 2013). The app is also is completely wireless unlike some electromagnetic tracking systems, making setup and operation more efficient. In order to establish compatible measurements among clinicians and researchers, it would be beneficial to utilize a single device that decreases human error and increases overall efficiency. A smartphone or iPod’s ability to deliver data via WiFi could allow patients and subjects to share their measurements with their clinician or a researcher from home or work. Applying the JPS app’s function to the wrist can aid in the process of learning more about proprioception of the wrist and how it is possibly different from body parts already studied with the app or in other research. Being able to efficiently and accurately quantify proprioception can assist in the process of detecting disease progression and conditional deficits such as multiple sclerosis, Parkinson’s disease, aging (Deshpande et al., 2003). Therefore, the first goal of the present study is to test the app’s reliability to measure proprioception of the wrist in order to help broaden the utilization of the app. The second goal is to test our hypothesis that the angular repositioning error will decrease as our target angle increases as observed in shoulder and elbow.

The Joint Position Sense (JPS) App

As the applications of technology continuously expand, both research and clinical environments benefit from new systematic methods of data collection. Recently, the JPS app has been used to test subject’s shoulder, elbow and ankle proprioception. As the app has proven reliable for these joints, we are looking to expand its applications to more body parts. Kolber et al. (2013) expressed the ease of using a smartphone vs. mechanical measuring devices such as an inclinometer or goniometer, stating how a mobile device would improve efficiency and accuracy in measurements. Therefore by continuing to test the reliability of the app on different body parts, researchers will able to expand the areas in which they study.

Wrist Anatomy and Movement

The wrist is heavily utilized in all ages and populations across the globe. It is classified as a condyloid synovial joint. Condyloid joints are biaxial allowing flexion, extension, adduction and abduction in sagittal and frontal planes. This study focuses on wrist flexion (figure 1), which involves bending the wrist toward the anterior portion of forearm, creating a smaller joint angle (Floyd, 2015, pp. 174). The muscles principally responsible for this action include the flexor carpi radialis and flexor carpi ulnaris. The flexor carpi radialis and flexor carpi ulnaris are assisted by the palmaris longus, abductor pollicis longus and the flexors of the phalanges. When in a supinated position, these muscles are located on the anterior side of the forearm (Moore, 2014, pp. 809).

Mechanoreceptors giving proprioceptive information are located within the muscles, ligaments, tendons, joints and skin of the wrist (Floyd, 2015, pp. 51). These sensory receptors react to changes in pressure, length, movement and speed of movement (Hagert, 2010). Adachi (2002) found a positive correlation between the number of mechanoreceptors and the joint position sense acuity. This suggests mechanoreceptors possess an important role in providing the CNS with sensory information for limb awareness. Of the numerous mechanoreceptors, muscle spindle fibers are commonly referred to as the main mechanoreceptors for proprioception (Erickson & Karduna, 2012). However, the wrist is mainly composed of Ruffini endings which suggests proprioception of the wrist may operate under different mechanisms than the more studied joints (Hagert, 2010).

Ruffini endings comprise 20% of the proprioceptive receptors in the ligaments and tendons of the hand and wrist (Purves, 2001). Ruffini endings are *slow adapting* and *low threshold receptors* and are highly sensitive to detecting changes in pressure, tension and skin stretch (Hagert, 2010). Although Ruffini endings are numerous in the wrist, researchers commonly categorize muscle spindle fibers as the most influential mechanoreceptor (Winter, Allen, & Proske, 2005). Muscle spindles run parallel to muscle fibers and activate with the elongation of muscles. A monotonic relationship exists between the muscle spindle firing rate and the muscle length (Winter et al., 2005). For instance, increases in the degree of muscular stretch cause the higher frequency muscle spindle firing rate. Another receptor influencing proprioception are the golgi tendon organs (GTOs), located in the musculotendinous junctions. GTOs respond to changes in force or tension in the muscle-tendon junction (Tsay et al., 2015).

When activated, these mechanoreceptors receptors send afferent signals to the spinal cord. From the spinal cord, the signal can take one of two tracts; it can continue along the medial lemniscus pathway to the primary sensory cortex or it can continue into reflex arc (Figure 2) (Jang, Kwon, Lee, Lee, & Hong, 2012; Guyton and Hall, 2011, pp.658). Reflexes allow for immediate corrections and predominately serve to protect a joint (Hagert, 2010). If there is a quick change in muscle status requiring an unconscious correction the signal will travel in a reflective arc. An example evoking a reflexive arch is when the ligaments and muscles of ankle become stretched in rapid ankle inversion and an immediate correction is needed to prevent an ankle sprain (Cordova, Cardona, Ingersoll, & Sandrey, 2000). Afferent neurons synapsing either once (monosynaptic) or multiple times (polysynaptic) onto interneurons in the spinal cord, the resultant is an efferent signal to the muscle. The efferent signal creates either contraction or relaxation of agonist and antagonist muscles (Hagert, 2010). If an immediate reflexive correction is not needed, proprioceptive information travels along the medial lemniscus pathway to the somatosensory cortex (Jang, Kwon, Lee, Lee, & Hong, 2012). Jang et al., (2012) speculates the primary motor cortex interprets information regarding the ascending proprioceptive information in order to generate muscle force and movement.

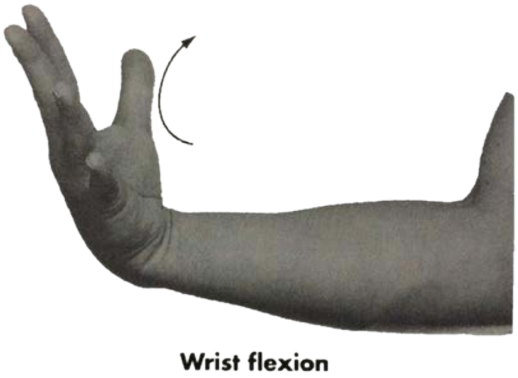


Figure 1: Wrist Flexion (Floyd, 2015, pp. 174)

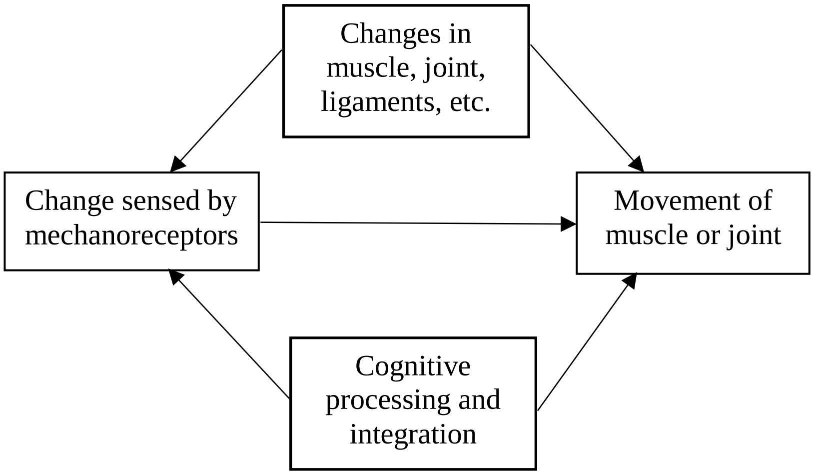


Figure 2: Simplified schematic of proprioception

Methods

Subjects

Fifteen healthy adults (10 females and 5 males) from the university community with a mean age of 21.7 ± 1.4 years old were recruited. There were 14 right-handed subjects and 1 left-handed subject. They had a mean weight of 63 ± 8.9 kg and a mean height of 1.7 ± .09 meters. Subjects were excluded if they had a recent wrist injury of their dominant hand or have been experiencing wrist discomfort and pain. Subjects reported for two testing times within 24-72 hour period of each other. Upon arriving, subjects signed an informed consent form approved by the Institutional Review Board at the University of Oregon. Subjects also completed a form detailing their demographics of: weight, height, age, exercise and sport participation, hand dominance and history of previous wrist injury.

Instrumentation

The Joint Position Sense App was downloaded to a 6th generation Apple iPod touch (4.86 inches x 2.31 inches x 0.24 inch). The iPod has a built in tri-axial accelerometer and a tri-axial gyroscope. The iPod touch was attached to the plastic side of the OBER Hand Orthosis Separate Finger Flex Spasm Extension Board Splint Apoplexy Hemiplegia (KONMED CO. LTD, Shenzhen, China) with a Quad Lock® (Quadlockcase.com) adhesive mount and universal adaptor. There were two separate medium-sized OBER hand paddles, one for left-handed subjects and one for right-handed subjects. The iPod was paired to a Bluetooth speaker.

For each trial, the app utilized the same protocol. Once the program was started, the subjects would hear a low tone, which indicated they should move their wrist into more wrist flexion. The low tone would transition into either no tone or a high tone depending on their position relative to the target position. If a high tone was heard, the subject needed to move their wrist into more wrist extension. When the subject heard no tone, they were within ± 2 degrees of the target angle and held this position for 3 seconds. After these 3 seconds, the app instructed the subject to "relax." The subjects would then return to their neutral position (± 10 degrees). The app's position hold times, angular uncertainty and position uncertainty values were chosen in order to coincide with previous joint position sense studies (King, Harding, & Karduna, 2013).

Measurement

The app was designed by the Orthopaedic Biomechanics Laboratory at the University of Oregon and developed by the University of Oregon InfoGraphics. The built-in accelerometer and gyroscope allow for limb orientations to be recorded with respect to gravity. The accelerometer located within the iPod touch was proven valid and reliable for assessing proprioception of the upper extremity (Gillespie, 2013).

Protocol

Subjects were seated in a custom-made lab chair and a stool was placed under their feet. The iPod touch was paired and connected to a Bluetooth speaker. The iPod was secured on the OBER hand paddles with the Quad Lock® and fitted to the subject's dominant hand. They then rested their elbow of their dominant hand on the lower horizontal bar of the customized chair. The medial epicondyle of their elbow was positioned in the middle of the bar. The forearm was placed in a vertical position with the palm of the hand facing their body and fingers fully extended. Their elbow location and seat height was then adjusted to accommodate a 90-degree shoulder angle. The forearm was secured with a Velcro® strap three finger widths distal to the styloid process of the radius. If the subject had a longer forearm the Velcro® straps could be moved to the middle horizontal bar located. All straps and positions were confirmed to be comfortable for the subject.

Located on the outside of the topmost horizontal bar, a custom-made jig in the shape of a “t” was positioned in order to align with the hand and forearm. The horizontal component of the jig was adjusted up or down in order to align with the proximal interphalangeal joint of the index, middle and ring fingers. This set up is demonstrated in figure 3 and 4 seen below.

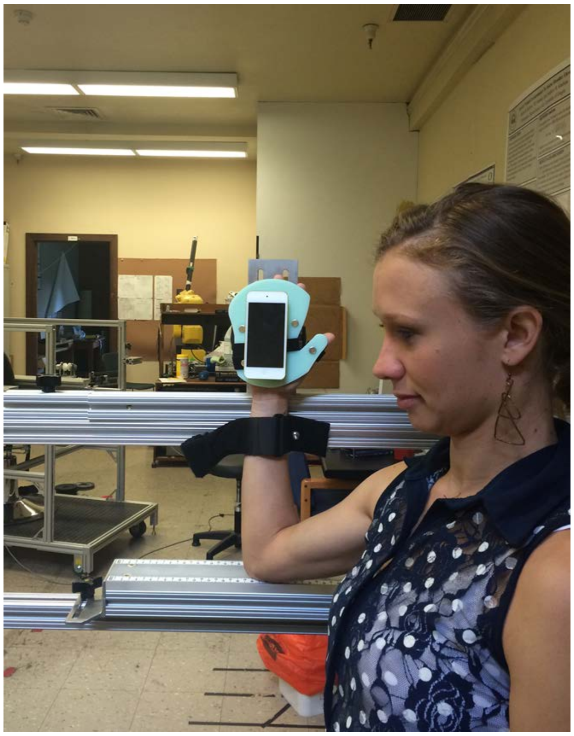


Figure 3: Set up and subject orientation

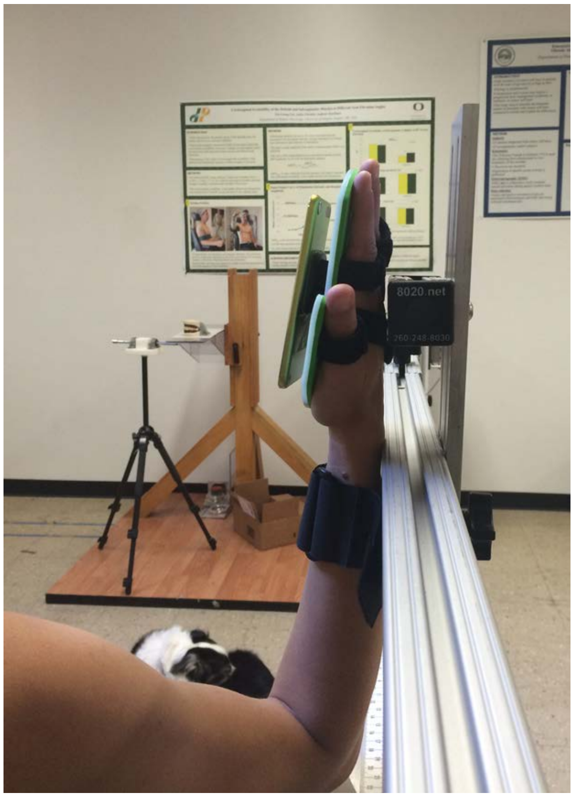


Figure 4: Neutral position

Procedure

This study aimed to examine the reliability and validity of the JPS app to assess wrist proprioception; therefore a repeated measure study was conducted. For both testing sessions subjects performed 9 iterations of wrist flexion. All flexion was performed with the subject's dominant wrist. The same active-active positioning and repositioning protocol was followed for both testing session.

Subjects were instructed to use the custom t-shaped jig to locate their neutral position by touching the horizontal bar with the back of their hand after completing each iteration (Figure 4). For this experiment, neutral position is described as having the scaphoid, lunate and triquetrum resting close to zero degrees on the radius and ulnar, with their forearm in a vertical position. The subjects were also instructed to keep their forearm in line with their elbow. They were only responsible for adjusting the position of their wrist joint during the trials.

The subjects were instructed how to interpret the auditory cues of the iPod. They were required to close their eyes throughout the practice and test trials. Four practice trials with the targets angles of 40 and 60 degrees were given before each testing session in order to familiarize the subjects with the equipment and procedure. The subjects were able to complete as many trial runs as they needed in order to feel comfortable and confident with the equipment and procedure (Winter et al., 2005). Once the subject felt comfortable, we proceeded to the testing trials. There were three target positions designated as 30, 50 and 70 degrees of wrist flexion. Each angle was presented in a randomized order for a total three trials per angle for a total of nine iterations.

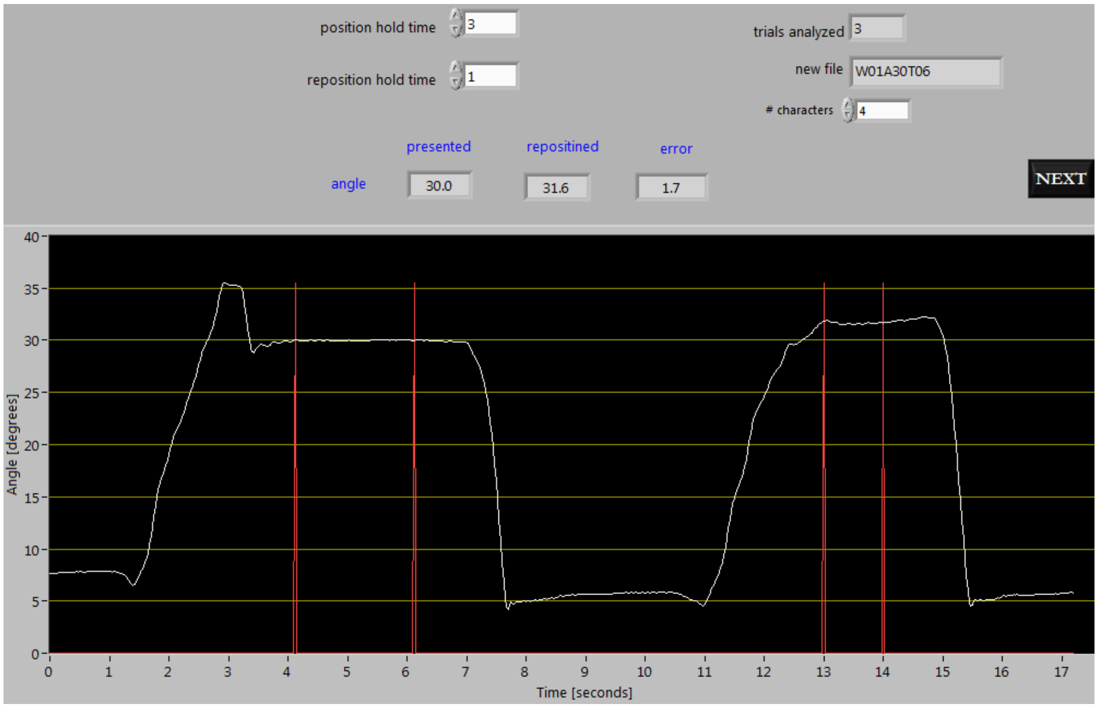
The test began when the subjects closed their eyes and verbally indicated they were ready (Figure 5). They began with the positioning phase by receiving auditory cues from the iPod. If the subject heard a low tone, they knew they were located below the target angle and needed to move their wrist into more wrist flexion. If they heard a high frequency tone, they had exceeded the target angle and needed to move their into more wrist extension. When the subject came within 2-degrees over or under the target angle, no tone was heard. They then held this position for 3 seconds. After these 2 seconds, the app would instruct them to "relax" and they returned to their neutral position (Figure 5). When they came within 10-degrees of their neutral position, they were given 2 seconds of rest. The app then commanded the subject to "find target," instigating the repositioning phase. The subjects then attempted to reposition their wrist to the target angle previously presented without any auditory cues (Figure 6). When the subject had a velocity equal or less than 0.25 °/s for one second, the app would record and store this angle as their repositioned angle. When one-iteration was completed, the next angle was presented.

Figure 5: Starting and neutral position

Figure 6: Subject in wrist flexion

Data Analysis

Once a set of active positioning and repositioning was achieved, the file was sent via Wi-Fi to Dropbox (dropbox.com). When all trials were completed for the testing period, they were processed in Labview (National Instruments Corporation, Austin, TX, USA) where they could be visually inspected for errors (Figure 6). Labview enables us to ensure all trials had been fully completed. Labview also calculated the error between the positioned and repositioned angle. Positioning error was calculated as the presented angle minus repositioned angle. A negative error would indicate the subject undershot the target angle. A positive error would indicate the subject overshot the target angle.



position hold time 3

reposition hold time 1

trials analyzed 3

new file W01A30T06

characters 4

	presented	repositined	error
angle	30.0	31.6	1.7

Figure 7: Screenshot of Labview analysis of 50 degrees wrist flexion

Statistical Anaylsis

SPSS version 22.0 (Armonk, NY: IBM Corp.) was used in order to run statistical anaylsis. Additionally, because error in angle reproduction was not dependent on testing day, an average of the two days was taken from the three target angles. We first performed a *one-way anaylsis of variance (ANOVA)* with angles 30, 50 and 70 degrees as the dependent variables. The ANOVA was performed to observe if any repositioning errors were significantly different. A *paired t-test* was then performed in order to determine differences within the groups and α was designated as 0.05. A mixed model *intraclass correlation coefficient (ICC)* was performed in order to test the reliability of the JPS app's measurements across the two testing sessions.

Results

Reliability

All 15 subjects completed the study successfully. On both testing days, subjects consistently overshot the 30-degree target and undershot the 50 and 70 degree target angles (Figure 3). The values determined by performing an ICC on the 30 trials suggest a varying reliability for the different target angles. ICC values in the parameters of .40-.75 indicate fair-good reliability while values 0.75 and up shows excellent reliability (Domingo & Lam, 2014; Portney and Watkins, 2009, pp. 588). Our ICC indicates a fair-good reliability for angles 30 and 50 degrees, while 70-degrees could be categorized as having excellent reliability (Table 1).

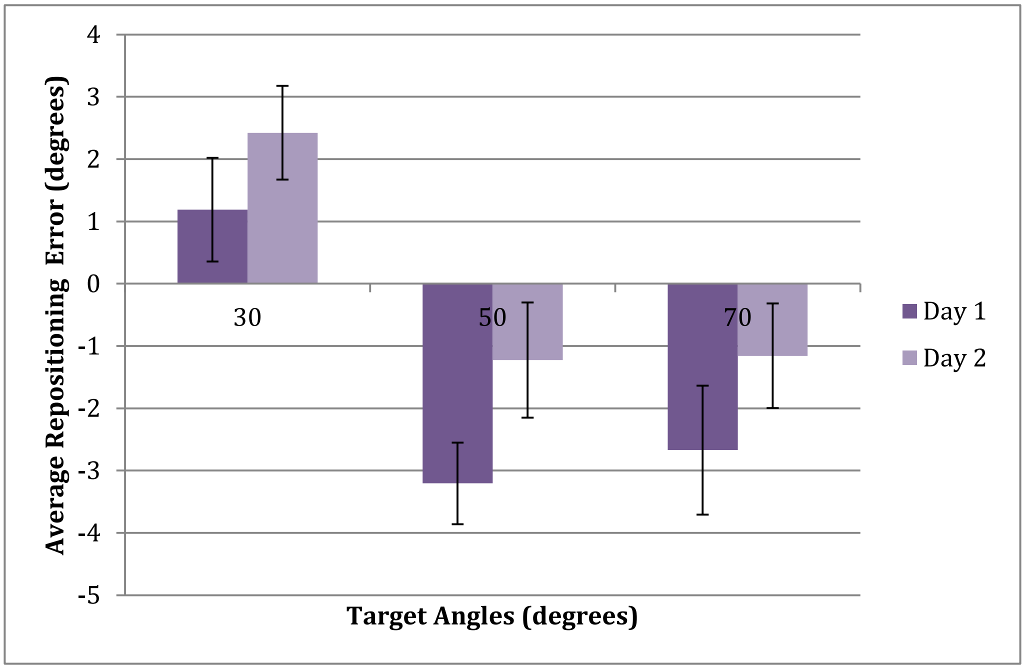


Figure 8: Day 1 and Day 2 averaged JPS errors

Variable	**ICC Value**
30º	0.566
50º	0.549
70º	0.884

Table 1: Reliability of JPS measurements

Angle Precision

An ANOVA performed with average angle error (combined between the two testing sessions) identified a difference in JPS error between at least two of the angles of 30, 50 and 70 degrees (p = 0.001). In order to determine which target angles were significantly different, paired t-tests were performed between 30-50, 30-70 and 50-70 (p = .05). The results of the paired t-test, as demonstrated in figure 4, reveal a significant difference (p = .05) between angles 30-50 ($p < 0.001$) and 30-70 (p = 0.008) but no difference between angles 50-70 (p = 0.799). These results suggest there is an effect of angle on the repositioning angle.

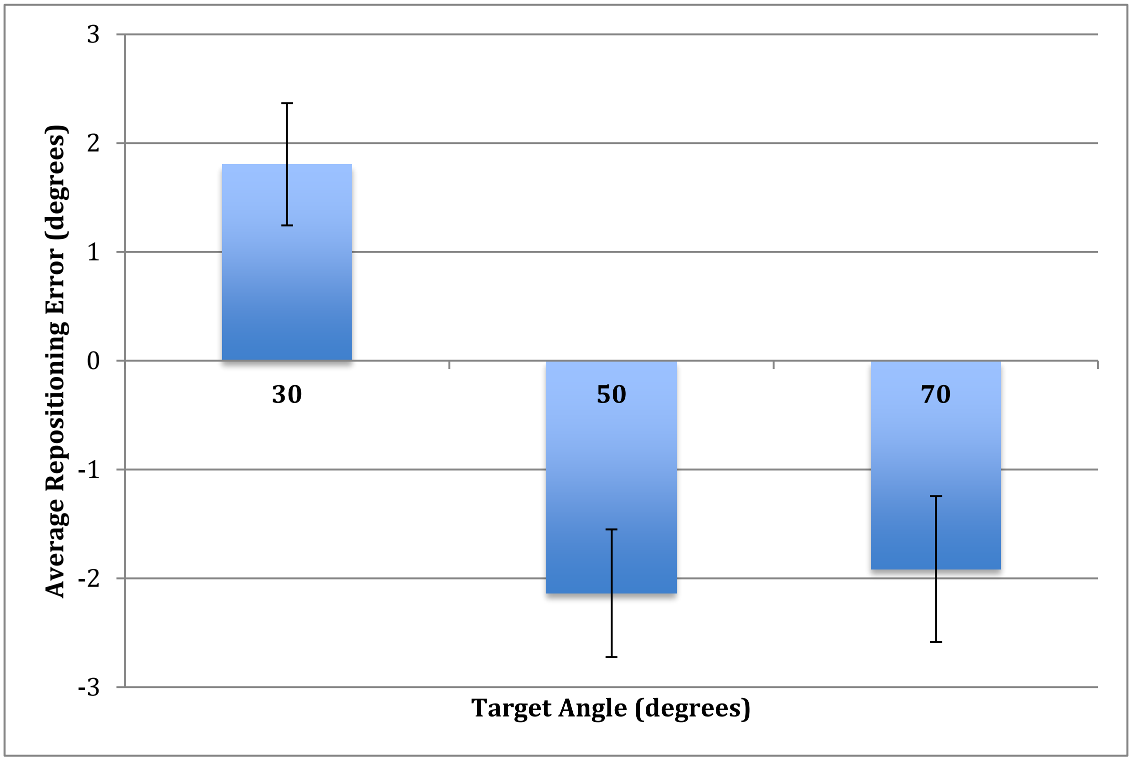


Figure 9: Average JPS error ± Standard error of the mean

Discussion

Proprioception enables smooth gross and fine motor control. It is hypothesized that joint position sense can be attributed to the slow adapting musculotendinous, consisting of muscle spindles and GTOs as well as capsuloligamentous mechanoreceptors (Ruffini endings) (D. Suprak, L. Osternig, P. Donkelaar, A. Karduna, 2006). Any impairment to the proprioceptive receptors, pathways or neurons can result in a decrease in limb function, balance or postural-control. Impairments can also increase the risk for re-injury and gaps in sensorimotor information (Myers et al., 2006). Collecting accurate clinical assessments of a patient's proprioception function is difficult (Cappello et al., 2015). Additionally, the way in which researchers quantify proprioception differs due to the utilization of different devices and their methodologies. Although devices such as inclinometers and goniometers are generally reliable, discrepancies can arise because researchers or clinicians lack a standard method. This can lead to poor data collection or misguided treatments. Therefore, advancing methodologies is important in order to help assess proprioception clinically. The present study was conducted to test the reliability of a mobile device to quantify proprioception of the wrist. We hypothesized that angular error would decrease as the joint angle increased. This relationship was observed in previous upper extremity joint position tasks conducted in our lab (Gillespie, 2013; King & Karduna, 2014).

The first aim of the present study was to determine the validity of using the JPS app on an iPod to measure wrist proprioception. In order to establish the reliability of the device's measurements, we assessed ICC's for the three target angles between the two testing sessions. Our ICC scores for repositioning errors at angles 30 and 50 degrees were relatively low (Table 1). There are discrepancies as to the value of a score below 0.75. ICC scores falling below 0.75 have been analyzed as “poor to moderate,” and fair-good (Portney and Watkins, 2009, pp. 568; Domingo et al., 2014). However, 70-degrees had a high ICC score, which is consistently considered to be in the “excellent” range (Domingo et al., 2014). The differences and magnitude of the scores will be discussed below.

The second purpose of this study was to observe whether the wrist joint follows a similar trend as the shoulder and elbow. We hypothesized joint position sense of the wrist improves as the flexion target angle increases. We found an overall effect of angle on JPS errors. A follow-up test shows there is a significant difference between 30-degrees and 50 as well as between 30 and 70 degrees. Our results are similar to those from the shoulder and elbow in that there is an effect of angle on JPS acuity, but contrary to our hypothesis, there was not a decrease in JPS error as the angle of the flexion increased.

Floyd (2015, pp. 172) defines the end range of wrist flexion as 70-90 degrees. As noted earlier, a majority of mechanoreceptors in the wrist are Ruffini endings, while muscle spindles are thought to contribute the most to propriocpetion in the shoulder and elbow (Purves 2001). Capsuloligamentous mechanoreceptors, like Ruffini endings, are activated more frequently during end point positions of a joint, while mechanoreceptors send proprioceptive information during mid-range positions (Suprak et al., 2006). Ruffini endings may provide the most proprioceptive information of the wrist because they are the most abundant receptor in wrist ligaments **(**Hagert, 2010). This numerical difference between Ruffini endings and muscle spindles may contribute to the decrease in repositioning error observed at 30 and 70 degrees compared to 50-degrees. These data can contribute to future assessments of the upper extremities. Future practice and research should take into account that proprioception of the wrist may be different than that of the shoulder and elbow.

Limitations

One limitation of the present study includes the small sample size. A total of 15 subjects completed the study. However, a larger sample size would increase the confidence of the values while decreasing the uncertainty. This limitation could coincide with our lower ICC scores for 30 and 50 degrees. Since increasing the sample size lowers variability, it is possible the small sample size of this study contributed to lower ICC scores (Portney and Watkins, 2009). Similarly, our subject population solely consisted of students in the university population (aging from 20-26 years). Age is important when considering accuracy of proprioception (King & Karduna, 2014).

Another limitation of this study is that we only measure JPS of wrist flexion. Therefore, future studies should try to incorporate all the degrees of freedom associated with the wrist in order to provide any clinical significance (Cappello et al., 2015). Wright et al. (2011) state that wrist flexors are composed of more muscle spindles than wrist extensors since they have a larger cross sectional area. It would be interesting to assess possible differences JPS acuity during these wrist motions.

Finally, the measurements collected on day 2 demonstrate a trend of increase joint position sense accuracy for angles 50 and 70 degrees compared to day 1 (Figure 1). Therefore, there is a possibility subjects were more comfortable with the protocol during the second testing session. This could also imply subjects remembered the general angles from day 1. To control for these limitations, future studies could employ more practice iterations during the first session and expand the gap between testing sessions.

Future studies

One of the main objectives of this study was to design a protocol for testing the validity of the JPS app's ability to measure proprioception of the wrist and for it to be implemented in future studies. For instance, a portion of an upcoming study in our laboratory plans to investigate the symmetry or lack of between dominant and non-dominant upper extremity joint position sense in males and females. In that study, the lab will be using the shoulder and elbow protocols previously established as well as this wrist protocol to collect proprioception data of the dominant and non-dominant upper extremity. They will then analyze these data to investigate if there is a difference in proprioception between dominant and non-dominant upper extremities as well as any discrepancies between genders.

Wrists are highly utilized in day-to-day activities, work and sports. Therefore maintaining wrist health is important for everyone, as it contributes to writing, typing, communication, driving, throwing, catching, etc. When patients experience wrist pain or discomfort, ice is commonly applied. Even though *cryotherapy* is often utilized for joint injuries and pain, many researchers have suggested the possibility of cold modalities such as ice inhibiting proprioception and therefore motor control. Although it has been shown icing for a short period of time (10min) will not affect lower limb reaction time (Thain, Bleakley, & Mitchell, 2015), it would be interesting to investigate if these results are mirrored in the wrist. This information could assist in determining if the treatment has any beneficial effects besides acting as an analgesic as well as its effects on proprioception.

Since proprioception is utilized in monitoring injuries, disease progression, and so forth, developing a protocol that is systematic could prove advantageous for researchers and clinicians. Fong et al. (2015) conducted a studied involving children with *Developmental Coordination Disorder (DCD)*, and used a number of measurements to quanitfy their mucsular latancies, balance and motor performances. Studies like these where there is an unknown reason for neuromuscular deficits could benefit from utlizing the JPS app and smartphone technology to quantify proprioception. With the simplicity and ease of use, the app offers the opporuntity for clinicians and reasearchers to track patient progression or degression and enable them to learn more about certain diseases and treatments.

Conclusion

Cappello et al. (2015) argue that clinical assessments of proprioception are inadequate and unrefined. Therefore neurological diseases and impairments as well as kinetic deficits such as stroke, multiple sclerosis, Parkinson’s disease, focal dystonia, peripheral sensory neuropathies or injury to body tissues could benefit from a cohesive and systematic method of assessing proprioception (Hoseini et al., 2015). The JPS app has the ability to create an efficient and simple modality for quantifying proprioception. Our results may have clinical and research importance by identifying the possibility that wrist proprioception does not follow the same linear trend as the shoulder and elbow. We did not see JPS linearly increase as the flexion target angles increased. Future research studies may need to account for this difference. Overall, the JPS app’s efficacy of quantifying proprioception leads us to determine it is valid for measuring proprioception of the wrist. While our results demonstrate JPS of the wrist joint is not affected by an increase in joint flexion, more studies are needed to observe if this trend can be replicated. It would also be beneficial to replicate this study with different age groups and with more degrees of flexion in order to form a more comprehensive idea of the mechanisms and trends of wrist proprioception compared to the other extremities.

Glossary

1. *Afferent Signals:* Sensory signals that travel along afferent nerve fibers to the CNS.

2. *Efferent Signals:* Carry motor commands away from the CNS to the muscles.

3. *Intraclass Correlation Coefficient (ICC):* used to measure reliability between two measurements.

4. *Cryotherapy:* treatment types involving extremely cold temperatures. Common examples are ice, ice packs

5. *Developmental Coordination Disorder (DCD):* Deficits in motor skills such as coordinated movements, balance that have no identifable caustion.

6. *Joint Position Sense (JPS):* ability to recognize a limb's spatials orientation.

7. *Kinesthesia:* awareness of joint or limb movements in space.

8. *Low threshold receptors:* receptors that are easily activated, small changes from homeostasis will cause them to generate action potentials.

9. *Mechanoreceptors:* Peripheral afferent neural receptors located in the skin, fascia, joint capsules, ligaments, muscles and tendons. They respond to physical deformation of the tissue and send neural signals to the central nervous system for integration.

10. *One-Way Analysis of variance (ANOVA):* a statistical test used to determine if there is a statistical difference between the averages or means of two or more groups.

11. *Paired t-test:* a test used to compare the means of two populations to determine if any statistical correlation exists between the two populations.

12. *Proprioception:* Integration of afferent information arising from muscles, joints, skin or ligaments, fascia and tendons with which contributes to limb awareness, motor control and postural stability.

13. *Sensorimotor system:* the integration of all the sensory and motor information in order to maintain joint stability. It is composed of:

proprioception, joint position sense, kinesthesia, force generation and neuromuscular control.

14. *Slow adapting receptors:* These receptors detect deformations or changes even if the stimulus is continuously applied.

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