ARTICLE IN PRESS

Journal of Biomechanics xxx (xxxx) xxx

Contents lists available at ScienceDirect

Journal of Biomechanics

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

Short communication

Does the examiner's experience matter in evaluation of the kinematics of the upper limb?

Diogo Henrique Magalhães Gonçalves [a], Fabiano Politti [a], André Serra Bley [a], Silvio Antonio Garbelotti jr [b], Wagner de Godoy [c], Paulo Roberto Garcia Lucareli [a,1]

[a] Human Motion Analysis Laboratory, Rehabilitation Sciences Department, Universidade Nove de Julho – UNINOVE, São Paulo, SP, Brazil
[b] Departament of Morphology and Genetics, Universidade Federal de São Paulo, São Paulo, Brazil
[c] Movement Analysis Laboratory, Albert Einstein Hospital, São Paulo, Brazil

ARTICLE INFO

Article history:
Accepted 17 December 2018
Available online xxxx

Keywords:
Reliability
Shoulder
Scapula
Kinematics
Upper limb

ABSTRACT

This study aimed to evaluate test and retest reliability according to examiner experience with the three-dimensional kinematics of the trunk, scapula, and arm segments during flexion and unilateral abduction of the arm. Ten men and 10 women (mean age, 25.1 [1.1] years) participated in this study. Each volunteer participated in six test sessions, four on the first day (two for each examiner) and two on the second day (one for each examiner). A 48-h interval was given between test days. The assessments were made by one examiner with movement analysis experience and a second examiner without experience. For each session (intra-day), the volunteers performed five repetitions of unilateral arm flexions and abductions using their dominant arms. After 1 h, the data were re-collected and all markers were replaced. Data from the trunk, scapula, and arm were analysed at 30°, 60°, 90°, and 120° of arm flexion and abduction using intraclass coefficient correlation, standard error of the measurement, and analysis of variance. The results did not differ between the experienced and inexperienced examiners except for trunk axial rotation at all studied angles and for arm rotation at 120° of abduction. The examiner previously trained in movement analysis marker placement demonstrated the same intra-tester reliability as the inexperienced tester when marker placement accuracy was the variable of interest.

1. Introduction

A joint kinematics analysis is essential in a musculoskeletal assessment since it may aid in the diagnosis, clinical management, and monitoring of patient outcomes (Lempereur et al., 2014; Artilheiro et al., 2014). In daily clinical practice, the evaluation is performed using instruments that evaluate two-dimensional movements, which can reduce clinical examination accuracy. Therefore, it is more advantageous to use a non-invasive device that allows an accurate and reliable measurement of three-dimensional joint movements (Adhia et al., 2013).

Despite the use of skin-based markers for the scapula as a valid method in different shoulder movements and conditions, scapular kinematics are particularly difficult to measure because of extensive scapular movements that occur under the skin. This difficulty of the markers following real movements may reflect less precise results depending on the evaluator's familiarity with the shoulder's complex movements, especially those >90° (Brochard et al., 2011; Hayk et al., 2014; Janes et al., 2012).

The manual placement of markers on the skin is related to palpation inaccuracies (Alexander et al., 2018) and can produce significant differences among trials, sessions, and examiners, thereby compromising the interpretation of the clinical responses observed on different days and/or by different examiners (Lucareli et al., 2016). The precision or degree of agreement between the measurements taken or observations made in different locations by different people could be clarified via the study of the reproducibility of the data and examiner experience.

In addition, the same examiners do not always perform the pre- and post-treatment evaluations; in some cases, the evaluators do not have the same experience in the examination procedure as that with marker placement, a factor that may interfere with the results (Bourne et al., 2011; Lempereur et al., 2014).

This study aimed to evaluate the intra- and inter-day reliability of the tri-dimensional kinematics of the trunk, scapula, and arm segments during arm flexion and abduction movements to test the hypothesis that marker placement performed by an experi-

[1] Address: Rua Vergueiro, 2355 – Liberdade, São Paulo 01504-001, SP, Brazil.
E-mail addresses: paulolucareli@uni9.pro.br, plucareli@hotmail.com (P.R.G. Lucareli)

https://doi.org/10.1016/j.jbiomech.2018.12.035

Please cite this article as: D. H. M. Gonçalves, F. Politti, A. S. Bley et al., Does the examiner's experience matter in evaluation of the kinematics of the upper limb?, Journal of Biomechanics, https://doi.org/10.1016/j.jbiomech.2018.12.035

enced evaluator can produce more reliable and accurate results than that performed by an inexperienced evaluator.

2. Methods

2.1. Participants

Ten healthy men and 10 healthy women were recruited from the local community through verbal invitation; all had right upper-limb dominance (defined by asking them which hand they normally used for daily activities), a mean age of 25.1 (1.1) years, mean weight of 65.6 (2.0) kg, mean height of 1.70 (0.2) cm, and mean body mass index of 22.53 (0.4) kg/cm^2. The study received approval from the local ethics committee. Participants with pain or joint instability (Lizzio et al., 2017), previous upper limb fracture, symptoms of cervical or lumbar spine disorders, or psychological or neurological disorders; those who demonstrated evident visual reduction in the active range of motion <120° or were under the influence of psychotherapeutic drugs; and those with positive results in clinical tests such as Neer, Hawkins-Kennedy, Jobe, or external rotation resistance were excluded (Michener et al., 2009).

2.2. Procedures and instrumentation

Each volunteer participated in 6 sessions over 2 weeks. Two sessions were performed on the first day with a 1-h interval between them, while one session was performed after 48 h. The inexperienced examiner performed the first 3 sessions and the experienced examiner performed the last 3 sessions. Two independent physical therapists had 8 years of experience each in clinical rehabilitation management: one of them had 5 years of experience in motion analysis data collection and marker placement using the marker set used in this study, while the other was the inexperienced examiner who had never collected or placed markers for motion analysis. The inexperienced examiner received a 45-min explanation about how and where markers had to be placed and the motion analysis process. To blind the sessions, the evaluators were not allowed to attend the sessions.

For each test session, eight 14-mm retro-reflective markers and two rigid clusters of 3 markers each were attached to the volunteers (Fig. 1).

A static reference trial was performed while the volunteers remained in the functional orthostatic position with the forearm supinated and the elbow flexed at 90°. Subsequently, one more static trial was performed using a pointer at the flat angle region of the acromion. This procedure was used to reconstruct the virtual markers in relation to the acromial and arm clusters (Cappozzo et al. 1995). For the dynamic trials, the anatomical markers were removed but the cluster was left for reconstruction of the virtual and anatomical markers.

During each session, 5 repetitions of unilateral arm flexion and abduction were performed for each dominant upper limb. The movement sessions were initiated and terminated with the arm alongside the body in extension and adduction, elbows in extension, hands in a neutral position, and thumbs and fingers in extension. The command given for each repetition of the movement was "Ready? Go!," and the interval between each flexion and abduction movement was 15 s. The movements were performed at an auto-selected speed and the upper limb was not guided by any external instrument in the plane of movement.

At the end of each session, the markers were removed and the skin cleaned to reduce the possibility of the examiner knowing where the markers were placed. The procedures were performed under the same experimental conditions and in the same movement sequence as in the first data collection.

An 8-camera Vicon system (Vicon Motion Systems Inc.; Denver EUA) was used to capture the data. Each camera was set up at a frequency of 120 Hz connected to a computer on which Vicon Nexus software was used for data acquisition and processing.

2.3. Data processing

An independent technician performed the data processing after each session was captured. Data were reconstructed and labelled using the Vicon Nexus and a routine made using a Vicon Body Builder was developed and run in a pipeline inside the Nexus to reconstruct the markers in the dynamic trials based on static reference trials.

Thereafter, the segments were defined and the movement segment sequences were calculated following the recommendations of the International Society of Biomechanics (Wu et al., 2005). The thorax movement relative to the laboratory reference was used for the trunk movement, while the scapula and arm movements were relative to the thorax.

A fourth-order low-pass 8-Hz Butterworth filter was used to reduce the vibratory noise that could arise during the marker trajectory due to excessive skin movement.

After the data were processed, angular values for the trunk, scapula, and arm motions were extracted at 30°, 60°, 90°, and 120° of arm flexion and abduction using Vicon ProCalc software.

2.4. Statistical analysis

All data were analysed using SPSS 20.0 software. The statistical analysis was performed by an independent examiner. The distribution of the data was verified by the Shapiro-Wilk test. The homogeneity of the variances was confirmed for all dependent variables (Levene's test, $p > 0.05$). For the analyses, values of $p < 0.05$ were considered statistically significant.

The reliability of the movements of the scapula, arm, and trunk at the 30°, 60°, 90°, and 120° angles of flexion and abduction of the arm obtained in each test session with 5 repetitions was verified by the intraclass coefficient correlations (ICCs) that considered the model ICC2,k for the intra- and inter-day conditions as well as the model ICC3,k for the inter-rater condition (Weir, 2005). The ICCs were interpreted using the following criteria: poor = 0.00–0.39, weak = 0.40–0.59, good = 0.60–0.74, and excellent = 0.75–1.00 (Cicchetti and Sparrow, 1981).

From the ICC, the standard error of measurement (SEM) was calculated to express the reliability of the absolute values, with higher values indicating a high level of error and implying non-reliability of the tested values and a lower SEM denoting $SEM = SD\sqrt{1-ICC}$.

3. Results

The analysis of variance revealed no significant differences in the variables studied during arm flexion (Table 1) or the measurement interactions performed by the experienced and inexperienced examiners that included consideration of the capture performed in session 1 (day 1) and session 2 (day 2). However, during arm abduction (Table 2), significant differences were found between the examiners for the trunk at 30°, 60°, 90°, and 120° as well as arm rotation at 120°.

The ICC and SEM values of the inexperienced and experienced examiners for the scapula, arm, and trunk movements at angles of 30°, 60°, 90°, and 120° of flexion and arm abduction are presented in Tables 1 and 2, while ranges of motion are shown in the supplementary data.

Please cite this article as: D. H. M. Gonçalves, F. Politti, A. S. Bley et al., Does the examiner's experience matter in evaluation of the kinematics of the upper limb?, Journal of Biomechanics, https://doi.org/10.1016/j.jbiomech.2018.12.035

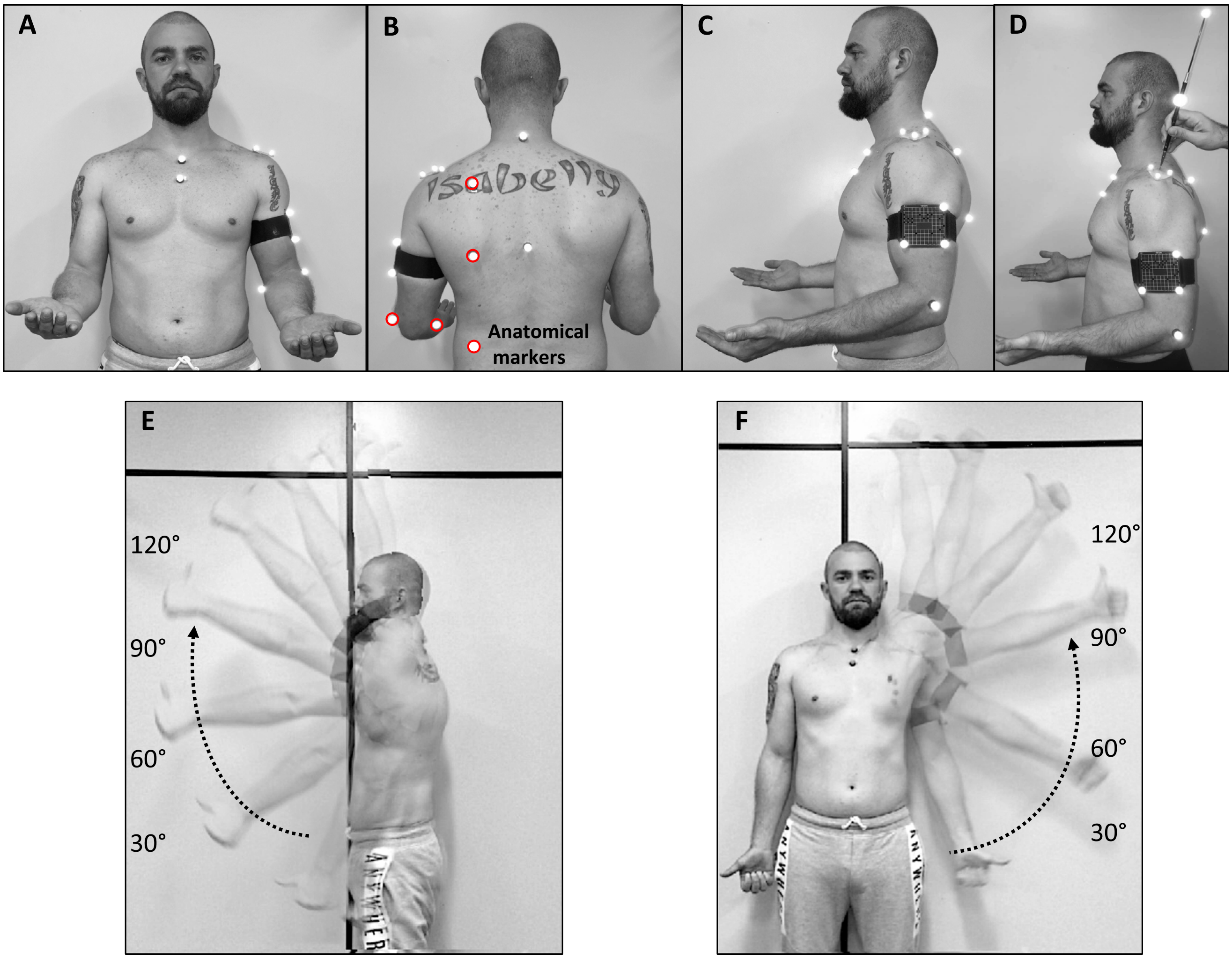

Fig. 1. Static trial – A. Anterior; B. Posterior; C. Lateral; D. Static trial with pointer. Dynamic Trial – E. Arm Flexion; F. Arm Abduction.

4. Discussion

This study evaluated the intra- and inter-day reliabilities of the experienced and inexperienced evaluators for measuring the scapula, arm, and trunk segments during flexion and abduction movements of the arm at 30°, 60°, 90°, and 120°. The hypothesis that the inter-examiner differences in experience could influence the evaluation results, i.e., better reliability for experienced examiners, was not confirmed in this study. The need for description and comparison of reliability between experienced and non-experienced evaluators in the collection of kinematic data was recently reported in two systematic reviews (Adhia et al., 2013; Cimolin et al., 2014). However, in this study, a difference between the reliability results of the experienced and inexperienced examiners was observed only in arm external rotation at 120°; this result may be associated with a soft-tissue artefacts (Blache et al., 2017). Trunk contralateral axial rotation differed at all abduction evaluated angles; this was probably due to trunk movements being more susceptible to arm abduction movements or being influenced by static trunk posture at an arm rotation of 120° during arm abduction. These findings require further study in the future.

The results found for each evaluator are generally similar to those found in the literature, in which good reliability was demonstrated for shoulder girdle kinematics, especially those of the scapula (Roy et al., 2007; Warner et al., 2015) and arm (López-Pascual et al., 2016; Scibek and Carcia, 2013). Although no reliability study evaluating the scapula, arm, and trunk has compared the experience of the evaluators, comparative reliability studies serve as a reference for the consistent analysis of this study's data as well as how well the results can be extrapolated to clinical experience. The results obtained in our study can be used as parameters of normality for the trunk, scapula, and arm movements of flexion and abduction.

Variations in measurements during arm flexion and abduction movements may arise from different sources of error. Some variations are due to experimental errors and passive to improvement in quality since they are extrinsic. Other variations occur naturally and can only be measured and managed since they are intrinsic. This study focused on verifying whether evaluator experience modified the measurement result on the same or a different day. Intra-sessions, different days, and therapist errors are extrinsic factors that arise from several methodological sources, including palpation, anthropometric measurements, marker positioning, and the spatial resolution of the motion capture system (Schwartz et al., 2004).

López-Pascual et al. (2016) demonstrated the important influence of the method on measurement errors. They asserted that even when intra-subject variability is small, the same motion may have different reliability values depending on the method used to represent the rotations and recommended attention to

Please cite this article as: D. H. M. Gonçalves, F. Politti, A. S. Bley et al., Does the examiner's experience matter in evaluation of the kinematics of the upper limb?, Journal of Biomechanics, https://doi.org/10.1016/j.jbiomech.2018.12.035

Table 1
Mean and standard deviation (SD), Intraclass coefficient correlation (ICC) and standard error of measurement (SEM) observed intra and inter-days for scapula, arm, and trunk movements during arm flexion in degrees.

	Examiner 1 (Inexperienced)								Examiner 2 (Experienced)								Examiner 1 vs Examiner 2								P-value
	Intra day (A × B)				Inter days (A × C)				Intra day (D × E)				Inter days (D × F)				Intra day (A × D)				Inter days (A × C × D × F)				
	Mean	SD	ICC	SEM	Mean	SD	ICC	SEM	Mean	SD	ICC	SEM	Mean	SD	ICC	SEM	Mean	SD	ICC	SEM	Mean	SD	ICC	SEM	
30°																									
Scapular upward rotation	−3.86	(5.61)	0.84	2.01	−2.82	(4.76)	0.46	3.79	−3.55	(4.45)	0.85	2.25	−2.05	(5.23)	0.72	3.21	−2.21	(6.34)	0.65	3.20	−4.17	(6.78)	0.76	2.75	0.07
Scapular tilt posterior	4.75	(4.52)	0.88	1.39	4.15	(3.29)	0.52	2.71	3.43	(3.30)	0.67	2.40	3.04	(4.61)	0.73	2.25	3.51	(3.87)	0.72	2.44	4.19	(4.08)	0.78	1.93	0.68
Scapular external rotation	48.04	(6.77)	0.90	2.13	48.08	(5.81)	0.80	2.77	47.47	(6.59)	0.90	2.11	45.95	(7.22)	0.74	3.15	45.68	(6.19)	0.92	1.92	46.19	(5.07)	0.91	1.86	0.87
Arm flexion	−30.53	(0.22)	0.59	0.14	−30.59	(0.17)	0.38	0.15	−30.64	(0.23)	0.51	0.12	−30.53	(0.20)	0.75	0.09	−30.50	(0.15)	0.67	0.12	−30.56	(0.16)	0.74	0.09	0.99
Arm abduction	−13.16	(5.21)	0.84	2.37	−11.94	(6.78)	0.62	3.71	−11.75	(6.75)	0.69	3.10	−12.77	(5.95)	0.82	2.53	−14.44	(5.26)	0.89	1.81	−12.90	(6.24)	0.91	1.81	0.29
Arm internal rotation	21.76	(9.69)	0.77	4.62	20.77	(7.80)	0.50	6.17	21.27	(9.91)	0.82	4.12	21.49	(9.45)	0.82	3.73	19.93	(9.92)	0.85	3.61	21.69	(8.15)	0.86	3.20	0.61
Trunk posterior inclination	2.80	(4.66)	0.98	0.70	4.08	(4.56)	0.84	1.83	3.26	(4.65)	0.98	0.63	3.07	(4.33)	0.95	0.89	3.30	(4.46)	0.93	1.18	3.69	(3.98)	0.96	0.90	0.41
Trunk internal rotation	0.69	(2.52)	0.83	1.09	0.37	(2.65)	0.60	1.62	0.30	(2.76)	0.87	1.30	0.41	(3.81)	0.78	1.64	0.67	(3.43)	0.79	1.39	0.64	(2.48)	0.78	1.30	0.2
Trunk lateral inclination	−0.85	(1.14)	0.78	0.58	−0.79	(1.35)	0.73	0.64	−0.63	(1.31)	0.74	0.57	−1.11	(1.24)	0.70	0.67	−1.08	(1.22)	0.44	0.88	−0.93	(1.20)	0.76	0.60	0.78
60°																									
Scapular upward rotation	−13.60	(6.02)	0.83	2.15	−12.68	(5.14)	0.47	4.03	−13.20	(4.54)	0.89	2.21	−12.16	(6.23)	0.79	3.14	−12.27	(7.31)	0.59	3.89	−13.67	(7.65)	0.76	3.02	0.24
Scapular tilt posterior	5.19	(5.50)	0.92	1.37	4.62	(4.39)	0.66	2.88	3.92	(3.87)	0.84	2.33	3.78	(5.79)	0.87	1.96	4.31	(5.85)	0.66	3.28	4.70	(5.34)	0.84	2.08	0.35
Scapular external rotation	51.01	(7.46)	0.90	2.27	51.19	(6.48)	0.83	2.82	50.75	(6.84)	0.91	2.27	49.16	(8.13)	0.77	3.35	48.86	(7.23)	0.94	1.94	49.39	(5.79)	0.91	2.05	0.97
Arm flexion	−60.59	(0.28)	0.83	0.11	−60.70	(0.31)	0.62	0.18	−60.61	(0.27)	0.79	0.11	−60.51	(0.25)	0.58	0.18	−60.60	(0.23)	0.67	0.15	−60.66	(0.29)	0.85	0.11	0.99
Arm abduction	−16.11	(5.96)	0.85	2.52	−15.03	(6.65)	0.65	3.73	−14.54	(7.14)	0.82	2.79	−15.75	(6.68)	0.88	2.40	−17.24	(6.40)	0.88	2.18	−15.66	(7.12)	0.92	1.83	0.46
Arm internal rotation	28.23	(9.23)	0.72	4.81	26.72	(6.40)	0.41	6.03	27.35	(9.30)	0.81	4.10	29.20	(8.90)	0.84	3.27	26.78	(9.97)	0.83	3.69	28.71	(7.62)	0.84	3.16	0.65
Trunk posterior inclination	1.94	(4.58)	0.98	0.66	3.08	(4.38)	0.84	1.79	2.27	(4.49)	0.98	0.65	2.24	(4.17)	0.95	0.87	2.32	(4.46)	0.93	1.18	2.72	(3.92)	0.96	0.88	0.38
Trunk internal rotation	1.70	(2.54)	0.82	1.14	1.53	(3.01)	0.65	1.63	1.34	(2.88)	0.87	1.38	1.43	(4.03)	0.76	1.81	1.85	(3.82)	0.80	1.42	1.74	(2.64)	0.80	1.34	0.38
Trunk lateral inclination	−0.35	(1.17)	0.77	0.61	−0.21	(1.31)	0.73	0.64	−0.12	(1.41)	0.80	0.67	−0.50	(1.49)	0.74	0.71	−0.51	(1.48)	0.49	0.94	−0.47	(1.28)	0.74	0.67	0.81
90°																									
Scapular upward rotation	−25.21	(6.89)	0.87	2.32	−24.33	(5.55)	0.53	4.25	−25.08	(5.88)	0.92	2.21	−24.44	(7.16)	0.84	2.99	−24.35	(8.54)	0.58	4.51	−25.84	(8.11)	0.78	3.25	0.33
Scapular tilt posterior	5.16	(6.86)	0.95	1.40	5.03	(6.09)	0.78	3.02	4.57	(5.26)	0.86	2.58	5.11	(6.65)	0.88	2.25	5.78	(7.41)	0.62	4.11	5.90	(6.54)	0.85	2.50	0.65
Scapular external rotation	53.55	(8.35)	0.89	2.49	53.84	(7.27)	0.83	3.20	53.36	(7.09)	0.91	2.60	51.79	(9.14)	0.79	3.69	51.30	(8.09)	0.90	2.73	51.70	(7.10)	0.90	2.50	0.84
Arm flexion	−90.51	(0.22)	0.87	0.09	−90.66	(0.33)	0.60	0.18	−90.55	(0.28)	0.62	0.14	−90.48	(0.23)	0.76	0.10	−90.54	(0.23)	0.73	0.11	−90.48	(0.19)	0.86	0.10	0.99
Arm abduction	−18.97	(5.85)	0.82	2.58	−18.65	(5.76)	0.64	3.44	−18.15	(6.34)	0.87	2.35	−19.91	(6.58)	0.86	2.49	−21.20	(6.76)	0.88	2.17	−19.85	(7.07)	0.90	1.96	0.86
Arm internal rotation	40.54	(9.31)	0.67	5.19	39.10	(6.08)	0.48	5.62	39.50	(9.08)	0.81	4.26	42.70	(9.31)	0.88	2.99	39.70	(9.97)	0.81	4.05	42.02	(7.91)	0.87	3.00	0.73
Trunk posterior inclination	1.16	(4.52)	0.98	0.65	2.08	(4.21)	0.86	1.64	1.36	(4.29)	0.98	0.64	1.39	(4.12)	0.95	0.89	1.34	(4.40)	0.92	1.20	1.73	(3.97)	0.96	0.85	0.42
Trunk internal rotation	3.33	(2.78)	0.81	1.23	3.46	(3.35)	0.66	1.77	3.16	(2.98)	0.89	1.44	3.32	(4.45)	0.77	1.93	3.90	(4.20)	0.82	1.50	3.85	(2.78)	0.81	1.41	0.42
Trunk lateral inclination	0.50	(1.34)	0.81	0.64	0.83	(1.39)	0.75	0.68	0.87	(1.61)	0.91	0.54	0.43	(1.97)	0.79	0.82	0.48	(1.98)	0.63	1.01	0.42	(1.42)	0.76	0.75	0.52
120°																									
Scapular upward rotation	−36.01	(7.34)	0.86	2.66	−35.48	(5.58)	0.58	4.17	−36.13	(6.91)	0.92	2.32	−37.23	(7.41)	0.86	3.01	−36.07	(8.87)	0.52	5.08	−38.39	(8.80)	0.75	3.68	0.53
Scapular tilt posterior	1.79	(8.82)	0.94	1.87	1.59	(8.74)	0.79	3.99	0.73	(7.12)	0.80	3.42	2.48	(6.91)	0.80	3.13	3.73	(8.31)	0.57	5.13	2.61	(7.40)	0.81	3.45	0.9
Scapular external rotation	53.44	(10.47)	0.90	2.94	53.38	(9.22)	0.76	4.74	52.85	(7.91)	0.91	3.04	50.31	(11.21)	0.81	4.31	50.78	(9.69)	0.89	3.60	49.89	(8.88)	0.88	3.38	0.88
Arm flexion	−120.40	(0.19)	0.89	0.06	−120.44	(0.22)	0.78	0.10	−120.38	(0.21)	0.64	0.12	−120.35	(0.22)	0.48	0.15	−120.36	(0.20)	0.81	0.09	−120.41	(0.20)	0.86	0.08	0.99
Arm abduction	−21.73	(6.29)	0.83	2.56	−22.42	(6.43)	0.74	3.20	−21.47	(6.23)	0.90	1.82	−24.24	(5.77)	0.81	2.67	−24.94	(6.05)	0.89	2.05	−24.10	(6.66)	0.88	2.15	0.62
Arm internal rotation	56.66	(10.24)	0.67	5.64	54.61	(6.96)	0.56	5.75	55.38	(9.49)	0.84	4.01	59.24	(9.54)	0.92	2.59	56.70	(10.66)	0.84	3.97	58.86	(8.65)	0.90	2.83	0.44
Trunk posterior inclination	0.51	(4.64)	0.97	0.73	1.13	(4.20)	0.88	1.49	0.55	(4.04)	0.98	0.59	0.55	(4.18)	0.94	1.05	0.31	(4.36)	0.90	1.37	0.72	(4.30)	0.95	0.92	0.56
Trunk internal rotation	4.61	(2.87)	0.83	1.18	4.76	(3.47)	0.66	1.82	4.59	(2.97)	0.91	1.26	4.44	(4.48)	0.83	1.68	5.16	(4.18)	0.83	1.54	5.18	(3.10)	0.83	1.42	0.38
Trunk lateral inclination	1.57	(1.62)	0.84	0.69	2.12	(1.56)	0.74	0.81	2.10	(1.86)	0.91	0.73	1.52	(2.57)	0.80	1.01	1.68	(2.47)	0.75	1.06	1.57	(1.67)	0.82	0.80	0.39

P-value: The analysis of variance measured repeated measurements (ANOVA) for two factors: day (day 1 and day 2) vs examiner (experienced and inexperienced) and utilized Bonferroni's corrections to verify if there is a difference between the measures carried out by the evaluators.

Table 2
Mean and standard deviation (SD), Intraclass coefficient correlation (ICC) and standard error of measurement (SEM) observed intra and inter-days for scapula, arm, and trunk movements during arm abduction in degrees.

	Examiner 1 (Inexperienced)								Examiner 2 (Experienced)								Examiner 1 vs Examiner 2								P-value
	Intra day (A × B)				Inter days (A × C)				Intra day (D × E)				Inter days (D × F)				Intra day (A × D)				Inter days (A × C × D × F)				
	Mean	SD	ICC	SEM	Mean	SD	ICC	SEM	Mean	SD	ICC	SEM	Mean	SD	ICC	SEM	Mean	SD	ICC	SEM	Mean	SD	ICC	SEM	
30°																									
Scapular upward rotation	−2.62	(5.72)	0.76	2.63	−1.53	(5.41)	0.46	4.07	−2.71	(5.19)	0.86	2.26	−1.36	(5.78)	0.85	2.38	−1.02	(6.37)	0.70	3.12	−3.24	(6.62)	0.84	2.37	0.09
Scapular tilt posterior	0.74	(4.63)	0.88	1.40	0.02	(3.07)	0.48	2.81	−0.80	(3.38)	0.76	2.14	−1.04	(4.80)	0.77	2.13	−0.55	(4.11)	0.67	2.73	0.60	(4.08)	0.78	1.97	0.09
Scapular external rotation	38.94	(7.02)	0.85	2.37	39.21	(5.43)	0.70	3.37	38.22	(5.17)	0.84	2.32	37.42	(6.79)	0.73	2.92	36.88	(4.96)	0.90	2.19	37.19	(4.42)	0.90	1.90	0.69
Arm flexion	4.26	(4.67)	0.83	2.14	5.54	(4.32)	0.65	2.64	4.80	(5.89)	0.91	1.68	5.02	(5.69)	0.92	1.62	4.30	(5.56)	0.68	2.90	5.17	(5.56)	0.88	1.73	0.51
Arm abduction	−30.43	−(0.21)	0.59	0.14	−30.11	(0.16)	0.38	0.15	−30.63	(0.22)	0.51	0.12	−30.54	(0.13)	0.75	0.09	−30.02	(0.14)	0.67	0.12	−30.56	(0.15)	0.71	0.09	0.99
Arm internal rotation	−24.36	(8.73)	0.79	4.13	−25.38	(8.11)	0.42	6.37	−25.61	(9.42)	0.62	6.58	−23.23	(8.66)	0.77	4.04	−25.41	(12.59)	0.69	4.80	−23.28	(8.51)	0.81	3.64	0.73
Trunk posterior inclination	3.15	(4.77)	0.96	0.89	3.56	(4.23)	0.91	1.35	3.17	(4.10)	0.97	0.71	2.90	(4.00)	0.94	0.95	3.09	(4.27)	0.93	1.12	3.73	(3.63)	0.95	0.90	0.55
Trunk internal rotation	−1.84	(2.99)	0.90	0.93	−2.43	(3.14)	0.59	1.96	−2.49	(2.91)	0.82	1.30	−3.05	(3.40)	0.72	1.63	−2.38	(2.76)	0.88	1.10	−1.38	(2.19)	0.84	1.20	0.004
Trunk lateral inclination	0.22	(1.16)	0.85	0.55	0.14	(1.44)	0.59	0.83	0.58	(1.63)	0.81	0.70	−0.15	(1.70)	0.77	0.76	−0.14	(1.58)	0.73	0.75	−0.07	(1.41)	0.79	0.65	0.76
60°																									
Scapular upward rotation	−13.34	(5.71)	0.79	2.57	−12.53	(5.24)	0.48	3.91	−13.90	(5.52)	0.90	2.11	−13.43	(6.47)	0.88	2.31	−13.15	(7.02)	0.73	3.11	−15.05	(6.79)	0.85	2.32	0.17
Scapular tilt posterior	0.70	(5.35)	0.90	1.52	0.14	(4.06)	0.56	3.11	−0.91	(3.97)	0.83	2.15	−0.67	(5.37)	0.84	2.00	−0.54	(5.15)	0.65	3.14	0.58	(4.60)	0.80	2.13	0.27
Scapular external rotation	37.70	(7.43)	0.87	2.37	37.83	(5.55)	0.70	3.54	36.91	(5.56)	0.85	2.54	36.56	(7.52)	0.75	3.04	35.66	(5.45)	0.91	2.16	36.35	(4.47)	0.90	1.96	0.79
Arm flexion	5.95	(5.33)	0.78	2.95	7.60	(4.83)	0.54	3.46	6.90	(7.34)	0.86	2.48	7.29	(6.68)	0.91	2.15	5.73	(6.82)	0.53	4.12	7.49	(7.48)	0.85	2.37	0.33
Arm abduction	−60.58	−(0.20)	0.83	0.11	−60.61	(0.38)	0.62	0.18	−60.61	(0.23)	0.79	0.11	−60.14	(0.24)	0.58	0.18	−60.60	(0.20)	0.67	0.15	−60.66	(0.20)	0.85	0.11	0.99
Arm internal rotation	−41.49	(9.07)	0.78	4.25	−43.19	(7.90)	0.42	6.44	−43.60	(9.36)	0.72	5.62	−39.50	(8.57)	0.81	3.57	−43.01	(12.13)	0.79	4.05	−40.40	(8.04)	0.84	3.37	0.75
Trunk posterior inclination	3.00	(4.72)	0.95	0.93	3.26	(4.21)	0.91	1.33	2.94	(4.09)	0.97	0.65	2.66	(3.97)	0.94	0.90	2.82	(4.12)	0.93	1.16	3.32	(3.56)	0.95	0.89	0.58
Trunk internal rotation	−2.48	(3.01)	0.89	0.96	−3.20	(3.18)	0.57	2.01	−3.06	(2.87)	0.79	1.41	−3.44	(3.51)	0.76	1.52	−3.20	(2.67)	0.86	1.22	−2.21	(2.20)	0.82	1.28	0.009
Trunk lateral inclination	1.52	(1.56)	0.91	0.51	1.44	(1.52)	0.77	0.74	1.73	(1.91)	0.89	0.71	1.02	(2.08)	0.80	0.86	1.00	(2.08)	0.84	0.73	1.06	(1.64)	0.84	0.68	0.85
90°																									
Scapular upward rotation	−25.01	(5.72)	0.79	2.62	−24.33	(4.90)	0.39	4.12	−25.36	(5.96)	0.89	2.15	−26.43	(6.64)	0.86	2.43	−25.86	(6.79)	0.68	3.46	−27.52	(6.55)	0.80	2.66	0.37
Scapular tilt posterior	−1.56	(7.07)	0.94	1.50	−1.32	(6.49)	0.74	3.44	−2.77	(5.79)	0.87	2.36	−1.12	(6.24)	0.84	2.33	−0.88	(6.86)	0.65	3.89	−0.32	(5.66)	0.84	2.50	0.81
Scapular external rotation	38.91	(8.81)	0.90	2.39	38.93	(6.92)	0.73	4.06	37.91	(6.68)	0.88	2.73	38.51	(9.18)	0.79	3.46	36.89	(6.78)	0.95	1.99	37.94	(5.71)	0.92	2.22	0.69
Arm flexion	7.61	(5.10)	0.75	3.20	10.06	(4.97)	0.33	4.18	9.13	(7.53)	0.88	2.75	9.04	(7.31)	0.88	2.75	8.28	(8.46)	0.46	4.60	10.96	(8.76)	0.82	2.84	0.44
Arm abduction	−90.41	(0.23)	0.87	0.09	−90.51	(0.33)	0.60	0.18	−90.54	(0.27)	0.62	0.14	−90.29	(0.26)	0.76	0.10	−90.52	(0.26)	0.73	0.11	−90.38	(0.18)	0.86	0.10	0.99
Arm internal rotation	−54.44	(9.27)	0.78	4.63	−57.04	(8.23)	0.43	6.60	−56.82	(10.44)	0.76	5.46	−52.25	(8.99)	0.83	3.66	−55.94	(12.98)	0.81	3.94	−53.68	(8.91)	0.85	3.38	0.65
Trunk posterior inclination	2.57	(4.64)	0.95	0.98	2.68	(4.13)	0.90	1.39	2.43	(3.99)	0.97	0.69	2.06	(3.89)	0.93	0.95	2.04	(3.96)	0.91	1.30	2.60	(3.56)	0.95	0.92	0.57
Trunk internal rotation	−2.74	(2.96)	0.91	0.87	−3.46	(3.26)	0.60	1.96	−3.38	(2.97)	0.80	1.43	−3.86	(3.78)	0.73	1.70	−3.62	(2.68)	0.87	1.22	−2.61	(2.32)	0.83	1.27	0.02
Trunk lateral inclination	2.83	(2.10)	0.94	0.53	2.61	(1.77)	0.83	0.78	2.94	(2.21)	0.93	0.66	2.27	(2.60)	0.98	0.73	2.14	(2.62)	0.85	0.90	2.13	(1.97)	0.86	0.78	0.92
120°																									
Scapular upward rotation	−36.44	(6.79)	0.78	3.12	−35.36	(5.50)	0.39	4.77	−36.48	(6.73)	0.86	2.65	−39.99	(7.27)	0.81	3.18	−38.66	(6.79)	0.58	4.63	−40.48	(7.65)	0.72	3.74	0.52
Scapular tilt posterior	−3.78	(10.21)	0.93	2.54	−3.33	(10.26)	0.74	5.16	−5.71	(8.92)	0.91	2.60	−1.88	(8.54)	0.86	3.13	−2.00	(8.78)	0.75	4.69	−1.53	(8.17)	0.85	3.54	0.95
Scapular external rotation	41.74	(11.97)	0.91	3.24	42.48	(10.15)	0.70	5.96	40.75	(9.92)	0.91	3.46	42.09	(13.35)	0.80	5.01	40.08	(10.11)	0.93	3.36	41.65	(8.78)	0.90	3.49	0.61
Arm flexion	13.72	(6.24)	0.85	2.73	16.68	(6.35)	0.46	4.70	15.43	(7.86)	0.84	3.35	16.37	(7.55)	0.86	3.30	15.59	(9.54)	0.67	4.01	18.82	(9.80)	0.84	3.09	0.53
Arm abduction	−120.39	(0.18)	0.89	0.06	−120.31	(0.24)	0.78	0.10	−120.37	(0.23)	0.64	0.12	−120.31	(0.19)	0.48	0.15	−120.31	(0.15)	0.81	0.09	−120.10	(0.15)	0.86	0.08	0.99
Arm internal rotation	−69.04	(9.28)	0.78	4.93	−72.02	(7.81)	0.42	6.55	−71.19	(11.59)	0.79	4.95	−67.69	(8.68)	0.86	3.43	−70.67	(12.60)	0.80	4.02	−68.74	(9.75)	0.86	3.28	0.0001
Trunk posterior inclination	1.54	(4.45)	0.94	1.00	1.53	(4.09)	0.88	1.47	1.28	(3.82)	0.96	0.76	0.71	(3.73)	0.90	1.13	0.58	(3.95)	0.87	1.49	1.20	(3.50)	0.93	1.00	0.65
Trunk internal rotation	−3.09	(3.20)	0.96	0.65	−3.58	(3.52)	0.71	1.80	−3.60	(3.33)	0.84	1.49	−4.16	(4.32)	0.75	1.93	−3.89	(3.20)	0.90	1.17	−2.78	(3.07)	0.86	1.33	0.04
Trunk lateral inclination	4.21	(2.59)	0.94	0.64	3.64	(2.09)	0.75	1.16	4.21	(2.54)	0.93	0.80	3.60	(3.17)	0.85	1.11	3.30	(3.10)	0.84	1.14	3.30	(2.46)	0.88	0.89	0.71

P-value: The analysis of variance measured repeated measurements (ANOVA) for two factors: day (day 1 and day 2) vs examiner (experienced and inexperienced) and utilized Bonferroni's corrections to verify if there is a difference between the measures carried out by the evaluators.

the description of movement in studies in which reliability or information about secondary movements is clinically relevant.

Our results suggest that an examiner previously untrained in motion analysis marker placement can demonstrate the same reliability as an experienced examiner when marker position accuracy is the variable of interest. To our knowledge, this is the first study to compare the influence of the evaluator's experience relative to trunk, scapula, and arm kinematic measurement reliability.

The results presented here should be interpreted within the context of possible study limitations. The first refers to the absence of a lowering phase assessment. Second, the evaluators were not responsible for all aspects of the motion capture system, such as the system setup, calibration, and data processing. These other aspects, in addition to marker placement, can introduce a data collection error (Chiari et al., 2005); thus, evaluator experience is then only a part of the process. Therefore, we limited ourselves to studying part of this process by analysing the placement precision of the anatomical markers applied in a biomechanical model. We consider this element one of the largest contributors to error in the motion capture field.

5. Conclusion

The results of this study suggest that examiner inexperience does not produce different measurement results of the trunk, scapula, or arm kinematics during flexion and abduction movements of the arm in healthy individuals.

Conflict of interest statement

The authors assert that there are no conflicts of interest of any type. This assertion is also included in the manuscript.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jbiomech.2018.12.035.

References

Adhia, D.B., Bussey, M.D., Ribeiro, D.C., Tumilty, S., Milosavljevic, S., 2013. Validity and reliability of palpation-digitization for non-invasive kinematic measurement - a systematic review. Man. Ther. 18 (1), 26–34.

Alexander, N., Wegener, R., Zdravkovic, V., North, D., Gawliczek, T., Jost, B., 2018. Reliability of scapular kinematics estimated with three-dimensional motion analysis during shoulder elevation and flexion. Gait Posture. 66, 267–272.

Artilheiro, M.C., Corrêa, J.C., Cimolin, V., Lima, M.O., Galli, M., de Godoy, W., Lucareli, P.R., 2014. Three-dimensional analysis of performance of an upper limb functional task among adults with dyskinetic cerebral palsy. 39 (3), 875–881.

Blache, Y., Dumas, R., Lundberg, A., Begon, M., 2017. Main component of soft tissue artifact of the upper-limbs with respect to different functional, daily life and sports movements. J Biomech. 6 (62), 39–46.

Bourne, D.A., Choo, A.M., Regan, W.D., MacIntyre, D.L., Oxland, T.R., 2011. The placement of skin surface markers for non-invasive measurement of scapular kinematics affects accuracy and reliability. Ann. Biomed. Eng. 39 (2), 777–785.

Brochard, S., Lempereur, M., Remy-Neris, O., 2011. Double calibration: an accurate, reliable and easy-to-use method for 3D scapular motion analysis. J. Biomech. 44 (4), 751–754.

Cappozzo, A., Catani, F., Della Croce, U., Leardini, A., 1995. Position and orientation in space of bones during movement: anatomical frame definition and determination. Clin. Biomech. 10 (4), 171–178.

Chiari, L., Della Croce, U., Leardini, A., Cappozzo, A., 2005. Human movement analysis using stereophotogrammetry. Part 2: instrumental errors. Gait Posture 21 (2), 197–211.

Cicchetti, D.V., Sparrow, S.A., 1981. Developing criteria for establishing interrater reliability of specific items: applications to assessment of adaptive behavior. Am. J. Ment. Defic. 86 (2), 127–137.

Cimolin, V., Galli, M., 2014. Summary measures for clinical gait analysis: a literature review. Gait Posture. 39 (4), 1005–1010.

Hayk, M.N., Alburquerque-Sendin, F., Camargo, P.R., 2014. Reliability and minimal detectable change of 3-dimensional scapular orientation in individuals with and without shoulder impingement. J. Orthop. Sports Phys. Ther. 44 (5), 341–349.

Janes, W.E., Brown, J.M., Essenberg, J.M., Engsberg, J.R., 2012. Development of a method for analyzing three-dimensional scapula kinematics. Hand 7 (4), 400–406.

Lempereur, M., Brochard, S., Leboeuf, F., Rémy-Néris, O., 2014. Validity and reliability of 3D marker based scapular motion analysis: a systematic review. J. Biomech. 47 (10), 2219–2230.

Lizzio, V.A., Meta, F., Fida, I.M., Makhni, E.C., 2017. Clinical evaluation and physical exam findings in patients with anterior shoulder instability. Curr. Rev. Musculoskelet. Med. 10 (4), 434–441.

Lopez-Pascual, J., Caceres, M.L., De Rosario, H., Page, A., 2016. The reliability of humerothoracic angles during arm elevation depends on the representation of rotations. J. Biomech. 49 (3), 502–506.

Lucareli, P.R., Contani, L.B., Lima, B., Rabelo, N.D., Ferreira, C.L., Lima, F.P., Correa, J.C., Politti, F., 2016. Repeatability of a 3D multi-segment foot model during anterior and lateral step down tests. Gait Posture 43, 9–16.

Michener, L.A., Walsworth, M.K., Doukas, W.C., Murphy, K.P., 2009. Reliability and diagnostic accuracy of 5 physical examination tests and combination of tests for subacromial impingement. Arch. Phys. Med. Rehabil. 90 (11), 1898–1903.

Roy, J.S., Moffet, H., Hebert, L.J., St-Vincent, G., McFadyen, B.J., 2007. The reliability of three-dimensional scapular attitudes in healthy people and people with shoulder impingement syndrome. BMC Musculoskelet. Disord. 8 (49), 1–10.

Schwartz, M.H., Trost, J.P., Wervey, R.A., 2004. Measurement and management of errors in quantitative gait data. Gait Posture 20 (2), 196–203.

Scibek, J.S., Carcia, C.R., 2013. Validation and repeatability of a shoulder biomechanics data collection methodology and instrumentation. J. Appl. Biomech. 29 (5), 609–615.

Warner, M.B., Chappell, P.H., Stokes, M.J., 2015. Measurement of dynamic scapular kinematics using an acromion marker cluster to minimize skin movement artifact. J. Vis. Exp. 96, e51717.

Weir, J.P., 2005. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. J. Strength. Cond. Res. 19 (1), 231–240.

Wu, G., Van der Helm, F.C., Veeger, H.E., Makhsous, M., Van Roy, P., Anglin, C., Nagels, J., Karduna, A.R., McQuade, K., Wang, X., Werner, F.W., Buchholz, B., 2005. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion–Part II: shoulder, elbow, wrist and hand. J. Biomech. 38 (5), 981–999.