Joint position sense – There’s an app for that

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1. Introduction

Mobile technology is expanding our ability to collect data outside of a laboratory environment, and the field of biomechanics is no exception. Several studies have taken advantage of motion sensors built into smartphones and other mobile devices to assess acceleration (LeMoyne et al., 2013; Wolfgang et al., 2014), physical activity (Bergman et al., 2012; Nolan et al., 2014), gait (Furrer et al., 2015; Sun et al., 2014), posture (Galan-Mercant and Cuesta-Vargas, 2014; Patterson et al., 2014) and range of motion (Bederak et al., 2014; Mitchell et al., 2014). However, to our knowledge, only one published study has reported using this technology to assess angular kinematics, in which head motion was measured for the purpose of assessing gaze stabilization (Huang et al., 2014).

Previous work from our laboratory has demonstrated that with low angular velocities and accelerations, angular kinematics can be accurately calculated with the use of a triaxial accelerometer (Amasay et al., 2010; Amasay et al., 2009). Since accelerometers and gyroscopes are common in current mobile devices, this technology has the potential for studying mobile-based assessments of motion. The focus of the present study was to demonstrate the ability of a mobile device to assess joint position sense (JPS), which is a sub-modality of proprioception. JPS represents the ability to identify the orientation of a limb in space, in the absence of vision. Many protocols for assessing JPS have used a passive model, in which an external apparatus moves a body segment. Recently, protocols have been developed based on active movements, which are more representative of functional activities. However, even these approaches require expensive testing equipment and the necessity of a visit to a research lab, as there are no commercially available mobile instruments that allow for the assessment of proprioception outside of a laboratory setting. The objective of this study was to demonstrate the validity and feasibility of using a mobile device (iPod Touch) to assess joint position. We conducted a concurrent validity study in the lab (n = 9) and a field based study (n = 79). The field based study was conducted at the 2012 American Society of Biomechanics meeting in Gainesville, Florida. The results of both studies demonstrate good agreement with our established protocol using a magnetic tracking device, with angular errors decreasing with increasing shoulder flexion angles. The studies demonstrate the validity and feasibility of using mobile devices for assessing motion-based parameters, both inside and outside of a laboratory setting.
or physical therapy was eliminated from data analysis. Also, any subject who participated in a sport involving overhead activity more than three times a week for more than five years was also excluded from data analysis. This resulted in 79 subjects for analysis (47 male and 32 female), with a mean age of 34 years (SD 11), a mean height of 174 cm (SD 10), and a mean body mass of 74 kg (SD 17). Both studies were approved by the Institutional Review Board at the University of Oregon and all subjects provided informed consent.

2.2. Protocol

Shoulder JPS was assessed with an active joint repositioning task, using an app developed for the 4th generation iPod Touch (Apple, Cupertino, CA). This device has a mass of 100 g, measures 4 cm × 6 cm × 0.6 cm and contains a 3-axis tri-axial accelerometer and a 3-axis gyroscope. The angle of the device with respect to gravity was calculated from the accelerometer data, as we have done previously for an ambulatory tri-axial accelerometer (Amasay et al., 2009). The 95% confidence interval of the accuracy of the iPod Touch to measure acceleration due to gravity is 1% (Khoo Chee Han et al., 2014). The JPS protocol used was a modification of a protocol from our lab in which we used a magnetic tracking device to record kinematics (King et al., 2013). Both protocols assessed JPS during shoulder elevation with the same target angles and number of trials. However, instead of visual cues, the app provides auditory commands to the subject, while subjects kept their eyes closed. Additionally, kinematics are calculated with respect to gravity, rather than with respect to a thoracic sensor (King et al., 2013).

Subjects were in a seated position on a stool with their feet flat on the ground, sitting up straight. The iPod Touch was attached to the lateral side of their dominant humerus with an armband (Fig. 1A). Subjects were instructed on the procedure and allowed practice trials at non-test angles in order for them to become familiar with the protocol. Subjects were told to only move their shoulder, keeping their elbow locked in full extension with their thumb pointing upwards. For the experiment, subjects were presented with three target ranges of shoulder flexion angles: 50°, 70°, and 90°, each plus or minus two degrees (Fig. 1B). Each target position was presented four times for a total of 12 trials, which were randomized.

At the start of a trial, there was a low frequency tone, which indicated that the shoulder was below the target range (eg., 48°). When the subject elevated their arm into the target range (eg., 48°–52°), the tone was silenced. If the subject overshoot the range (eg., 52°), then there was a high frequency tone. Subjects continued to adjust their elevation angle (increased elevation if there was a low tone and decreased elevation if there was a high tone), until they were in the target range (no sound). They had previously been instructed to memorize their arm position during this time. After the position had been held for two seconds, the subject was prompted by a “relax” cue, which instructed them to return to the starting position (arm at the side). After three seconds, they were instructed to “find target,” at which point they attempted to replicate the target angle they had just memorized. The device recorded their repositioned angle when their velocity was less than 0.25 degree/sec for a one second time period. Once the testing for a given angle had finished, the subject was automatically prompted on to the next trial. The differences between the actual angle reached with auditory cues and the repositioned angle, with no auditory cues, were calculated and the constant and variable errors and was used for analysis (Schmidt and Lee, 2005). As noted above, the actual angle was always within two degrees of the target angle.

For the field based study, only the iPod Touch was used. To help facilitate the collection of data from as many subjects as possible, three subjects were tested simultaneously. For the lab based study, subjects were also instrumented with a Liberty magnetic tracking device (Polhemus, Colchester, VT), as described previously (Lin and Karduna, 2016). Sensors were mounted on the manubrium of the sternum, the flat area of the acromion, and on the distal humerus via a custom-molded cuff. Anatomic landmarks were palpated and digitized, using the standards recommended by the International Society of Biomechanics (ISB) (Wu et al., 2005). Kinematic data were converted from sensor coordinate systems to anatomic coordinate systems. The JPS protocol was performed exactly the same as the field based study, with the exception that kinematics data were collected simultaneously from the iPod Touch and the magnetic tracking device. Errors were calculated from both sets of kinematics data.

2.3. Statistical analysis

SPSS version 23 (IBM, Chicago IL) was used for statistical analysis. For the lab based study, we performed paired t-tests, comparing constant and variable errors between the iPod Touch and magnetic tracking devices at each target angle (50°, 70°, and 90°). For the field based study, we performed a one-way repeated measures analysis of variance (ANOVA) with target angle (50°, 70°, and 90°) as the independent variable and constant and variable errors as the dependent variables. Pairwise comparisons were performed when a significant main effect was found with the ANOVA. Additionally, the data were qualitatively compared with the results from our previous lab-based study of JPS (King et al., 2013).

Fig. 1. Picture of subject during testing protocol with iPod Touch mounted on the arm. A) Shoulder at the side. B) Reaching for target.
3. Results

For the lab based study, there were no significant differences at any angles for both the constant errors ($p > 0.40$) and variable errors ($p > 0.05$). The differences between the mean errors calculated with the iPod Touch and magnetic tracking device range from $0.1°$–$0.4°$ (Fig. 2).

For the field based study, the results from the ANOVA demonstrated a significant effect of target on constant error ($p < 0.001$) and variable error ($p = 0.025$). Follow-up pairwise comparisons revealed that constant errors at $50°$ ($M=4.5°$) were significantly larger than errors at $70°$ ($M=2.8°$) and $90°$ ($M=2.3°$). Similarly, variable errors at $50°$ ($M=2.4°$) were significantly larger than errors at $70°$ ($M=2.1°$) and $90°$ ($M=2.0°$). These data are similar to our previous study (King et al., 2013), both in terms of the value of the errors, and the general shape of the response (Fig. 3).

4. Discussion

With the exception of low tech options, like goniometers (Vafadar et al., 2015), inclinometers (Dover et al., 2003), and laser pointers (Balke et al., 2011), quantitative assessments of proprioception have largely remained limited to laboratory settings. The long-term goal of this project is to evaluate an inexpensive, portable and relatively quick method for the assessment of proprioception that would be applicable in both a clinical and research setting. Such an instrument would be useful in allowing larger scale proprioception questions to be addressed. The main objectives of the current study were to demonstrate the validity and feasibility of using an iPod Touch.

Despite the numerous differences in kinematic assessment for the iPod Touch (eg, greater mass, no thoracic sensor, gravity based) when compared to a magnetic tracking device, our lab based validation study demonstrated remarkable agreement when compared to a magnetic tracking device, for example at an athletic event or a nursing home. The results in the present study are consistent with previous work from our laboratory (King et al., 2013; Suprak et al., 2006) and others (Balke et al., 2011; Hung and Darling, 2012; Vafadar et al., 2015) that demonstrated that as shoulder targets approached $90°$ of elevation, the errors of joint repositioning decreased. The present study demonstrated a similar pattern although with a larger subject population. When compared to King et al. (2013), which used the same shoulder motion (flexion) and same targets ($50°$, $70°$, and $90°$), not only was there a similar trend observed, but the errors at each of the target angles were similar in magnitude, with less than a one degree of deviation (Fig. 2).

Mobile devices have been used to assess joint angles during static tasks at the spine (Bedekar et al., 2014), elbow (Ferriero et al., 2011), knee (Jenny et al., 2015), wrist (Kim et al., 2014), shoulder (Johnson et al., 2015), and foot (Otter et al., 2015). In fact, there are several commercial apps available on the iTunes store that are specifically designed for clinicians or researchers to assess joint angles (eg, DrGoniometer, Simple Goniometer, GetMyROM, Knee Goniometer). However, we are not aware of any application in which the dynamic assessments of joint motion can be incorporated into the app. Although the focus of the present study was on shoulder JPS, we have also utilized this app for assessing JPS of the elbow, wrist, knee and ankle and are optimistic that the app has utility for multiple joints.

With the efficacy that this device provides, it not only allows more data to be collected, but also allows the potential for wider ranges of studies to be performed. In addition to allowing for a large subject pool to be collected, wireless transmission of accelerometer data is possible. We used a cloud-based service (Dropbox, San Francisco, CA) to view the data from a trial within $15$ s of it being collected, which allowed for the verification of proper completion of the trial and also supplied immediate data response. Furthermore, the device is portable, as well as efficient and easy to use. The iPod Touch also provided verbal commands through wireless headphones. These commands would allow for other types of vibrotacile and auditory feedback to be used. For example,
an iPhone was used to deliver vibrotactile feedback, in assistance with balance positioning (Lee et al., 2012). Our JPS app along with other apps could be useful in the assessment of ROM, biofeedback and training tools. We chose to use an iPod Touch because we did not need cellular data; however, the app will work equally well on an iPhone. Future versions could be targeted for Android based devices.

It is important to acknowledge several limitations to this present study. Firstly, because this is an ipsilateral remembered task, this protocol may not be suitable for patients with short term memory deficits (Goble, 2010). This would likely be more of a concern to patients with neurological, as opposed to musculoskeletal pathologies. Another consideration is that the device measured angles with respect to gravity. Therefore, since the device was attached to the humerus, we were unable to consider or calculate the sway of the trunk. Traditional JPS studies are able to account for trunk sway due to their ability to attach multiple devices to the body. Finally, with the current version of the app, we can only use an ipsilateral remembered model. However, it is technically possible to link two devices together, which would allow for a contralateral matching model to be used.

5. Conclusions

The results of the present study of JPS with an iPod touch was found to be consistent with assessment made with a magnetic tracking device, demonstrating that subjects had the highest errors at 50° of shoulder flexion, with errors decreasing as flexion angles increased. The iPod Touch provides an ideal platform for a quick and inexpensive assessing joint position sense.

Conflict of interest

There are no known conflicts of interest associated with this work. Specifically, there are no financial or personal relationships with other people or organizations that could inappropriately influence or bias this work.

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References


