Journal of Biomechanics 194 (2026) 113064

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech

Short communication

An accelerometer-based single-arm dynamic stability test for the assessment of the sensorimotor control of the shoulder

Pietro Picerno [a], Enzo Iuliano [b], Marco Bravi [c,*], Fabio Santacaterina [c,d], Amador García Ramos [e,f], Uroš Pešović [g], Rigoberto Martínez Méndez [h], Taian Martins Vieira [i]

[a] *Department of Engineering, University of Sassari, Sassari, Italy*
[b] *Department of Theoretical and Applied Sciences, eCampus University, Novedrate, Italy*
[c] *Fondazione Policlinico Universitario Campus Bio-Medico, Roma, Italy*
[d] *Department of Engineering, Università Campus Bio-Medico, Roma, Italy*
[e] *Department of Physical Education and Sport University of Granada, Granada, Spain*
[f] *Department of Sports Sciences and Physical Conditioning, Universidad Catolica de la Santísima Concepción, Concepción, Chile*
[g] *Faculty of Technical Sciences, Čačak, University of Kragujevac, Serbia*
[h] *Facultad de Ingeniería, Universidad Autónoma del Estado de México, Toluca, Mexico*
[i] *Department of Electronics and Telecommunications, Polytechnic University of Torino, Italy*

ARTICLE INFO

Keywords:
Neuromuscular control
Accelerometry
Shoulder stability
Sway assessment
Field test
Inertial sensors
Kinesiology

ABSTRACT

The study aimed at designing and validating a variation of the Single-Arm Dynamic Stability test as performed in Open Kinetic Chain for assessing the shoulder's sensorimotor control with the subject lying supine while holding a dumbbell still in one hand with the extended arm. The dumbbell's sway, monitored via a triaxial accelerometer, was modelled as an inverted pendulum pivoted at shoulder level. Twenty college students performed bilateral tests for 30 s using loads of 15 %, 25 %, and 35 % of a reference load determined as the mass measured by a scale placed under the hands during a quadruped position. The test was repeated 30 min and 24 h later. Time- and frequency-domain stabilometric parameters were computed using both the entire 30 s test duration and the first 20 s. ICC analysis revealed that the test as performed at 15 % of the reference load exhibited the highest intra- and inter-day reliability for both sides and durations, while reliability decreased at higher loads. Specifically, *Jerk* and *swayArea* exhibited good-to-excellent intra-day reliability (ICC = 0.866–0.947) and moderate-to-good inter-day reliability (ICC = 0.707–0.766), with 30 s test duration. All other stabilometric parameters showed moderate or moderate-to-good reliability (ICC > 0.5). The test provides a reliable, accessible, and ecologically valid assessment of shoulder sensorimotor control, with potential applications in clinical settings.

1. Introduction

Functional shoulder joint stability results from the interaction between the mechanical and dynamic restraints of the glenohumeral joint (Lephart and Fu, 2000). This interaction is mediated by the sensorimotor system, which includes all the sensory, motor, and central integration components involved in maintaining joint stability (Riemann and Lephart, 2002a, 2002b).

Quantitative approaches to assess the sensorimotor system consist of evaluating the function of sensory and motor components along either afferent or efferent neural pathways, respectively (Riemann et al., 2002). Among the various approaches used for assessing the integrity of efferent pathways in a stability-deficient shoulder, Myers and coll. pioneered a functional approach based on kinetic measurements. Their Single-Arm Dynamic Stability (SADS) test assesses shoulder stability by measuring the sway of the centre of pressure (CoP) of the supporting hand while the subject maintains a one-handed push-up position on a force platform with their feet positioned on an unstable board (Myers et al., 1999). In the SADS test, CoP sway relates to the adjustment made by the shoulder's muscles to stabilize the joint while maintaining

---

* Corresponding author at: Fondazione Policlinico Universitario Campus Bio-Medico, Via Alvaro del Portillo 200, Roma 00128, Italy.
E-mail addresses: ppicerno@uniss.it (P. Picerno), enzo.iuliano@uniecampus.it (E. Iuliano), m.bravi@policlinicocampus.it (M. Bravi), f.santacaterina@policlinicocampus.it (F. Santacaterina), amagr@ugr.es (A.G. Ramos), uros.pesovic@gradina.ftn.kg.ac.rs (U. Pešović), rigo@ieee.org (R.M. Méndez), taian.martins@polito.it (T.M. Vieira).

https://doi.org/10.1016/j.jbiomech.2025.113064
Accepted 11 November 2025
Available online 13 November 2025

steadily the body in a push-up position. Since then, variations of the instrumented SADS test have been introduced by other researchers (Edouard et al., 2012; Pontillo et al., 2007).

Although the SADS test has demonstrated reliability (Edouard et al., 2012) and clinical applicability (Edouard et al., 2016, 2014; Ehmann et al., 2022) several limitations remain unaddressed. First, since the hand is not the only point of support for body weight, stability is not exclusively dependent on the shoulder's musculature. Second, the load corresponding to the fraction of the body weight supported in the push-up position may be excessive for individuals recovering from shoulder injuries, and it cannot be adjusted to match their recovery progression. Moreover, as noted by Edouard and colleagues, a closed kinetic chain configuration is poorly representative of motor tasks performed in real-life situations and weakly reflects typical shoulder injury patterns (Edouard et al., 2012).

These limitations can be addressed by performing the test in open kinetic chain with the subject lying supine while holding a dumbbell in one hand with fully extended elbow. In this variation, referred to as the *Single-Arm Dynamic Stability Open Kinetic Chain* (SADS-OKC) test, stability demands are mainly imposed to the shoulder's muscles if no motion of the elbow and wrist occurs during the test. Moreover, the external resistance can be adjusted by modifying the load directly, while the CoP trajectory of the hand can be replaced by the acceleration of the dumbbell while considering the upper arm to move as an inverted pendulum. Aim of this study is to design the SADS-OKC test and to assess the reliability of its metrics for characterising the sensorimotor control of the shoulder in healthy subjects.

2. Methods

2.1. Mechanical principle, signal processing and stabilometric parameters calculation

We select a dumbbell to represent the pendulum's endpoint. Our choice is based on the ease with which dumbbells can be retrieved and adjusted to individual's needs. Shoulder stability is assessed indirectly from accelerations of the dumbbell as the subject is instructed to maintain still the upper limb posture. In doing so, the sway of the dumbbell would be imputable to changes in shoulder muscle excitation and thus to reflects the individual ability to stabilize the shoulder joint. Dumbbell sway is quantified from the linear accelerations measured by a wireless triaxial accelerometer placed on the dumbbell, and characterised using the same mechanical assumptions, signal processing, and metrics proposed for assessing standing balance by means of a waist-mounted accelerometers at the lumbar level (Ghislieri et al., 2019; Mancini et al., 2012; Martinez-Mendez et al., 2012). Similarly, the SADS-OKC test models the upper limb as an inverted pendulum, which mass is represented by the dumbbell (Fig. 1A). The metrics that the SADS-OKC test generates are the same as those normally derived from waist-mounted accelerometer-based standing balance assessment, as detailed in Table 1.

Raw accelerometer's readings were processed by: 1) transforming the sensor-embedded accelerations to an absolute horizontal reference system to get pure antero-posterior (AP) and medio-lateral (ML) accelerations (i.e., *tilt correction*) (Millecamps et al., 2015; Moe-Nilssen and Helbostad, 2002) to remove the constant gravity component caused by an off-level positioning of the sensor). This holds under the reasonable assumption that shoulder movements are sufficiently small to ensure the accelerometer x-y plane (Fig. 1B) matched the horizontal plane; 2) a linear detrend of AP and ML accelerations (Martinez-Mendez et al., 2012; Moe-Nilssen and Helbostad, 2002) to remove low frequency drift associated with a possible slow migration of the dumbbell position during the test; 3) a 4th order low-pass Butterworth smoothing filter to improve signal-to-noise ratio (Mancini et al., 2012). For standing balance analysis, commonly used cut-off frequencies range between 0.5 and 10 Hz (Ghislieri et al., 2019). For the SADS-OKC test, the Winter's residual analysis (Winter, 2009) was performed on the whole set of trials ($N = 456$) to compute the ideal cut-off frequency that resulted, on average, 11 ± 1.5 Hz. The cut-off frequency was, hence, set to 14 Hz (mean plus two standard deviations).

Time- and frequency domain stabilometric parameters were then computed from the horizontal acceleration signal. Detailed equations for

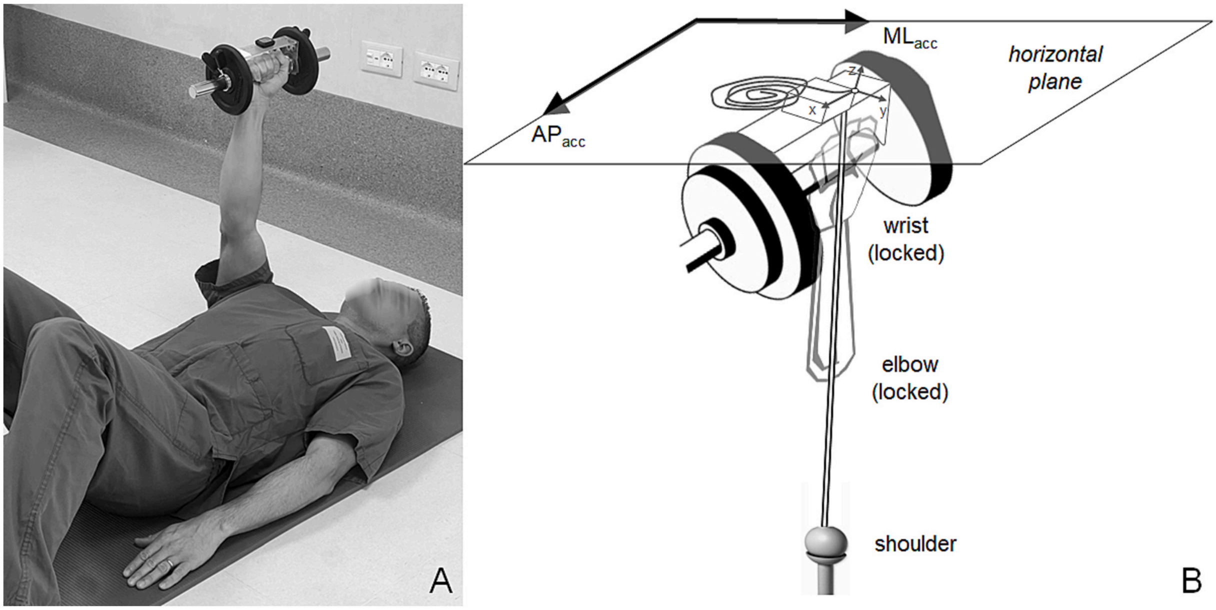

Fig. 1. A subject performing the SADS-OKC test (A). The accelerometer is fixed on an inverted U-shaped support secured on the dumbbell that allows the subject's hand to hold the dumbbell's bar without impediment. In the SADS-OKC test, the sway of the dumbbell in the horizontal plane is modelled as the motion of an inverted pendulum linked at shoulder level with the dumbbell as the endpoint and the upper arm as the rigid bar of the pendulum, assuming no rotational motion at wrist and elbow level (B). Sway path consists of the trace formed by the AP and ML accelerations of the dumbbell, i.e. "spaghetti" plot, in red (AP = antero-posterior; ML = medio-lateral). Note that the dumbbell must be hold so that the sensor's z-axis is pseudo-vertical and points upward, the x-axis is pseudo-AP and points to the little finger, y-axis is pseudo-ML and points medially to the subject's body when the right arm is used and laterally when the left arm is used.

Table 1
Stabilometric parameters derived from time- and frequency-domain analysis of the horizontal acceleration measured by a triaxial accelerometer placed on the dumbbell.

Name	Description	Unit
Time-domain stabilometric parameters		
Jerk	The average rate of change of the 2D horizontal acceleration signal (a measure of sway jerkiness/ smoothness)	m/s^3
mDist	Mean distance (deviation) from the centre of the sway path (trace of the spaghetti plot)	m/s^2
RMS	Root mean square of the 2D horizontal acceleration time series (quantifies the magnitude of the signal)	m/s^2
Range	The maximum amplitude of the 2D horizontal acceleration signal	m/s^2
swayArea	This parameter approximates the area enclosed by the envelop of the sway path	m^2/s^4
ellipseArea	The area of an ellipse enclosing all points of the sway path with 95 % confidence	m^2/s^4
swayFreq	Mean sway frequency (the number, per second, of loops that have to be run by the dumbbell to cover a trajectory equal to the total sway path)	Hz
Frequency-domain stabilometric parameters		
TP	Total power of the signal	$m^2/s^4/Hz$
F50	Median frequency, frequency containing the 50 % of TP	Hz
F95	95 % power frequency, frequency containing the 95 % of TP	Hz
CF	Centroidal Frequency, the frequency at which spectral mass is concentrated	Hz
FD	Frequency Dispersion is a measure of the variability in the frequency content of the power spectrum and it ranges from 0 (no dispersion) to 1 (uniform spectral bandwidth)	–

deriving such parameters can be found elsewhere (Martinez-Mendez et al., 2012). Power spectrum estimation for computing frequency-domain parameters was performed on the filtered acceleration signal using a modified Welch's method, with 3 segments, 50 % overlapping, and after linearly detrending each segment (Vieira et al., 2009). Only the 0.1–14 Hz band was considered for subsequent analyses. The algorithm used for signal processing is graphically summarized in the Supplementary Material C. A custom Matlab script was used for this purpose (ver. R2022b, The Mathworks Inc., Natick, Massachusetts).

2.2. Study participants

Twenty college students (16 male, 4 female; age: 23 ± 2 years; height: 1.7 ± 0.1 m; body mass: 71.6 ± 12.3 kg) met the screening criteria of no shoulder injury history in the past two years and ability to maintain a push-up position on both hands with extended elbows and protracted shoulders for 30 s minimum. The study received approval from the University of Rome "Campus Biomedico" Ethics Committee (Prot. PAR 23.23). All the participants provided informed consent.

2.3. Test design

SADS-OKC test designing involves defining three key aspects: load selection, test duration, and optimal stabilometric parameters for reliability purposes. Load administration used a reference load (RL) for generalizability. RL has been defined as the load measured on a digital scale while the subject is in a stable quadruped position with both hands on the scale (Pontillo et al., 2007). This position is easily standardizable by asking subjects to keep their upper arms and thighs perpendicular to the trunk. Test validation employed loads of 15 %, 25 %, and 35 % of RL, considering that heavier loads in open kinetic chain could be challenging for subjects with shoulder pathology without offering any advantage over the typical test. Test duration selection accounted for previous SADS test (10 s (Myers et al., 1999), 20 s (Pontillo et al., 2007), 30 s (Edouard et al., 2012)) and was set to 30 s. However, statistical analysis was also performed on stabilometric parameters derived from the first 20 s of the test.

2.4. Experimental setup

Initial RL determination used five independent measurements obtained with a digital scale. Between each measurement, participants returned to a standing position and then resumed the standardized quadruped posture. The final RL was calculated as the mean of the five measurements. For SADS-OKC testing, subjects maintained supine position with knees bent and feet flat, holding a dumbbell in one hand with fully extended arm and protracted shoulder (Fig. 1A). To avoid direct visual control of the dumbbell and to standardize visual input, participants were asked to fix their gaze on a ceiling marker, to breathe normally, and to avoid speaking. No corrections were given during the test, unless safety concerns required intervention.

The dumbbell incorporated a custom-made inverted aluminium U-shaped bracket securing a triaxial wireless accelerometer (Movella DOT, The Netherlands), which was firmly fixed at its centre using tape. The accelerometer was positioned so that its x-axis was aligned with the longitudinal axis of the bracket pointing toward the little finger (Fig. 1B). Signals were collected via Bluetooth using a proprietary mobile application which, in such a recording modality, limited the sampling rate to 60 Hz. Although higher frequencies are commonly recommended, this setting was considered adequate given the 14 Hz low-pass filtering applied to the signals. To validate the inverted pendulum model assumption, elbow and wrist kinematics were monitored using an 8-camera stereophotogrammetric system (Smart-DX, BTS Bioengineering, Italy) by placing retroreflective markers on the acromion, lateral epicondyle, radius styloid process, and hand centre.

2.5. Experimental protocol

The experimental protocol (Table 2) was designed to determine both intra- and inter-day reliability (Hopkins, 2000).

The session consisted of single trials (tests) at 15 %, 25 %, and 35 % of RL. Each session included randomized trials at 15 %, 25 %, and 35 % of RL for both arms (dominant first). Individual trials lasted 30 s with 3-minute rest intervals ensuring ATP restoration. Sessions were separated by 30 min (Sessions 1–2) and 24 h (Sessions 2–3).

2.6. Statistical analysis

Reproducibility of RL determination was assessed by means of coefficient of variation (CV) computed over the 5 performed measurements. Elbow and wrist kinematics were computed over the entire duration of the trial. Intra-day (Session 1 *vs.* Session 2) and inter-day (Session 1 *vs.* Session 3) reliability of the stabilometric parameters were assessed by Intraclass Correlation Coefficient (ICC). The ICC was independently computed for all the 6 experimental conditions (3 loads, 2 test durations), and for dominant and not dominant arm. A two-way mixed, single measures, consistency ICC analysis was used ($ICC_{3,1}$) (Koo and Li, 2016; Shrout and Fleiss, 1979). Finally, a Spearman's rank

Table 2
Experimental protocol used to assess inter-session and inter-day reliability of the SADS-OKC test, and its predictivity in detecting changes in the sensorimotor control of the shoulder following a fatigue-inducing protocol.

Day	Session number	Limb
day 1	session 1	dominant
day 1	session 1	non-dominant
	(30 min rest)	
day 1	session 2	dominant
day 1	session 2	non-dominant
	(24 h rest)	
day 2	session 3	dominant
day 2	session 3	non-dominant

correlation analysis was performed to assess the relation between the amount of load and changes in the stabilometric parameters. Statistical analyses were performed using MedCalc Statistical Software (MedCalc Software bvba, v. 17.6, Ostend, Belgium).

3. Results

The average RL was 28.3 ± 5.5 kg, with an average CV of 2.2 % across the five attempts. The average ranges of flexion at the elbow and at the wrist while holding 15 %, 25 % and 35 % of RL were 1°, 1.5°, 1.3° and 1.9°, 2.1°, and 2.1°, respectively. Intra- and inter-day reliability of stabilometric parameters are reported in Table 3, while results of the Spearman correlation analysis are reported in Fig. 2.

4. Discussion

The present research aimed at designing a novel instrumented test for assessing shoulder neuromuscular control in a non-intrusive manner and in field settings. While the original SADS test requires a force platform to assess shoulder neuromuscular control in terms of CoP trajectory of the supporting hand, the newly proposed SADS-OKC test employs a triaxial accelerometer fixed on a dumbbell to quantify its horizontal acceleration, which is reasonable expected to reflect the subject ability to stabilize the shoulder joint. This assumption apparently held true as rotations of the elbow and wrist joints were remark ably small (<2.1°), suggesting that sway of the dumbbell was controlled almost exclusively by shoulder musculature, while elbow and wrist muscles mainly acted isometrically to maintain the arm complex as a rigid pendulum shaft. Such a slow and minimal joint drifts (<2.1° over 30 s) are unlikely to have substantially affected the measured stability parameters.

The design of the SADS-OKC test entailed the definition of some key characteristics of the test. First, a standardized and subject-specific procedure to individualize the loads: to this end, the quadruped position adopted by Pontillo and coll. for their variation of the SADS test was used to identify a RL equal to the fraction of the body mass sustained by the hands on a digital scale (note that such an approach may not be suitable for an obese population). RL showed high reproducibility (CV = 2.2 %). Second, the percentage of the RL to use for the test: this choice was made between three loads (15 %, 25 % and 35 % of RL). Third, the choice of test duration (20 or 30 s). The 15 %, 25 % and 35 % of RL, and 20 s and 30 s test conditions were tested for intra-day and inter-day reproducibility of a set of stabilometric parameters that were chosen among those commonly used for accelerometric-based standing balance assessment. Theoretically, the lowest load and test duration yielding the highest reproducible stabilometric parameters should be used for the execution of the SADS-OKC test for safety reasons.

ICC analysis revealed that only the SADS-OKC test performed at 15 % RL exhibited intra- and inter-day reliability ranging from moderate to excellent across both sides and test durations for all time-domain stabilometric parameters and the sole frequency-domain *F95* parameter. In particular, with regard to intra-day reliability, *Jerk* exhibited good-to-excellent reliability at both 20 s and 30 s. *swayArea* showed moderate-to-good reliability at 20 s and good-to-excellent reliability at 30 s, while *swayFreq* improved from moderate at 20 s to good-to-excellent at 30 s. *Range* maintained moderate-to-good reliability in both conditions. *ellipseArea* demonstrated moderate reliability at 20 s and moderate-to-good reliability at 30 s. The remaining parameters (*mDist*, *RMS*, and *F95*) consistently exhibited moderate reliability across both durations. Regarding inter-day reliability, ICC values were moderate-to-good for *Jerk* and *swayArea* at 20 s, while all other parameters displayed moderate reliability in both test duration (Table 3). Overall, ICC values obtained with 30 s trials were slightly higher than those observed with 20 s trials, suggesting that extending trial duration may provide an increase in reproducibility of stabilometric parameters. Generally, reliability of the stabilometric parameters decreases as the load increases. A possible explanation is that the higher reliability observed at 15 % RL reflects reduced neuromuscular fatigue and smaller compensatory adjustments required at lower loads, which may minimize the variability of stability parameters. A more complete overview of the reliability values across all loads is provided in the Supplementary Material D. Consistently, the lower ICC values observed at 25 % and 35 % RL may be related to the fact that several frequency-domain parameters (*swayFreq*, *F50*, *F95*, *CF*, and *FD*) appeared to be moderately affected by load increase, as suggested by Spearman's correlation analysis ($0.4 < \rho < 0.59$) (Fig. 2). This load-dependent variability could partly explain the reduced reliability at higher intensities.

The highest test–retest reliability is relative to *Jerk* and aligns with previous findings in standing balance assessments (Mancini et al., 2012), where *Jerk* also served as a sensitive index of postural stability in neurological disorders (Ghislieri et al., 2019), thus supporting its potential as an outcome for clinical applications of SADS-OKC test. Similarly, the low inter-session reliability of frequency-domain parameters mirrors findings from standing-balance studies, where spectral measures are typically less consistent than time-domain metrics. When compared

Table 3

Stabilometric parameters whose reliability analysis showed ICC values of higher than 0.5 in all testing conditions (RL = reference load; s = seconds; S = session). The complete version of this table, which also includes parameters with ICC values below 0.5 (i.e., showing poor reliability at 25 % and 35 % of RL), is provided in Supplementary Material D.

Testing condition	Stabilometric parameters	Intra-day Dominant arm (S1vsS2)	Intra-day Non-dominant arm (S1vsS2)	Inter-day Dominant arm (S1vsS3)	Inter-day Non-dominant arm (S1vsS3)
15 % RL(20 s)	Jerk	0.896	0.930	0.717	0.766
	mDist	0.506	0.646	0.690	0.614
	RMS	0.522	0.684	0.671	0.633
	Range	0.683	0.790	0.590	0.655
	swayArea	0.849	0.879	0.696	0.755
	ellipseArea	0.518	0.703	0.623	0.698
	swayFreq	0.676	0.723	0.605	0.610
	F95	0.676	0.723	0.605	0.610
15 % RL(30 s)	Jerk	0.899	0.947	0.714	0.736
	mDist	0.568	0.716	0.693	0.683
	RMS	0.502	0.740	0.683	0.691
	Range	0.706	0.765	0.535	0.674
	swayArea	0.866	0.917	0.707	0.740
	elipseArea	0.536	0.761	0.668	0.748
	swayFreq	0.899	0.947	0.714	0.736
	F95	0.635	0.801	0.536	0.647

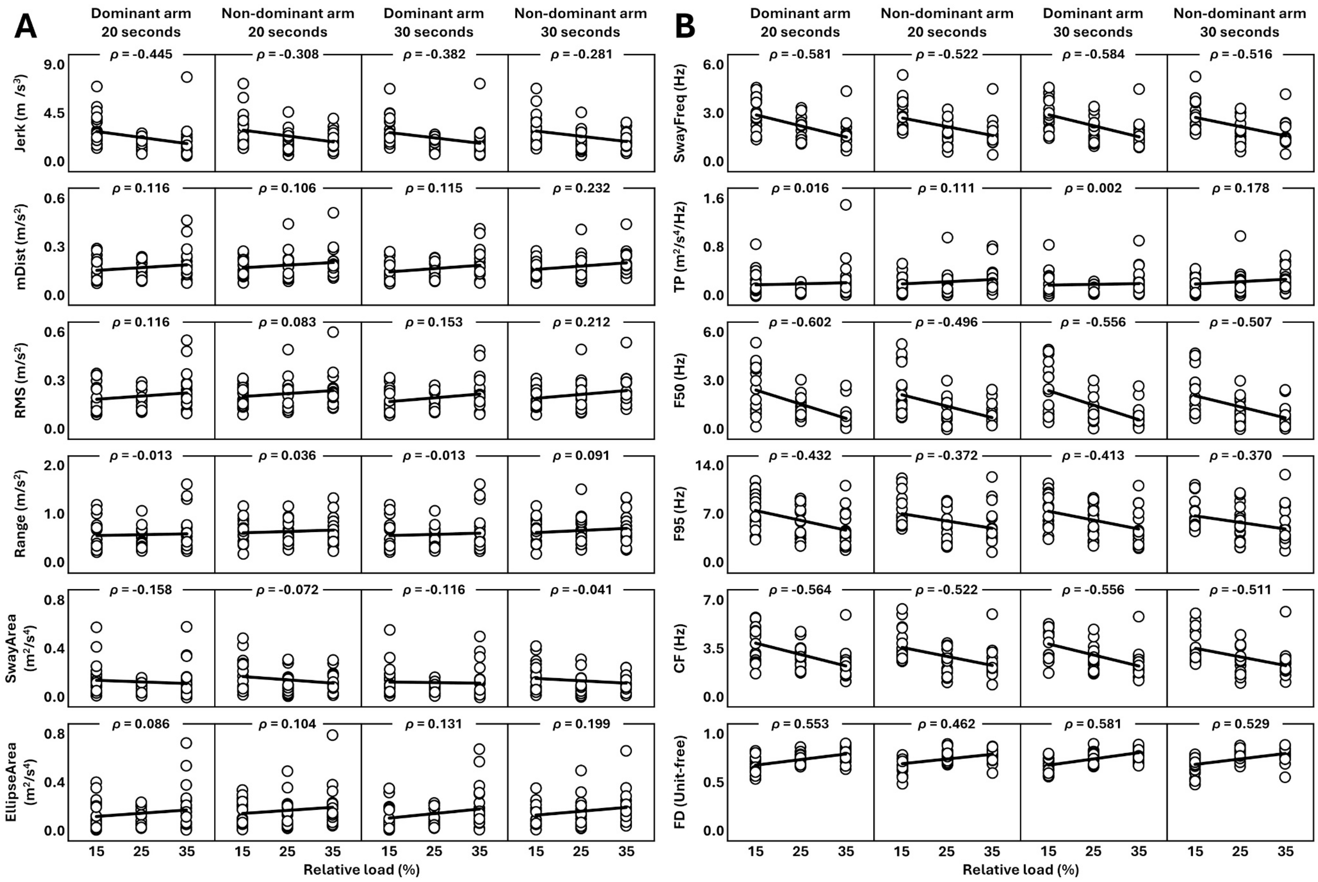

Fig. 2. Time- (A) and frequency-domain (B) parameters (white dots) as computed across the three sessions and grouped by each of the three test loads during 20 s and 30 s test duration for both dominant and non-dominant sides. ρ represents the Spearman correlation coefficient. Note that *swayFreq* is grouped on the right side for space convenience.

to the SADS test, although relevant metrics are not directly comparable, the SADS-OKC test showed a higher inter-session reliability with respect to Edouard and coll. (Edouard et al., 2012), while no inter-day reliability of the SADS test has been previously assessed. Consistently with the SADS test, where reliability seems to be configuration-dependent and the more supported position yields higher ICCs than more demanding setup (Edouard et al., 2012), in the SADS-OKC test the easiest condition (15 % RL) delivers the highest ICCs, indicating a similar dependence on task difficulty. From a user point of view, the SADS-OKC test offers enhanced ecological validity and accessibility, requiring only standard equipment and minimal setup requirements. No specific recommendations are needed for either the choice of the triaxial accelerometer (a smartphone could also be used) or the sensor-to-dumbbell support. No formal user feedback was collected in this validation study. However, participants did not report difficulties in performing the test.

5. Conclusion

Although the sample size was limited to 20 participants, results of the present study suggest that the newly-proposed SADS-OKC test, as performed with 15 % of RL for 30 s, has proven to produce a set of reliable stabilometric parameters that may be related to the neuromuscular control of the shoulder. Further studies should investigate whether any of these parameters can also identify deficits in the neuromuscular control of the unstable shoulder so that a rehabilitation progress may be monitored. In this perspective, the SADS-OKC test represents a safer alternative to the traditional SADS test, as subjects with an unstable shoulder condition do not have to sustain the large portion of their body mass required in the push-up position.

Data availability statement

Joint kinematics and time- and frequency parameters are available in the Supplementary Material A and B, respectively (while raw accelerometer data can be shared upon reasonable request). A PhyPhox experiment (Staacks et al., 2018) implementing the SADS-OKC test (time-domain parameters only, Android tested) can be found in the Supplementary Material E, while the Matlab code for computing time- and frequency-domain stabilometric parameters can be download under GNU General Public License v3.0 at: https://github.com/pietro-picerno/SADS-OKC-test-Matlab-.git.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Pietro Picerno: Writing – original draft, Methodology, Formal analysis, Conceptualization. **Enzo Iuliano:** Formal analysis. **Marco Bravi:** Supervision, Investigation, Conceptualization. **Fabio Santacaterina:** Investigation. **Amador García Ramos:** Methodology. **Uroš Pešović:** Software. **Rigoberto Martínez Méndez:** Writing – review & editing, Software. **Taian Martins Vieira:** Writing – review & editing, Software.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jbiomech.2025.113064.

References

Edouard, P., Gasq, D., Calmels, P., Degache, F., 2014. Sensorimotor control deficiency in recurrent anterior shoulder instability assessed with a stabilometric force platform. J. Shoulder Elbow Surg. 23, 355–360. https://doi.org/10.1016/j.jse.2013.06.005.

Edouard, P., Gasq, D., Calmels, P., Ducrot, S., Degache, F., 2012. Shoulder sensorimotor control assessment by force platform: Feasibility and reliability. Clin. Physiol. Funct. Imaging 32, 409–413. https://doi.org/10.1111/J.1475-097X.2012.01140.X.

Edouard, P., Lardy, G., Damotte, A., Gasq, D., 2016. Shoulder sensorimotor control in overhead athletes: A pilot study. Isokinet. Exerc. Sci. 24, 231–236. https://doi.org/10.3233/IES-160622.

Ehmann, Y.J., Berthold, D.P., Reuter, S., Beitzel, K., Köhler, R., Stöcker, F., Muench, L.N., Pogorzelski, J., Rupp, M.C., Braun, S., Imhoff, A.B., Buchmann, S., 2022. Center of pressure (COP) measurement in patients with confirmed successful outcomes following shoulder surgery show significant sensorimotor deficits. Knee Surg. Sports Traumatol. Arthrosc. 30, 2060–2066. https://doi.org/10.1007/S00167-021-06751-0.

Ghislieri, M., Gastaldi, L., Pastorelli, S., Tadano, S., Agostini, V., 2019. Wearable inertial sensors to assess standing balance: A systematic review. Sensors (basel) 19. https://doi.org/10.3390/S19194075.

Hopkins, W.G., 2000. Measures of reliability in sports medicine and science. Sports Med. 30, 1–15. https://doi.org/10.2165/00007256-200030010-00001.

Koo, T.K., Li, M.Y., 2016. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J. Chiropr. Med. 15, 155–163. https://doi.org/10.1016/j.jcm.2016.02.012.

Lephart, S.M., Fu, F.H., 2000. Introduction to the sensorimotor system, in: Lephart, S.M., Fu, F.H. (Eds.), Proprioception Control in Joint Stability. Human Kinetics, Champaign, pp. XVII–XIV.

Mancini, M., Salarian, A., Carlson-Kuhta, P., Zampieri, C., King, L., Chiari, L., Horak, F. B., 2012. ISway: A sensitive, valid and reliable measure of postural control. J. Neuroeng. Rehabil. 9, 59. https://doi.org/10.1186/1743-0003-9-59.

Martinez-Mendez, R., Sekine, M., Tamura, T., 2012. Postural sway parameters using a triaxial accelerometer: Comparing elderly and young healthy adults. Comput. Methods Biomech. Biomed. Eng. 15, 899–910. https://doi.org/10.1080/10255842.2011.565753.

Millecamps, A., Lowry, K.A., Brach, J.S., Perera, S., Redfern, M.S., Sejdić, E., 2015. Understanding the effects of pre-processing on extracted signal features from gait accelerometry signals. Comput. Biol. Med. 62, 164–174. https://doi.org/10.1016/j.compbiomed.2015.03.027.

Moe-Nilssen, R., Helbostad, J.L., 2002. Trunk accelerometry as a measure of balance control during quiet standing. Gait Posture 16, 60–68. https://doi.org/10.1016/S0966-6362(01)00200-4.

Myers, J.B., Guskiewicz, K.M., Schneider, R.A., Prentice, W.E., 1999. Proprioception and neuromuscular control of the shoulder after muscle fatigue. J. Athl. Train. 34, 362–367.

Pontillo, M., Orishimo, K.F., Kremenic, I.J., McHugh, M.P., Mullaney, M.J., Tyler, T.F., 2007. Shoulder musculature activity and stabilization during upper extremity weight-bearing activities. N Am J Sports Phys Ther 2, 90–96.

Riemann, B.L., Lephart, S.M., 2002a. The sensorimotor system, Part I: The physiologic basis of functional joint stability. J. Athl. Train. 37, 71.

Riemann, B.L., Lephart, S.M., 2002b. The sensorimotor system, Part II: The role of proprioception in motor control and functional joint stability. J. Athl. Train. 37, 80.

Riemann, B.L., Myers, J.B., Lephart, S.M., 2002. Sensorimotor system measurement techniques. J. Athl. Train. 37, 85.

Shrout, P.E., Fleiss, J.L., 1979. Intraclass correlations: Uses in assessing rater reliability. Psychol. Bull. 86, 420–428. https://doi.org/10.1037/0033-2909.86.2.420.

Staacks, S., Hütz, S., Heinke, H., Stampfer, C., 2018. Advanced tools for smartphone-based experiments: Phyphox. Phys. Educ. 53, 45009. https://doi.org/10.1088/1361-6552/aac05e.

Vieira, T.M.M., Oliveira, L.F., Nadal, J., 2009. Estimation procedures affect the center of pressure frequency analysis. Braz. J. Med. Biol. Res. 42, 665–673. https://doi.org/10.1590/S0100-879X2009000700012.

Winter, D.A., 2009. Biomechanics and Motor Control of Human Movement, Hoboken, N. J: John Wiley & Sons. Doi: 10.1002/9780470549148.