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Shoulder loading reliability in seated able-bodied subjects

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A B S T R A C T

Shoulder performance and sensorimotor control assessments help to identify shoulder instabilities and document the rehabilitation progress. Testing seated subjects in a position of hand prehension requires less controlled adjustments to maintain body balance in a clinically relevant situation. The objective of this work was to determine the test–retest repeatability of a novel shoulder stability test in seated subjects with the ipsi-lateral hand in prehension during four arm loading conditions. Able-bodied subjects were seated on a rigid chair fixed to a force plate. A horizontally and posteriorly directed force was applied to the hand for four 4 loading conditions ranging from 0 to 3 kg. Ten postural balance parameters were calculated from the center of pressure displacements and its corresponding free moments. Intra-class correlation coefficients were calculated for three consecutive trials and for four loading conditions. Generally, the intra-class correlations values increased gradually with the load and varied from 0.727 to 0.948. Tz values increased non-linearly with the applied load. The test–retest reliability of a new shoulder stability test in seated able-bodied subjects was high with sufficient loading (3 kg) and 3 trials.

1. Introduction

Shoulder stability is ensured by a complex balance between mechanical constraints such as the articular geometry, capsule and ligaments [1,2] and the sensorimotor elements comprising of proprioception and neuromuscular control [3]. Proprioception acts as a feedback mechanism to the muscle groups to protect the shoulder against joint instability. After joint instability, surgery restores the mechanical functions of the shoulder lost by joint injury and restores in part the sensory deficits present after injury [3].

Riemann et al. [4] reviewed the techniques to evaluate shoulder integrity and functions. These cover joint position and kinesthesia for proprioception, evoked potential and electromyography [5], joint torque and joint stiffness measurements as well as postural control evaluations for efferent neuromuscular control. Because of the complex relationships between the sensorimotor system and the mechanical joint constraints, measuring and analyzing shoulder stability is difficult [6]. Furthermore, these techniques are used separately focusing on a single type of measurements rather than globally assessing shoulder performance and sensorimotor control [4].

A novel approach to globally test shoulder sensorimotor control and joint integrity was proposed and validated by Edouard et al. [1]. In that study, subjects were asked to lie in a prone position on a table with the hands resting on a single force platform. The upper limbs were at the vertical with a 90° flexion at the shoulder and the arm in internal rotation. This ensures both joint stability and shoulder muscle cocontraction [7]. The center of pressure (CoP) excursion was calculated from force-plate data to estimate shoulder stability and its sensorimotor control mechanisms. Edouard et al. reported a moderate to high reliability values and concluded that shoulder sensorimotor control assessment by force platform is feasible [1]. To assess shoulder sensorimotor control, the authors positioned the subjects so that only the lower limbs were on the table. Nonetheless, adding extra loads to exacerbate joint instability is difficult in this position. The load conditions of the previous study were not controlled. Authors applied the body weight or part of it but without control [1,8]. Furthermore, the position is not clinically relevant because it is not measured in a

Abbreviations: CoP, Center of pressure; ICC, intra-class correlation; SEM, standard error of measurements; CV, coefficient of variation.

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position of apprehension (abduction and external rotation), in which anterior instability episodes are more apparent.

In an attempt to reduce the above limitations, we propose to test subject in a seated position. For quiet sitting, body sway area and CoP velocity are smaller than for quiet standing, requiring fewer controlled adjustments to maintain equilibrium [9]. This could be explained in part by the differences in the number of body segments that are in motion during quiet sitting and standing [9,10]. It is assumed that two hand upper-limb weight-bearing balance is more challenging posture than a seated one. This assumption is based on the work of Kerr and Eng [11], who reported moderate to very high reliability (0.64–0.94) for CoP displacements and velocity in sitting. These values are above those reported by Edouard et al. for subject in upper-limb weight-bearing positions [1]. To test shoulder instability, it is preferred to have the subject in the apprehension position (abduction and external rotation), in which anterior instability episodes are more apparent, and rotator cuff muscles are more solicit to stabilize the shoulder [12,13]. The results of that kind of test could lead to an evaluation protocol to test shoulder instability and document the patient's improvements during the rehabilitation program.

A torque applied on the upper limb will increase the shoulder muscles activity. This will modify the horizontal excursion of the CoP of the seated, standing and upper-limb weight-bearing balance positions [1,14]. However, it is not possible to get an insight on the instability around the longitudinal axis of the body with these stability parameters alone. The vertical torque acting at the CoP or the free moment, Tz, is used to quantify the oscillation around the longitudinal axis of the body in standing balance [15] and running instabilities [16]. Here, the free moment variability reflects muscles action to ensure shoulder steadiness due to an external force applied on the upper limb. It could reflect the muscular activity of the internal and external rotator cuff muscles, playing a major role in compression and stability of the glenohumeral joint.

The hypothesis to be tested is that shoulder steadiness characterized by the center of pressure excursion displacement and free moment variation of seated subjects will decrease with load increase. The objective of this work was to determine the test–retest repeatability of a shoulder stability test method where able-bodied subjects with the shoulder in abduction and external rotation were asked to resist against four arm loading conditions while in a seated position.

2. Materials and methods

Seventeen men and three women were recruited on the university campus to participate to this study. Their mean age, height, mass and body mass index were 26.6 ± 5.8 years, 175.9 ± 8.1 cm, 71.8 ± 12.5 kg and 23.1 ± 2.9 kg/m^2, respectively. All subjects were examined by an orthopedic surgeon and none had any observable neurological or musculo-skeletal ailments or medical history that could perturb shoulder or shoulder girdle motion. Subjects were excluded if shoulder pain was present or if a clinical injury was suspect based on the clinical evaluation. All subjects gave their consent after being fully informed of the test procedure, which was approved by the local university ethics committee, and the rights of the subjects were respected.

For the experiment, the subject was seated on a rigid chair fixed to a force platform AMTI (Newton, MA, USA) as shown in Fig. 1. Only the shoulder of the dominant upper limb was tested. The arm was in 90° abduction and 90° external rotation with the elbow flexed at 90° so the palm of the hand was facing forward. This arm orientation corresponds to the maximum shoulder instability position [13]. A horizontally and posteriorly directed force was applied to the hand by means of a rope and a pulley system attached to a dead weight. During the experiment, subjects were

Fig. 1. Experimental set-up illustrating a subject sitting on chair resting on a force plate (FP). The load (*L*) is attached to the hand by a rope to create a horizontal force through a pulley (*P*) system. The upper limb joint positions and the applied load were set at 90°.

asked to look at a target located at 1.2 m in front of them and set at eye level. They had to keep fixing the target, lean against the chair's backrest and remained immobile during each test. The experimenter visually verified that this posture was fully respected. Trials were rejected when trunk rotations, an arching back or a shoulder rotation were noticed. Any excessive or abnormal sideway motion was verified afterwards by force platform data. The noise and light conditions were identical between tests.

Four loading conditions were applied corresponding to no load and to loads of 1, 2 and 3 kg. Prior to the experiment, subjects had 3 minutes for practice trials with the different loads. Afterwards, each loading condition was tested three times in a randomized order. Each evaluation lasted 32 s and subjects had a 60 s resting period between each trial to avoid fatigue and shoulder training.

Force plate data were sample at 1000 Hz during the experiments and then smoothed using a 7 Hz low-pass filter. Ten seated balance parameters were calculated. These are the mean anterior-posterior (AP) and medio-lateral (ML) CoP, their ranges, the length, speed and sway area of the CoP displacement as well as three free moment values, namely, its range, rms and centered rms value [15,17]. The Tz centered corresponds to the Tz minus the Tz mean value calculated during the trial. It represents the oscillation around the Tz mean. This was done to eliminate in part the effect the different loads on the free moment.

The mean CoP indicated if the seated subject maintained or not a straight and vertical back position with no tendency to lean on either side during shoulder loading. For all loading condition, the mean ML CoP value of an individual trial did not exceed 1 cm from the mean of the three trials. The AP and ML CoP range and the CoP length, speed and sway area were representative of shoulder steadiness or neuro-muscular demand to stabilize the shoulder under the various loading conditions. The free moment values correspond to the difficulty in reacting to the applied torque on the shoulder. These reflect the integrity of the shoulder and could identify any imbalance or musculo-skeletal disorder or injury [17].

Table 1
Intra-class correlation (ICC), 95% Confidence Interval (CI), Standard Error of Measurements (SEM) and Coefficient of variation (CV) values of all the parameters for three trials with loads varying from zero to 3 kg. Values are presented as ICC (lower-upper 95% CI) and %SEM–%CV.

Parameters	No weight ICC (95%CI) %SEM–%CV	1 kg ICC (95%CI) %SEM–%CV	2 kg ICC (95%CI) %SEM–%CV	3 kg ICC (95%CI) %SEM–%CV
COP AP mean	0.988 (0.975–0.995) 31.7–29	0.977 (0.952–0.990) 6.6–32.8	0.987 (0.972–0.994) 5.2–9.8	0.988 (0.974–0.995) 3.3–4.8
COP AP range	0.540 (0.044–0.804) 14.6–18.7	0.650 (0.280–0.852) 14.0–19.2	0.897 (0.783–0.955) 10.4–15.9	0.939 (0.971–0.975) 8.9–14.5
COP area	0.645 (0.263–0.849) 17.4–23.1	0.903 (0.798–0.958) 18.2–22.7	0.930 (0.854–0.970) 15.6–19.3	0.958 (0.910–0.982) 9.3–23.8
COP ML mean	0.981 (0.925–0.985) 10.1–34.6	0.968 (0.895–0.979) 14.7–60.4	0.974 (0.919–0.983) 17.7–46.2	0.956 (0.904–0.981) 27.0–23.0
COP ML range	0.603 (0.164–0.828) 35.9–24.1	0.894 (0.780–0.955) 9.2–13.4	0.830 (0.644–0.927) 13.1–17.4	0.924 (0.836–0.968) 7.9–17.8
COP speed	0.969 (0.936–0.987) 4.4–8.2	0.992 (0.984–0.997) 3.4–5.2	0.994 (0.987–0.997) 1.6–2.8	0.994 (0.987–0.997) 1.9–2.9
COP length	0.970 (0.938–0.987) 4.3–8.2	0.992 (0.984–0.997) 3.4–5.2	0.994 (0.986–0.997) 1.7–3.0	0.994 (0.987–0.998) 1.9–2.9
Tz range	0.395 (0.360–0.742) 16.8–22.7	0.422 (0.220–0.759) 26.2–21.5	0.888 (0.765–0.952) 12.1–18.7	0.914 (0.818–0.964) 10.0–13.5
Tz rms	0.985 (0.968–0.993) 5.1–13.8	0.847 (0.684–0.935) 5.8–6.8	0.963 (0.923–0.984) 2.4–3.9	0.951 (0.895–0.979) 3.1–5.1
Tz centered rms	0.294 (0.080–0.697) 5.0–14.7	0.297 (0.076–0.698) 50.6–32.5	0.842 (0.671–0.932) 22.4–28.2	0.862 (0.705–0.942) 19.8–28.6
Mean ICC	0.737	0.794	0.930	0.948

CoP: Center of pression, AP: antero-posterior, ML: medio-lateral, Tz: free moment, ICC: intra-class correlation.

In order to determine the reliability of a shoulder stability test, we estimate its test–retest repeatability for three consecutive trials and for four externally applied load conditions. Prior to analysis, the normal distribution and heteroscedasticity were tested by the Kolmogorov–Smirnov with Lilliefors correction tests. The intra-class correlation (ICC) (3,3) coefficient was calculated for each parameter with three successive trials with a 95% confidence interval (CI). To reach a general view of the variability of the measured performance indices, repeated measures ANOVA (analysis of variance) was used to calculate the reliability. An ICC value above 0.9 is considered as high and if it lies between 0.8 and 0.9 it is moderate. Below 0.8 the ICC has a low value [18]. The standard error of measurement (SEM) was calculated which makes an absolute index of reliability available and allows for the quantification of each measurement's precision. The standard error of measurements (SEM) was obtained by the square root of the mean quadratic error from the one-way ANOVA for repeated measurements. The coefficient of variation (CV) was used to ascertain absolute reproducibility as: CV = Standard Deviation/mean $*100$.

The non-parametric Friedmann test for repeated measures was performed to determine if the loading conditions modified the shoulder stability parameters. If a significant difference was observed, then a Wilcoxon post-hoc with a Bonferroni correction procedure was performed. For all statistical tests, alpha was set at 0.05. Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 21.0 (Armonk, NY: IBM Corp).

3. Results

Table 1 present the ICC, %SEM and %CV values for three consecutive trials for all 10 seated posture balance parameters with loads varying from 0 to 3 kg. The mean ICC varies from about 0.727 to 0.948. The ICCs increase with the load application. Below 2 kg, the mean ICCs are very close to moderate whereas above 2 kg the mean ICCs are high [18]. In the no load condition half of the ICCs are below 0.8. At 1 kg, only three parameters have an ICC less than 0.8. For 2 kg and above, all the ICCs are greater than 0.8and at 3 kg, only Tz centered rms is less than 0.9 (0.862). Absolute reliability values were globally good (1.7–35.9%SEM and 2.9–34.6%CV) except for the Tz centered rms at 1 kg condition.

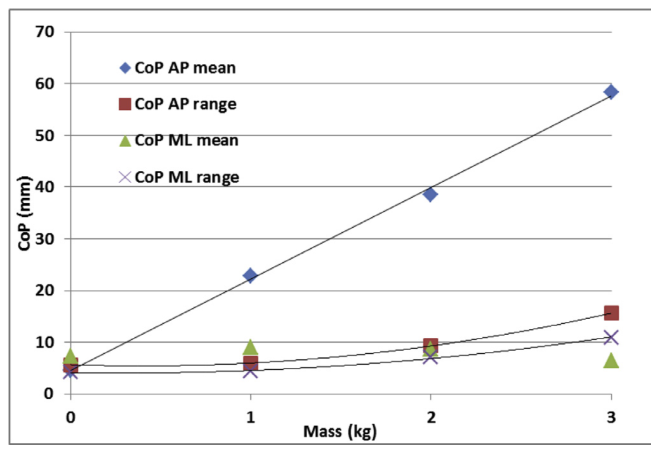

Fig. 2. Center of pressure (CoP) mean and range for the antero-posterior (AP) and medio-lateral (ML) direction for four shoulder loads.

Figs. 2–4 depict the CoP parameters as well as the free moment values for the four shoulder loads. The standard deviations on the figures were omitted for clarity and a tendency curve was added to illustrate the progression in the balance parameter values with load increase. The general pattern is towards an increase values as the shoulder load increases with the exception of the CoP ML mean values (Fig. 2) that remain at about 7.8 mm ($p > 0.168$) to the right of the body centerline. This implies that the subjects remain seated with the trunk erect with no disposition to lean on either side of the body with shoulder loading. CoP AP increased linearly between the no load to the 3 kg condition ($p < 0.000$). This reflects the effect of the applied horizontal force by the applied loads. Both CoP ranges do not change significantly between the no load and the 1 kg condition ($p = 1.000$) but increased non-linearly from these conditions to the 2 kg and 3 kg loads ($p < 0.000$). This is indicative of a greater difficulty in stabilizing the shoulder under the latter two loads.

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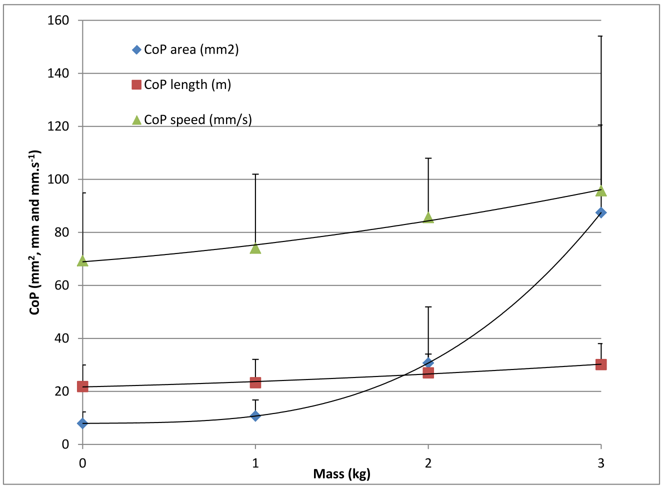

Fig. 3. Center of pressure (CoP) area, length and speed for four shoulder loads. The vertical bars represent the upper values of their respective standard deviation.

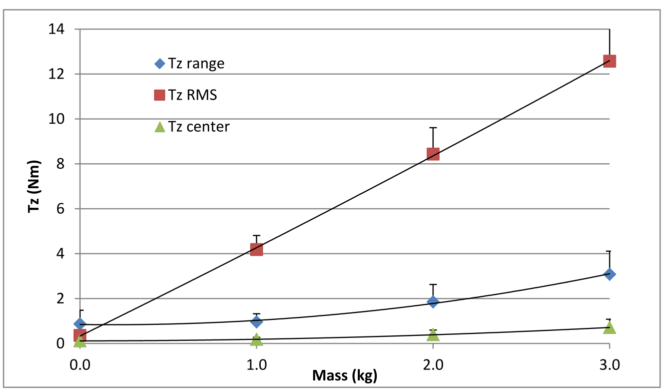

Fig. 4. Free moment (Tz) range, rms and centered rms value for four shoulder loads. The vertical bars represent the upper values of their respective standard deviation.

The CoP area, length and speed shown in Fig. 3 display an analogous pattern where the first two conditions are similar ($p > 0.126$) but are statistically different from the last two ($p < 0.000$) and they themselves different from each other ($p < 0.000$). All curves increased in a non-linearly manner with the load though this is more visible with the CoP area.

The Tz centered rms values are not significantly different between the no load and the 1 kg condition ($p = 0.150$) but increased significantly ($p > 0.000$) at the 2 kg and 3 kg. The Tz rms and Tz centered rms values were statistically different between all the shoulder loading conditions ($p < 0.006$). All Tz values increased in a non-linearly fashion with the applied load.

4. Discussion

The test–retest reliability of a new shoulder stability test in seated able-bodied subjects using different arm loading conditions was high with sufficient loading (3 kg) and 3 trials.

The high ICC reported in our study could be associated in part with the seated position. In quiet sitting, the ICC values of the center of pressure parameters were reported to be more reproducible than in quiet standing [9]. Benvenuti et al. [14] reported ICC values ranging from 0.71 to 0.76 for CoP parameters for standing balance. For children [19] and subject sitting on an unstable base [20,21] moderate ICC were reported. Kerr et al. [11] instructed subjects to reach forward, backward and sideways while sitting on a force platform. For these seated conditions, the test–retest ICCs were generally around 0.8. It appears that seated posture provide highly reliable data as in this study where the mean ICC value was above 0.9 for a load of 2 kg or more and for three repetitions. A high ICC could also be attributed to the loading conditions. With the shoulder in flexion and internal rotation Edouard et al. [1] reported lower ICCs than in our study for a shoulder positon in abduction and external rotation. Our upper arm attitude corresponds to the apprehension position where the head of the humerus tends to loosen its centering on the glenoid cavity due to less active stability [12] and worsens with disrupted static anatomical structures [22]. With loading, the joint becomes more unstable [23] and shoulder muscle activity increases [7]. This is noticeable in the systematically lower ICC values for the no load conditions where there is less muscle activity.

Present clinical shoulder instability evaluations are based on visual inspection, palpation, range of motion, hand manipulations, apprehension, relocation and surprise tests [24]. All these evaluations provide only a qualitative and subjective assessment of shoulder instability. According to Watson et al. [25], clinical and radiographic parameters of shoulder instability are proposed but none is validated. Furthermore, most of these methods test for mechanical stability neglecting the function of sensorimotor components of the shoulder [4]. To improve proprioception, shoulder stability and strength, upper extremity weight-bearing exercises are routinely used in physical therapy [7,26]. Pontillo et al. measured muscle activity during three different upper extremity weight-bearing positions of increasing difficulty [26]. They concluded that differential loading of the upper limb facilitate neuromuscular re-education. The position presented in our study allows using different arm loading conditions. Subsequently, Edouard et al. [27] evaluated patients with unilateral recurrent anterior post-traumatic shoulder dislocation using a similar shoulder procedure to test shoulder integrity but with part of the trunk and lower body lying prone on a table. Though they were able to associate sensorimotor control deficiency with recurrent anterior shoulder instability, their method was limited to a single load.

In our study four different loads were tested. There was no reference load in literature. We test load that appeared the most clinical relevant. The no load and 1 kg conditions displayed moderate repeatability with some parameters having low ICC. It is assumed that some muscle force is required to resist 2 kg and more, leading to higher ICC values. Furthermore, the rms and rms centered values of the free moment were able to discriminate between all the shoulder loads. These Tz values increases non-linearly with the applied load underlying the contribution of the role of the sensorimotor system in maintaining joint steadiness [1,27]. They could be clinical parameters to estimate shoulder integrity in patients even in varying loading conditions with a new compact clinical device.

It was necessary to validate this new assessment method in healthy subjects before evaluating in patients with shoulder injury.

In this study, trunk, head and arm positions were not constrained during the experiment to avoid undesired muscle actions on the scapula where most of shoulder muscles originate. Large medio-lateral trunk motion could occur to compensate for one-side shoulder loading [28]. Any trial where an excessive mean CoP values was noticeable was discarded. The loads used to test shoulder steadiness were only applied to able-bodied subjects. Different loads could be required for testing individuals with shoulder instability, rotator cuff tear or shoulder arthrosis [29]. Since the role of the examiner is not considered essential, interrater reliability was not test. Nonetheless, our method has the advantage over a fixed load determined from body weight and shows the potential of using different weights to determined shoulder instability or injury [26].

5. Conclusion

The test–retest reliability of a new shoulder stability test in seated able-bodied subjects using different arm loading conditions was high with sufficient loading (3 kg) and 3 trials.

Though the mean ICCs were very good for the no weight and the 1 kg conditions, the magnitudes of certain ICC parameters were low and exhibited correspondingly higher %SEM and %CV. This could reflect in part adjustments in the tension of the shoulder muscles and some difference in muscle activity recruitment. At 2 kg and above, all the ICCs were more in the very good and excellent range though it was more difficult to maintain shoulder steadiness during the experimentation. The free moment RMS and RMS centered values increase significantly with the applied load while maintaining high repeatability. These parameters were the best to test shoulder stability under the range of applied loads. Potential outcomes of this study are an evaluation protocol for testing shoulder disease and estimate shoulder stability improvements during rehabilitation with a future compact clinical device.

Level of evidence

Bench research, pre-test–post-test, Level 2b.

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Competing interests

None declared.

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Ethical approval

Local Ethic Committee.

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