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Original Research

# Shoulder and elbow joint position sense assessment using a mobile app in subjects with and without shoulder pain - between-days reliability

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ABSTRACT

*Objectives:* To determine between-days reliability and the minimal detectable change for shoulder and elbow joint position sense assessment using a validated mobile app, in subjects with and without shoulder pain.
*Design:* Reliability study.
*Setting:* Clinical measurement.
*Participants:* Subjects with (n = 25) and without shoulder pain (n = 29).
*Main outcome measures:* Subjects were assessed by the same examiner in two sessions, with one-week interval. Active joint repositioning tests of shoulder flexion and scaption and elbow flexion were assessed at the target-angles of 50°, 70°, 90° and 110°. Intra-class correlation coefficient, standard error of measurement and minimal detectable change were calculated for constant, absolute, total and variable errors.
*Results:* Good to excellent reliability was found for constant, absolute and total errors at the target-angle of 50° of scaption for healthy subjects; at 110° of shoulder flexion and all target-angles for elbow for both groups.
*Conclusions:* The mobile app is a reliable tool and may be useful for assessing shoulder joint position sense mainly at 110° of flexion and for elbow between 50° and 110° of flexion in subjects with and without shoulder pain. Minimal detectable changes were demonstrated and may help clinicians to follow-up rehabilitation and researchers to interpret findings of studies.


## 1. Introduction

Proprioception plays an important role in sensorimotor control and is essential for maintaining functional joint stability (Riemann & Lephart, 2002). The shoulder joint depends heavily on sensorimotor control due to its poor capsuloligamentous and osseous stability (Myers & Lephart, 2002) and shoulder proprioception has been widely investigated in different populations and disorders (Ager et al., 2017; Fyhr, Gustavsson, Wassinger, & Sole, 2015). Proprioception assessment is usually divided in three submodalities: joint position sense (JPS), that is the ability to determine a segment position in space; kinesthesia, the ability to identify joint movement; and force sense, the ability to appreciate and interpret forces applied to or generate within a joint (Myers & Lephart, 2000). Joint position sense is the most frequently modality assessed, through joint positions matching tasks, performed passively or actively (Goble, 2010). It has been assumed that active tests are more functional (Ager et al., 2017; Erickson & Karduna, 2012; Suprak, Osternig, van Donkelaar, & Karduna, 2006), considering the enhanced muscle spindles sensitivity and the role of the efferent copy that may be used for target position replication (Goble, 2010).

Several tools have been used for JPS assessment, with most of

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the studies using laboratory equipments, such as motion analysis systems (Suprak et al., 2006; Vafadar, Côté, & Archambault, 2015), isokinetic dynamometer (Haik et al., 2013; Myers, Guskiewicz, Schneider, & Prentice, 1999) and other devices specifically designed for laboratory assessments (Lönn, Crenshaw, Djupsjöbacka, Pedersen, & Johansson, 2000; Lubiatowski et al., 2013). Considering the importance of assessing shoulder proprioception for injury prevention and rehabilitation in clinical and sports settings, portable and low-cost devices for JPS assessment in clinical practice and field-based research have been investigated (Dover & Powers, 2003; Vafadar, Côté, & Archambault, 2016). However, the described methods have some limitations, such as presenting the target position passively (Dover & Powers, 2003), unspecific target position presentation and low reliability in high arm elevation positions (Vafadar et al., 2016).

In order to provide an accurate method for assessing JPS during active joint repositioning tests in specific target angles, Edwards et al. (Edwards, Lin, King, & Karduna, 2016) have developed a mobile app for JPS assessment. The app validity was demonstrated, with a good agreement with an established position matching protocol using a magnetic tracking device (Edwards et al., 2016). For use in research and clinical settings, validity, reliability and precision of a measurement need to be demonstrated (Clark et al., 2016). The lack of psychometric studies on shoulder proprioception assessment has been pointed out by a recent systematic review (Ager et al., 2017). A study investigating the effects of fatigue and Kinesio taping on shoulder JPS has demonstrated moderate to good reliability of the app (Zanca, Mattiello, & Karduna, 2015). However, that study involved only healthy subjects and assessment was performed up to 90° of arm elevation (Zanca et al., 2015), which may not be representative for some daily life and sports activities (Fleisig, Bolt, Fortenbaugh, Wilk, & Andrews, 2011; Skejø, Møller, Bencke, & Sørensen, 2019; Taylor, Kedgley, Humphries, & Shaheen, 2018) and does not comprehend ranges involved in the pathomechanics of shoulder pain (Lawrence, Braman, Staker, Laprade, & Ludewig, 2014).

In order to use the app for assessing JPS deficits and following-up intervention effects, it is important to know its reliability and the minimal detectable change (MDC). Considering that the shoulder and elbow present similarities in JPS acuity patterns (Karduna & Sainburg, 2012) and that elbow JPS is also affected in subjects with shoulder pain (Ettinger, Shapiro, & Karduna, 2017), the present study involved the assessment of both shoulder and elbow JPS. Therefore, the aim of this study was to assess between-days reliability of shoulder and elbow JPS using a mobile app in subjects with and without shoulder pain.

## 2. Methods

### 2.1. Participants

Twenty-five subjects with shoulder pain (15 female and 10 male; 25 years (SD 7.6); 168 cm (SD 8); 71.6 kg (SD 12.5)) and 29 healthy subjects (15 female and 14 male; 26.3 years (SD 6); 170 cm (SD 9); 69.6 kg (SD 13.4)) were included in this study. Among healthy subjects, 17 (59%) reported to be involved in regular physical activity for recreational or health purposes. Among subjects with shoulder pain, 13 (52%) were physically active. Subjects with shoulder pain presented symptoms for at least 6 months and positive clinical tests for shoulder impingement (Cools, Cambier, & Witvrouw, 2008). Exclusion criteria for both groups were previous shoulder or elbow joints dislocation or surgery, joint laxity, neurological or systemic diseases, overhead athletes. This study was approved by the Ethics Committee of the University and all volunteers signed informed consent agreements.

### 2.2. Procedures

The same examiner assessed subjects in two sessions, with a one-week interval between sessions. All assessments were performed in the same laboratory and subjects were tested in the same time of the day in both sessions. The *Shoulder Pain and Disability Index* (SPADI) was administered before each testing session. Shoulder and elbow JPS was assessed during active joint repositioning tests using the mobile app (Edwards et al., 2016; Zanca et al., 2015) installed on a 5th generation iPod (Apple, Cupertino, USA). Subjects seated on a stool, were blindfolded and used Bluetooth headphones for auditory commands (Fig. 1). JPS was assessed during elbow and shoulder flexion and scaption (arm elevation in the scapular plane). Target-angles were 50°, 70°, 90° and 110° for all tests. These target-angles include functional range of motion for most daily-life and sports activities (Taylor et al., 2018; Wagner, Buchecker, von Duvillard, & Müller, 2010) and have been used by previous studies (Suprak et al., 2006; Suprak, Sahlberg, Chalmers, & Cunningham, 2016). For shoulder tests, the device was attached below the deltoid muscle origin, in order to avoid possible muscle contractions artifacts. For elbow tests, the device was attached on anterior lower arm, just above the wrist. The iPod long axis was parallel to the bone shafts and attached using a sport's band.

Tests started with the limb relaxed at the side of the body. No previous calibration was necessary, since the app uses iPod sensors to calculate the angles relative to gravity. In pilot tests, subjects tended to move the shoulder towards extension while performing elbow flexion. Therefore, a cylindrical support was used for a light touch of the upper arm during elbow tests to minimize compensatory movements (Fig. 1D). Subjects started moving the segment tested when hearing a tone. Low-frequency tones indicated that the segment was below the target-angle and was silenced when it reached the target-angle (±2°). High-frequency tone indicated when the segment overshot the target. Subjects were oriented to find the target following the auditory cues, to hold the position for 3 s, and then were instructed to relax. All commands were standardized and given by the app. After 2 s at the initial position, subjects were prompted to reposition the segment at the target-angle with no visual or auditory feedback. Each target was presented three times in a random order. Before each test, subjects performed two trials of each movement in different target-angles (40° and 60°) for familiarization. For symptomatic subjects, the painful shoulder side was assessed. For healthy subjects, the assessed side was randomized, since dominance does not influence JPS (King, Harding, & Karduna, 2013; Voight, Hardin, Blackburn, Tippett, & Canner, 1996). Pain (10-points Numerical Pain Scale) and muscle fatigue (10-points Borg Scale) were assessed before and following each session, in order to control possible influences of these factors on the reliability results.

### 2.3. Data analysis

Test data were recorded by the app and then exported and analyzed using a customized program written in LabView (version 2013, National Instruments Corporation, Austin, TX, USA). The difference between the reproduced angle ($\theta r$) and the presented angle ($\theta t$) was calculated for each joint reproduction trial (i), resulting in $\theta ei$. Four JPS errors were calculated according to the following equations:

Constant error (CE): $\Sigma(\theta ei)/3$;

Absolute error (AE) $= \Sigma(|\theta ei|)/3$;

Variable error (VE) $= \sqrt{\Sigma(\theta ei - CE)^2/3}$;

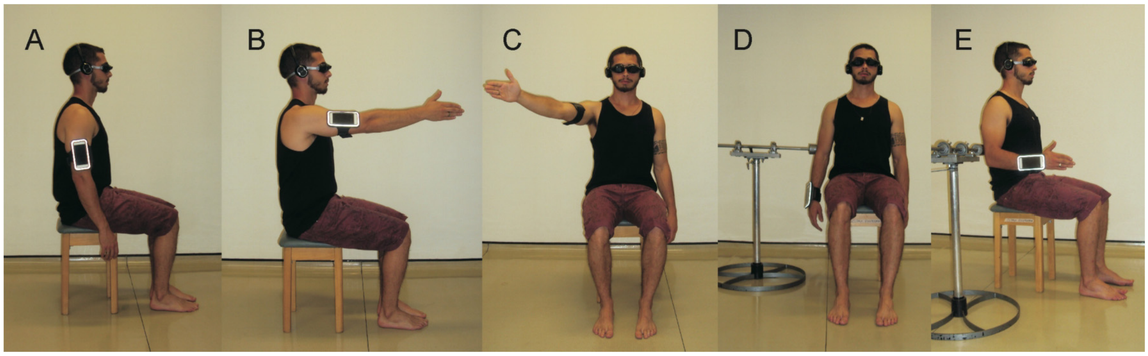


**Fig. 1.** Setting for joint position sense assessment using the mobile app: initial position for shoulder tests (A); target-angle at 90°of shoulder flexion (B); target-angle at 90° of scaption (C); initial position for elbow tests (D); target-angle at 90° of elbow flexion (E).

Total error (TE) = ($\sqrt{\Sigma(\theta ei^2)}$).

SPSS 17.0 (Chicago, IL, USA) was used for statistical analysis. Relative reliability was determined by intraclass correlation coefficient ICC(2,3), interpreted as poor reliability when below 0.4; moderate to good reliability when between 0.4 and 0.74; and excellent reliability when higher than 0.75 (Fleiss, 1986). Absolute reliability was analyzed by the standard error of measurement (SEM), calculated as SEM=SD*$\sqrt{(1\text{-}ICC)}$, where SD is relative to mean of all subjects. Furthermore, MDC with 95% confidence (SEM*$\sqrt{2}$*1.96) was calculated.

Wilcoxon tests were used to compare SPADI scores between-days ($\alpha = 0.05$) and shoulder pain and fatigue before and following each test session ($\alpha = 0.0125$, with Bonferroni correction for multiple comparisons). For assessing JPS error patterns, three-way mixed-model ANOVAs for first session repositioning errors of shoulder (group as between-subjects and target-angles and movement as within-subject factors) and two-way mixed ANOVAs for elbow (target-angles as within-subject and group as between-subjects factor) were performed (considering $\alpha = 0.05$ with Sidak correction for multiple comparisons).

## 3. Results

Tables 1 and 2 present results for shoulder and Table 3 for elbow JPS reliability. The highest ICCs (equal or higher than 0.75) were found for CE and TE at 50° of scaption for healthy subjects, for TE at 70° and AE at 110° of shoulder flexion for subjects with pain. Among these conditions, the SEM and MDC varied, respectively, from 0.7° to 1.9° for AE at 110° of shoulder flexion in subjects with shoulder pain to 2.3° and 6.3° for CE at 50° of scaption in healthy subjects. For the elbow, the highest ICC were found for CE at 70° and AE at 110° of elbow flexion for healthy subjects; and for CE at 90° and 110°, AE and TE at 70° and 90° of elbow flexion for subjects with shoulder pain. The SEM and MDC for these conditions varied, respectively, from 2.3° to 6.4° for CE at 110° to 4.3 and 11.8° for TE in subjects with shoulder pain.

Between-subjects variance of repositioning errors was not significant ($P < 0.05$), according to the F-test from SPSS output for ICC, for several repositioning errors in all target-angles of scaption, except for healthy subjects at 50°; at 50° and 70° of shoulder flexion for healthy subjects; and at 90° of shoulder flexion for both groups. In these cases, results may not be considered valid (Portney & Watkins, 2009). Among valid analyses, the lowest ICC was found for AE at 90° of shoulder flexion in subjects with shoulder pain, with a SEM and MDC of 1.7° and 4.8°, respectively.

There were no significant interactions on ANOVAs, but significant main effects of target-angle for CE, AE and TE for shoulder and elbow. VE presented main effect for shoulder movement, with larger errors during scaption ($P = 0.006$).

SPADI scores were not different between-days, with all healthy subjects presenting score of 0 and subjects with shoulder pain presenting median (first; third quartile) of 20 (10.7; 24.6) on Day 1 and 15.3 (6.9; 20) on Day 2 ($P = 0.31$). Subjects with pain had significant increase of pain (both days pre-test: 0 (0; 1); post-test: 2 (1; 4); $P < 0.001$) and fatigue (Day 1 pre-test: 1 (0; 2), post-test: 4 (2; 5); Day 2 pre-test: 0,5 (0; 2), post-test: 3 (1; 4); $P < 0.001$) following tests in both sessions, and higher fatigue in the first session compared to the second ($P = 0.007$).

## 4. Discussion

Considering the ICC values and the confidence interval, the results demonstrate excellent between-days reliability for JPS assessment using CE and TE at 50° of scaption for healthy subjects and using CE at 70° and AE at 110° of flexion for subjects with pain. Good reliability was found for CE, AE and TE at 110° of shoulder flexion and AE at 50° of scaption in healthy subjects; and for TE at shoulder flexion in subjects with shoulder pain. Regarding elbow tests, all target-angles presented at least one repositioning error (CE, AE or TE) with good to excellent reliability, in both groups. The more consistent errors for the elbow tests suggests that the results found for shoulder tests may be related to intrinsic factors of the shoulder joint complex and not to the tool used for JPS assessment. Furthermore, for most shoulder target-angles, between-subjects variance was not significant, according to the ANOVA for ICC calculation. In these cases, ICC values may be negative and cannot be considered valid (Portney & Watkins, 2009). Therefore, it is not possible to draw conclusions about reliability in these cases.

Scaption is considered a functional plane for arm movements and the target-angle of 50°, that presented good to excellent reliability in healthy subjects, is close to the range of movement of daily life activities (Taylor et al., 2018) and, therefore, may be considered suitable for assessing general healthy population. Similar result was previously found for AE at shoulder flexion between 45° and 65° using a laser pointer, inclinometer and goniometer (Vafadar et al., 2016). However, that study assessed target-ranges of 20° (55°±10°, 90°±10°, 125°±10° of shoulder flexion) instead of specific target-angles, because targets were presented to subjects using verbal feedback provided by the examiner, which caused delays in subjects' response and interfered in their ability to reach an exact angle, as reported by the authors. The wide ranges used as targets represent a limitation for the position matching tests, since it has been demonstrated that shoulder and elbow repositioning errors significantly differ between elevation angles with a 20° interval (King et al., 2013; Suprak et al., 2006; Zanca

**Table 1**
Mean repositioning errors and standard deviation at each day, standard error of measurement (SEM) and minimal detectable change (MDC) for shoulder JPS assessment using the mobile app in subjects with and without shoulder pain during scaption. Errors are presented in degrees.

| | Healthy subjects (n = 29) | | | | | Subjects with shoulder pain (n = 25) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Day 1 | Day 2 | ICC (95% CI) | SEM | MDC | Day 1 | Day 2 | ICC (95% CI) | SEM | MDC |
| 50° | | | | | | | | | | |
| CE | 7.8 (5.6)[a] | 7.9 (4.9) | 0.81 (0.58; 0.91) | 2.3 | 6.3 | 6.9 (5.2)[a] | 6.6 (3.6) | 0.39 (−0.42; 0.74)[b] | 3.5 | 9.6 |
| AE | 8.6 (4.5)[a] | 8.6 (4.2) | 0.73 (0.42; 0.87) | 2.3 | 6.2 | 7.5 (4.5)[a] | 6.9 (3.4) | 0.45 (−0.25; 0.76)[b] | 2.9 | 8.2 |
| VE | 3.4 (1.9)[b] | 3.0 (1.8) | 0.26 (−0.59; 0.66)[b] | 1.6 | 4.4 | 3.1 (1.8) | 2.9 (1.6) | −0.04 (−1.49; 0.55)[b] | 1.7 | 4.8 |
| TE | 9.2 (4.5)[a] | 8.9 (4.2) | 0.75 (0.46; 0.88) | 2.2 | 6.1 | 8.1 (4.7)[a] | 7.5 (3.4) | 0.40 (−0.38; 0.74)[b] | 3.1 | 8.7 |
| 70° | | | | | | | | | | |
| CE | 6.1 (4.9)[a] | 5.3 (4.5) | 0.54 (0.01; 0.78) | 3.2 | 8.8 | 5.6 (4.4)[a] | 4.5 (4.5) | 0.52 (0.08; 0.79) | 3.1 | 8.5 |
| AE | 6.8 (4.2)[a] | 6.1 (3.5) | 0.28 (−0.54; 0.67)[b] | 3.2 | 9.0 | 6.1 (3.8)[a] | 6.0 (3.1) | 0.31 (−0.63; 0.70)[b] | 2.8 | 7.8 |
| VE | 3.3 (1.8)[b] | 3.2 (1.7) | 0.26 (-0.63; 0.66)[b] | 1.5 | 4.1 | 3.1 (1.5) | 3.4 (1.5) | 0.10 (−1.13; 0.62)[b] | 1.4 | 4.0 |
| TE | 7.4 (4.5)[a] | 6.8 (3.7) | 0.36 (−0.38; 0.70)[b] | 3.2 | 9.0 | 6.8 (3.9)[a] | 6.6 (3.2) | 0.32 (−0.59; 0.71)[b] | 2.9 | 8.1 |
| 90° | | | | | | | | | | |
| CE | 2.9 (3.2)[a] | 3.0 (3.9) | 0.45 (−0.20; 0.75)[b] | 2.6 | 7.3 | 1.8 (3.9)[a] | 2.9 (4.0) | 0.47 (−0.18; 0.76)[b] | 2.9 | 8.0 |
| AE | 4.6 (1.4) | 4.5 (2.5) | −0.17 (−1.61; 0.46)[b] | 2.2 | 6.0 | 3.9 (2.2) | 4.6 (2.4) | 0.57 (0.05; 0.81) | 1.5 | 4.2 |
| VE | 3.2 (1.6)[b] | 2.6 (1.8) | 0.03 (−1.03; 0.54)[b] | 1.7 | 4.6 | 2.6 (1.4) | 2.8 (1.2) | 0.12 (−1.08; 0,62)[b] | 1.2 | 3.4 |
| TE | 5.3 (1.7)[a] | 5.1 (2.9) | −0.06 (−1.34; 0.51)[b] | 2.3 | 6.2 | 4.6 (2.3)[a] | 5.2 (2.5) | 0.63 (0.17; 0.84) | 1.5 | 4.1 |
| 110° | | | | | | | | | | |
| CE | 1.3 (4.0)[a] | 3.1 (3.1) | −0.17 (−1.29; 0.43)[b] | 4.0 | 11.0 | 0.8 (2.9)[a] | 1.5 (3.6) | 0.46 (−0.22; 0.76)[b] | 2.4 | 6.7 |
| AE | 4.0 (2.5) | 4.5 (2.4) | 0.23 (−0.65; 0.64)[b] | 2.1 | 5.9 | 3.6 (1.4) | 3.6 (2.1) | 0.29 (−0.68; 0.69)[b] | 1.5 | 4.1 |
| VE | 2.8 (1.9)[b] | 2.9 (1.5) | 0.07 (−1.13; 0.58)[b] | 1.6 | 4.5 | 2.9 (1.5) | 2.7 (1.4) | 0.17 (−1.00; 0.64)[b] | 1.3 | 3.6 |
| TE | 4.8 (2.6)[a] | 5.0 (2.6) | 0.27 (−0.60; 0.66)[b] | 2.2 | 6.1 | 4.1 (1.6)[a] | 4.2 (2.4) | 0.33 (−0.58; 0.71)[b] | 1.7 | 4.6 |

CE: Constant Error; AE: Absolute Error; VE: Variable Error; TE: Total Error.
[a] Significant difference when compared to the other target-angles.
[b] Between-subjects variance was not significant.

**Table 2**
Mean repositioning errors and standard deviation at each day, standard error of measurement (SEM) and minimal detectable change (MDC) for shoulder JPS assessment using the mobile app in subjects with and without shoulder pain during shoulder flexion. Errors are presented in degrees.

| | Healthy subjects (n = 29) | | | | | Subjects with shoulder pain (n = 25) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Day 1 | Day 2 | ICC (95% CI) | SEM | MDC | Day 1 | Day 2 | ICC (95% CI) | SEM | MDC |
| 50° | | | | | | | | | | |
| CE | 7.6 (4.5)[a] | 8.1 (3.8) | 0.30 (−0.52; 0.67)[b] | 3.5 | 9.6 | 6.8 (5.1)[a] | 6.8 (3.8) | 0.56 (−0.02; 0.81) | 2.9 | 8.2 |
| AE | 8.3 (3.5)[a] | 8.4 (3.5) | 0.19 (−0.79; 0.62)[b] | 3.1 | 8.7 | 7.6 (4.0)[a] | 7.1 (3.7) | 0.53 (−0.09; 0.79) | 2.6 | 7.2 |
| VE | 3.1 (2.1)[b] | 4.0 (2.7) | 0.44 (−0.17; 0.73)[b] | 1.8 | 5.1 | 2.4 (1.5) | 3.1 (2.4) | −0.21 (−1.78; 0.47)[b] | 2.2 | 6.1 |
| TE | 8.8 (3.7)[a] | 9.4 (4.8) | 0.19 (−0.77; 0.62)[b] | 3.3 | 9.3 | 8.3 (4.6)[a] | 7.7 (4.0) | 0.50 (−0.15; 0.78) | 3.0 | 8.3 |
| 70° | | | | | | | | | | |
| CE | 5.5 (4.4)[a] | 6.3 (4.1) | 0.47 (−0.13; 0.75) | 3.1 | 8.6 | 5.4 (3.7)[a] | 4.5 (3.6) | 0.76 (0.46; 0.89) | 1.8 | 5.0 |
| AE | 6.4 (3.2)[a] | 7.1 (3.6) | 0.49 (−0.08; 0.76) | 2.4 | 6.8 | 6.0 (3.0)[a] | 5.6 (2.7) | 0.56 (−0.002; 0.81) | 1.9 | 5.2 |
| VE | 3.2 (2.3)[b] | 3.2 (2.1) | 0.27 (−0.60; 0.66)[b] | 1.9 | 5.2 | 2.8 (1.4) | 3.6 (2.1) | 0.47 (−0.12; 0.76) | 1.3 | 3.7 |
| TE | 7.2 (3.6)[a] | 7.6 (3.8) | 0.40 (−0.30; 0.72)[b] | 2.8 | 7.9 | 6.6 (3.0)[a] | 6.4 (3.0) | 0.60 (0.06; 0.82) | 1.9 | 5.3 |
| 90° | | | | | | | | | | |
| CE | 2.8 (3.0)[a] | 2.9 (3.6) | 0.36 (−0.39; 0.70)[b] | 2.6 | 7.2 | 2.3 (3.0)[a] | 2.8 (3.1) | −0.19 (−1.84; 0.49)[b] | 3.3 | 9.1 |
| AE | 4.2 (2.2) | 4.3 (2.5) | 0.25 (−0.64; 0.66)[b] | 2.0 | 5.6 | 3.7 (1.9) | 4.2 (2.1) | 0.27 (−0.65; 0.68) | 1.7 | 4.8 |
| VE | 2.4 (1.8)[b] | 2.5 (2.0) | 0.18 (−0.82; 0.63)[b] | 1.7 | 4.7 | 2.3 (1.1) | 2.0 (1.0) | 0.01 (−1.29; 0.57)[b] | 1.0 | 2.9 |
| TE | 4.5 (2.2)[a] | 4.8 (2.8) | 0.22 (−0.69; 0.64)[b] | 2.2 | 6.1 | 4.1 (1.8)[a] | 4.6 (2.3) | 0.16 (−0.93; 0.63)[b] | 1.9 | 5.2 |
| 110° | | | | | | | | | | |
| CE | 1.8 (3.2)[a] | 2.5 (3.1) | 0.68 (0.33; 0.85) | 1.8 | 4.9 | 0.9 (3.1)[a] | 0.9 (2.6) | 0.53 (−0.09; 0.80) | 1.9 | 5.4 |
| AE | 3.6 (1.5) | 3.6 (2.2) | 0.68 (0.30; 0.85) | 1.1 | 2.9 | 3.4 (1.6) | 3.7 (1.6) | 0.82 (0.60; 0.92) | 0.7 | 1.9 |
| VE | 2.3 (1.2)[b] | 2.0 (1.0) | 0.06 (−1.0; 0.56)[b] | 1.1 | 3.0 | 2.5 (1.1) | 2.9 (2.0) | 0.40 (−0.35; 0.73)[b] | 1.3 | 3.5 |
| TE | 4.1 (1.8)[a] | 4.0 (2.2) | 0.69 (0.33; 0.86) | 1.1 | 3.1 | 3.8 (1.7)[a] | 4.2 (1.7) | 0.71 (0.36; 0.87) | 0.9 | 2.5 |

CE: Constant Error; AE: Absolute Error; VE: Variable Error; TE: Total Error.
[a] Significant difference when compared to the other target-angles.
[b] Between-subjects variance was not significant.

et al., 2015). Therefore, the app has the advantage of assessing a more accurate target-position (target-angle ±2°), similar to other testing protocols involving laboratory equipment (Haik et al., 2013; Myers et al., 1999; Suprak et al., 2006; Vafadar et al., 2015).

The app also demonstrated good to excellent reliability at the target of 110° of shoulder flexion for both groups, while other low-cost instruments have presented poor reliability in overhead positions (Vafadar et al., 2016). This angle of arm elevation has been related to the pathomechanics of shoulder impingement (Lawrence et al., 2014) and is within the painful arc identified in this shoulder disorder (Hegedus, 2012). Furthermore, although the present study has not included athletes, it is important to acknowledge the potential of the app for assessing this position in overhead athletes, since sports such as baseball and handball involve ranges of motion up to 110° of arm elevation (Fleisig et al., 2011; Skejø et al., 2019).

The magnitude of repositioning errors and the pattern of smaller CE and AE at higher angles of shoulder elevation and elbow flexion found in this study are consistent with the literature using an electromagnetic tracking system (Ettinger et al., 2017; Suprak et al., 2006). The SEM values found for the shoulder were also similar to those previously reported (Suprak et al., 2006). The SEM consists in an absolute index, also referred as “typical error”, and

**Table 3**
Mean repositioning errors and standard deviation (SD) at each day, standard error of measurement (SEM) and minimal detectable change (MDC) for elbow flexion JPS assessment using the mobile app in subjects with and without shoulder pain. Errors are presented in degrees.

| | Healthy subjects (n = 29) | | | | | Subjects with shoulder pain (n = 25) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Day 1 | Day 2 | ICC (95% CI) | SEM | MDC | Day 1 | Day 2 | ICC (95% CI) | SEM | MDC |
| 50° | | | | | | | | | | |
| CE | 13.4 (7.6) | 13.3 (5.8) | 0.68 (0.30; 0.85) | 2.7 | 7.6 | 12.4 (7.5) | 13.9 (5.9) | 0.65 (0.20; 0.85) | 2.9 | 7.9 |
| AE | 13.5 (7.5)[b] | 13.4 (5.7) | 0.66 (0.26; 0.84) | 2.2 | 5.9 | 12.8 (7.1)[b] | 13.9 (5.9) | 0.65 (0.20; 0.85) | 3.11 | 8.63 |
| VE | 4.5 (2.6) | 3.9 (2.1) | 0.32 (−0.44; 0.68)[c] | 1.7 | 4.7 | 4.7 (2.6) | 4.6 (2.9) | −0.44 (−2.71; 0.41)[c] | 2.59 | 7.19 |
| TE | 14.5 (7.5)[b] | 14.2 (5.6) | 0.70 (0.34; 0.86) | 2.5 | 7 | 13.9 (7.7)[b] | 14.9 (6.2) | 0.63 (0.14; 0.84) | 2.47 | 6.84 |
| 70° | | | | | | | | | | |
| CE | 11.4 (7.4) | 10.9 (6.7) | 0.82 (0.61; 0.91) | 3.9 | 10.7 | 11.1 (4.9) | 11.6 (6.3) | 0.74 (0.40; 0.89) | 4.0 | 11.1 |
| AE | 12.5 (6.5)[b] | 11.4 (5.7) | 0.72 (0.40; 0.87) | 3.9 | 10.7 | 11.3 (4.8)[b] | 11.8 (6.2) | 0.76 (0.44; 0.90) | 3.9 | 10.7 |
| VE | 4.7 (2.4) | 4.4 (2.9) | 0.20 (−0.77; 0.64)[c] | 1.9 | 5.3 | 4.4 (2.2) | 4.6 (2.3) | 0.04 (−1.35; 0.59)[c] | 3.4 | 9.3 |
| TE | 13.5 (6.2)[b] | 12.2 (6.0) | 0.70 (0.38; 0.86) | 3.6 | 10.0 | 12.1 (4.9)[b] | 12.8 (6.1) | 0.78 (0.49; 0.90) | 4.3 | 11.8 |
| 90° | | | | | | | | | | |
| CE | 8.2 (5.3)[a] | 7.0 (5.2) | 0.38 (−0.31; 0.71) | 3.0 | 8.3 | 6.4 (6.8) | 5.9 (5.4) | 0.86 (0.67; 0.94) | 2.9 | 8.0 |
| AE | 8.9 (5.0) | 8.3 (4.1) | 0.69 (0.35; 0.86) | 3.2 | 9.0 | 7.6 (5.9) | 7.5 (3.7) | 0.81 (0.57; 0.92) | 2.7 | 7.5 |
| VE | 4.0 (2.4) | 3.6 (1.9) | −1.57 (−5.23;-0.12)[c] | 2.4 | 6.6 | 4.0 (2.2) | 3.6 (2.2) | −0.05 (−1.50; 0.55)[c] | 2.2 | 6.1 |
| TE | 9.9 (5.1) | 9.0 (4.1) | 0.62 (0.19; 0.82) | 3.4 | 9.3 | 8.4 (6.0) | 8.2 (3.7) | 0.80 (0.53; 0.91) | 2.6 | 7.2 |
| 110° | | | | | | | | | | |
| CE | 6.6 (5.1)[a] | 5.9 (5.1) | 0.71 (0.39; 0.86) | 4.1 | 11.4 | 4.2 (6.9)[a] | 3.3 (5.0) | 0.77 (0.46; 0.90) | 2.3 | 6.4 |
| AE | 7.5 (4.2) | 6.8 (4.4) | 0.75 (0.47; 0.88) | 2.5 | 7.1 | 6.4 (3.6) | 6.3 (3.2) | 0.18 (−1.02; 0.66)[c] | 2.1 | 5.9 |
| VE | 3.7 (2.4) | 2.3 (1.5) | 0.31 (−0.29; 0.66)[c] | 3.5 | 9.7 | 3.7 (2.3) | 3.8 (2.0) | −0.50 (−2.90; 0.39)[c] | 2.3 | 6.2 |
| TE | 8.3 (4.4) | 7.3 (4.4) | 0.67 (0.31; 0.84) | 2.9 | 7.9 | 7.4 (3.6) | 6.6 (2. 9) | 0.44 (−0.34; 0.76)[c] | 2.2 | 6.2 |

[a] Significant difference when compared to the other target-angles.
[b] Significant difference when compared to 90° and 110° target-angles.
[c] Between-subjects variance was not significant.

represents the precision of the individual results on a test (Weir, 2005). In the present study, in general, the SEM tended to be lower for the higher target-angles of the shoulder, following the lower CE and AE values at these positions. For the elbow, this pattern could not be clearly observed.

The MDC is the smallest difference that represents true change, i.e., beyond the threshold of error (Portney & Watkins, 2009). Despite its great importance for clinical decision making and interpretation of changes following intervention protocols, a systematic review found that only two studies out of twenty-one have reported the MDC for shoulder JPS assessment (Ager et al., 2017), which makes the comparison and interpretation of the present findings more difficult. The app presented greater MDC for the AE of shoulder flexion repositioning in both groups compared to those found for a previous study in healthy subjects using a laser pointer, inclinometer and goniometer (Vafadar et al., 2015), except at the target of 110°. The other study that reported the MDC, have assessed only scapular repositioning errors (Deng & Shih, 2015) and comparisons with our results would not be appropriate.

There was no difference in repositioning errors between planes of arm elevation, corroborating with a previous study (Suprak et al., 2006). The largest VE associated with poorer reliability for scaption suggests that subjects presented more inconsistent performance on scapular plane. This result may be related to the higher degree of difficulty reported by subjects to concentrate on maintaining the arm on scapular plane than for elevating the arm forward. However, this finding should be interpreted with caution, considering that ICC results could not be considered valid for VE in all tests and for other JPS errors during shoulder flexion and scaption, due to the non-significant between-subjects variability for this variable (Portney & Watkins, 2009).

The present study investigated four repositioning errors commonly used in the literature for JPS assessment. The CE indicates if subjects undershot (when negative) or overshot (when positive) the target. The AE does not consider the direction of the error, just its magnitude (Röijezon, Clark, & Treleaven, 2015). The VE indicates the consistency of repositioning error, independent of its magnitude and it is considered an estimate of precision (Röijezon et al., 2015). The TE is interpreted as the total variability around a target (or error), since it represents the combination of VE and CE (Schmidt & Lee, 2011). Takasaki et al. (Takasaki, Lim, & Soon, 2016) has recommended that studies report the AE together with the VE or TE, since there is still no consensus of which error is more representative of JPS deficits of the shoulder. Considering the general findings of the present study and the different possible meaning of each error, we suggest to reporting AE, CE or TE, since the reliability of VE is questionable for both shoulder and elbow joints testing in all target-angles and groups.

Although shoulder pain and perception of fatigue in subjects with shoulder pain increased following repositioning tests, it is likely that these factors did not influence reliability, since both groups presented similar behavior. Subjects with shoulder pain presented low levels of pain and disability, which should be considered when interpreting the results. Furthermore, our sample was comprised of young adults, non-athletes, and the results should not be generalized to other populations, since shoulder JPS may be altered by aging (Herter, Scott, & Dukelow, 2014) and overhead sports (Badagliacco & Karduna, 2018; Dover, Kaminski, Meister, Powers, & Horodyski, 2003).

Mobile applications have been increasingly explored for physical assessment in several fields, considering its portability, low cost and facility to manage (Awatani, Enoki, & Morikita, 2018; Höchsmann et al., 2018; Yang, Grooten, & Forsman, 2017). The JPS app has been shown to be a valid tool for proprioception evaluation (Edwards et al., 2016), which typically requires laboratory equipment. The present study demonstrated the app is a reliable tool for assessing shoulder JPS in some shoulder positions and all tested elbow positions. Further studies with more heterogeneous samples are necessary for determining between-days reliability of the shoulder JPS assessment using the app, including other shoulder movements.

## 5. Conclusions

The mobile app is a reliable tool for assessing shoulder JPS at 50° of scaption in healthy subjects; at 70° of shoulder flexion in subjects with shoulder pain; at 110° of shoulder flexion and 50°, 70°, 90° and 110° of elbow flexion in both groups. Repositioning errors may be expressed as CE, AE and TE. The MDC were demonstrated and may help clinicians to follow-up intervention programs and researchers to interpret study findings.

## Declaration of ethical approval

This study has been approved by the Human Research Ethics Committee of the Universidade do Sagrado Coração (Approval number 1.216.029) and was conducted in agreement with the Declaration of Helsinki. All subjects gave informed consent to participate in the work.

## Conflicts of interest

None declared.

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