Intrarater Agreement of Elbow Extension Range of Motion in the Upper Limb Neurodynamic Test 1 Using a Smartphone App

Joana Cruz, MSc, Nuno Morais, MSc

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INTRARATER AGREEMENT OF ELBOW EXTENSION RANGE OF MOTION IN THE UPPER LIMB NEURODYNAMIC TEST 1 USING A SMARTPHONE APP

Joana Cruz[1,2] MSc, Nuno Morais[2] MSc

[1]Lab 3R – Respiratory Research and Rehabilitation Laboratory, School of Health Sciences, University of Aveiro (ESSUA), Aveiro, Portugal

[2]Polytechnic Institute of Leiria, School of Health Sciences (ESSLei – IPL), Department of Health Technologies, Leiria, Portugal.

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Keywords: outcome measurement error; pain thresholds, peripheral nerves; range of motion

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Institutional Review Board: The study protocol was approved by the Ethics Committee of ICBAS-UP, Portugal (Project n. 064/2014).

Corresponding author:

Nuno Alexandre Valente Morais

Rua Engenheiro Duarte Pacheco, 19C, Fração AC

3850-040 Albergaria-a-Velha, Portugal

Telephone: (+351) 919 528 026

Email: rpgnunomorais@gmail.com

INTRARATER AGREEMENT OF ELBOW EXTENSION RANGE OF MOTION IN THE UPPER LIMB NEURODYNAMIC TEST 1 USING A SMARTPHONE APP

ABSTRACT

Objective: To estimate the intrarater agreement of the Compass application of a smartphone (iPhone 4) in the assessment of the elbow extension range of motion (EE–ROM) at pain onset and maximum tolerable point during the upper limb neurodynamic test 1 (ULNT1).

Design: Within-day intrarater agreement study.

Setting: Private and university clinical settings.

Participants: 41 volunteers (age = 31.34 ± 13.27 years, 21 males, height = 1.67 ± 0.07m, and body mass = 70.53 ± 12.37kg) recruited from the community, with no symptoms or musculoskeletal abnormalities in their upper body quadrant and no regional or systemic nerve dysfunction.

Interventions: Not applicable

Main Outcome Measures: 95% limits of agreement (95% LoA), standard error of the measurement (SEM) and minimal detectable change (MDC_{95}) of elbow extension range of motion (EE–ROM) at pain onset and maximum tolerable point during the ULNT1.

Results: SEM and MDC_{95} were relatively high on both sides when considering the onset of pain (SEM=6.6–6.8º; MDC_{95}=18.4–18.8º). Better results were found for the maximum tolerable point (SEM = 4.2–4.8º; MDC_{95} = 11.7–13.2º). The 95% LoA showed a similar trend.

Conclusion: Smartphone measurements showed relatively wide agreement parameters of elbow extension during the ULNT1. These results are, nevertheless, comparable to previous studies using goniometric assessment

when considering maximal pain tolerance. Further research is needed before the possible widespread use of the smartphone in neurodynamic assessment.

Key Words: outcome measurement error; pain thresholds, peripheral nerves, range of motion

List of abbreviations

CI confidence intervals

EE–ROM elbow extension range of motion

GRRAS guidelines for reporting reliability and agreement studies

LoA limits of agreement

MDC minimal detectable change

SEM standard error of the measurement

ULNT1 upper limb neurodynamic test

The neurodynamic tests of the upper limb are routinely used during physical examination to evaluate the involvement of neural tissues in pain mechanism and disability of the upper body quadrant[1, 2]. They consist of a sequence of movements of the upper body segments that exert mechanical forces to a portion of the nervous system, gradually causing motion and tension in those neural structures[3, 4]. A positive sign of neural involvement is present when the neurodynamic test reproduces, at least partially, the patient's pain and this response is altered by a differentiating maneuver[5, 6]. Side-to-side differences in range of motion and/or in sensory responses may also be indicative of the presence of a neural component in the pathogenesis of pain and disability[4, 5, 7]. One standard neurodynamic test for the upper limb is directed at the median nerve and/or brachial plexus, also known as the upper limb neurodynamic test 1 or simply ULNT1[3, 4] (Figure 1). In high mechanosensitive tissues, it is expected that a greater response (ie, hypersensitivity, hyperalgesia, or more resistance to

62 motion due to muscle spasm) occurs which stops the elbow extension range of
63 motion (EE–ROM) at an earlier phase during the test and/or determines its
64 end[8]. For this reason, the assessment of EE–ROM frequently complements the
65 diagnostic criteria mentioned above and is used to evaluate the effects of
66 interventions[6-9].
67
68 Several measurement instruments are available to assess the movements of
69 body segments in space. These include universal goniometers, inclinometers,
70 electrogoniometers, imaging techniques including medical imaging, and 6
71 degrees of freedom motion tracking devices (eg, Table 1). However, most of
72 these instruments are expensive, time-consuming, of limited portability and
73 some of them require more than one examiner to perform the measurement,
74 making it difficult to use them in different clinical contexts. Innovative solutions,
75 such as the use of smartphones, have been suggested to overcome these
76 limitations[10, 11]. At present, most smartphones have embedded motion sensors
77 (eg, triaxial accelerometers, electro-mechanical gyroscopes, magnetometers)
78 which, through software applications, allow real time detection and
79 quantification of linear and angular motion of the device in the three planes of
80 orientation. A number of studies have shown that smartphone measurements
81 provide, in general, valid and reliable results for the evaluation of curvatures
82 and movements of the spine and the orientation and range of motion of different
83 segments and joints of the upper and lower limbs[10, 12-18]. Furthermore, as they
84 are easy-to-use, portable and frequently used by clinicians for communication
85 purposes, smartphones have the potential to assist these professionals in

clinical decision-making and evaluation of interventions both inside and outside the clinics without involving significant costs. However, smartphone measurement properties have never been tested during neurodynamic assessment.

The purpose of this study was to therefore estimate the intrarater agreement properties of the Compass application of a smartphone (iPhone 4) in the assessment of the EE-ROM at pain onset and maximum tolerable point during the ULNT1.

METHODS

Study design

A within-day intrarater agreement study was conducted. The study was registered at ClinicalTrials.gov (NCT02159924) and is reported according to the general guidelines for reporting reliability and agreement studies (GRRAS) [19].

Ethical Approval Statement

The study protocol was approved by the Ethics Committee of ICBAS-UP, Portugal (Project n. 064/2014).

Participants

Adults without impairments/limitations were recruited to participate in the study. Recruitment was conducted using the dissemination channels of the

111 management services of an academic organization in the central region of
112 Portugal (Leiria). The aims, procedures and eligibility criteria of the study were
113 provided. Inclusion criteria included being ≥ 18 years old and able to move all
114 upper body quadrant joints in a normal ROM without any pain or movement
115 restriction. Participants were excluded if they presented: musculoskeletal
116 abnormalities in the upper body quadrant; any complaints in that region over the
117 past 3 months; health conditions that may disrupt nerve function (eg, diabetes);
118 leg length discrepancy of more than 1.5 cm [20]; or cognitive impairment. Given
119 the limited number of answers received through the dissemination channels
120 abovementioned (n = 15) after 2 months of recruitment, a number of
121 participants were brought into the study through snowball sampling in two
122 physical therapy private clinics in Oporto, Portugal.
123
124 All participants were informed about the aims and procedures of the study and
125 of their right to withdraw at any time during the study. A physical therapist with
126 17 years of clinical experience in musculoskeletal and neurodynamics
127 evaluation ensured that the participants met the eligibility criteria. The
128 assessments were undertaken at the places where the recruitment was held,
129 from June to August 2014. Written informed consent was obtained from each
130 participant before data collection and their rights protected.
131
132 Instrumentation
133 To assess EE-ROM, a smartphone with built-in sensors that measure the
134 position and orientation of the device in the space (iPhone 4, iOS 7.2, Apple

Inc., Cupertino, CA) was used. Measurements were undertaken with a native application of the iPhone 4 operating system, the Compass app, in compass vision mode. This hardware/software set has demonstrated good validity criteria and intrarater reliability results when measuring body movements in the 3 planes of orientation [21].

Procedures

Sociodemographic information (age, gender), height and body mass were first collected to characterize the sample. Measurements of the EE–ROM during the ULNT1 were then conducted using the smartphone. Participants were asked to remain in the supine position close to the border of a massage table, with the lower limbs straight, the body aligned and the upper limbs in neutral position. The head and neck were stabilized in maximum comfortable contralateral side-flexion using a 5kg sand bag (Figure 1). One examiner (an experienced physical therapist) performed the measurements twice on both sides. A resting period of 5–10 minutes was allowed between measurements. The smartphone was coupled to the participant's forearm using an armband with an extended Velcro strip to tightly adjust the smartphone (Figure 1). Before each test, the examiner assessed the quality of smartphone coupling (eg, avoiding armband slip during elbow extension) to ensure consistency of the measurements. All participants underwent a practice trial in the contralateral side prior to the first measurement which included performance of the ULNT1 movement sequence and a structural differentiating maneuver (returning contralateral cervical side-flexion to the midline). With this procedure, participants could become familiar

with the mechanosensations (eg, pain or paresthesia, stretch) that may occur during the ULNT1 and could identify the sensory responses they should report during the test – the onset of pain and the maximum tolerable point. 'Onset of pain' was described as 'the moment when the least experience of discomfort/pain was recognized' whereas 'maximum tolerable point' was defined as 'the greatest level of discomfort/pain which the subject was prepared to tolerate'[22]. Measurements were conducted by the same researcher, with 17 years of clinical experience in musculoskeletal and neurodynamics evaluation. The ULNT1 sequence was performed in the following order, reaching the recommended range of motion of each segment without leading to discomfort or compensatory movements in the adjacent segments[4]: (1) maximal contralateral cervical side-flexion; (2) arm at 90° of shoulder abduction preventing scapular elevation; (3) 90° of shoulder external rotation and 90º of elbow flexion (this position defined the 0º of testing range of motion); (4) maximal forearm supination; (5) maximal extension of the wrist and fingers; and (6) elbow extension. This sequence was selected in order to constrain the movement of the forearm within the same plane of orientation (horizontal plane, forearm and hand moving parallel to the ground) consistently throughout elbow extension. Small deviations of the forearm/smartphone coupling from this plane were expected because the flexion/extension axis of the elbow is a loose hinge joint, involving 3-dimensional motion[23, 24]. The examiner was able to monitor such deviations on the device with the Compass app. Participants were instructed to inform the examiner when pain onset and maximum tolerable point occurred during elbow extension, the latter indicating the end of the test. Then, the

examiner registered the angular positions related to these events in independent recording sheets, for each measurement. In practice, neither the examiner nor the participant had access to the values of EE-ROM, since they were subsequently calculated by the difference between the initial and final angular positions registered.

Data analysis

Descriptive statistics were used to characterize the sample and to provide the scores of each test. Intrarater agreement of the EE-ROM using the smartphone was assessed at the onset of pain and at the maximum tolerable point of the ULNT1. The following agreement parameters were used: the standard error of the measurement (SEM), the minimal detectable change at the 95% level of confidence (MDC_{95}, also known as the repeatability coefficient or the smallest real difference), and the 95% limits of agreement (95% LoA) and its precision estimates. SEM was calculated as follows (equation 1):

$$SEM = SD_{diff}/\sqrt{2} \quad (1)$$

in which SD_{diff} represents the standard deviation of the mean of the differences ($\bar{d}$) between the two measurements performed on each side[25]. The SEM was then used to determine the MDC_{95} (equation 2)[25, 26], representing the minimum amount of change in a participant's EE-ROM that can be considered as a "true change":

$$MDC_{95} = 1.96 * \sqrt{2} * SEM \quad (2)$$

The 95% LoA delimit the extremes within which the differences between the two measures will be located in 95% of the times, which are thus comparable to the MDC_{95}. The LoA were defined as follows (equation 3)[26]:

$$95\%LoA = \bar{d} \pm 1.96 * SD_{diff} \quad (3)$$

Precision of the estimated LoA were calculated accordingly[26], using the 95% confidence intervals (CI) of the bias (equation 4) and 95%CI for the limits of agreement (equation 5):

$$95\%CI(\bar{d}) = \bar{d} \pm t(n-1) * SE(\bar{d}) \quad (4)$$

where the standard error of the bias ($\bar{d}$) was defined as $SE(\bar{d}) = SD_{diff}/\sqrt{n}$

$$95\%CI(LoA) = LoA \pm t(n-1) * SE(95\%LoA) \quad (5)$$

where the standard error of the 95%LoA was defined as $SE(95\%LoA) = 1.71SE(\bar{d})$. These indicate how large the (dis)agreement between two measurements will be in 95% of the occasions.

Analyzes were carried out using GraphPad Prism 6.0 (GraphPad Software, Inc., La Jolla, CA).

RESULTS

Participants

All of the 41 volunteers met the eligibility criteria and thus were included in the study. Participants had a mean (±SD) age of 31.34±13.27 years (21 males, 51.2%), height of 1.67±0.07m and body mass of 70.53±12.37kg. The right side was the dominant side for most participants (n = 35; 85.4%).

Intrarater agreement

Table 1 shows the descriptive statistics and the estimates of the agreement parameters of the EE-ROM at the onset of pain and at the maximum tolerable point of the ULNT1, for the dominant and non-dominant limbs. The SEM and MDC_{95} were relatively high on both sides when considering the onset of pain (SEM = 6.6–6.8º; MDC_{95} = 18.4–18.8º). Better results were found when the maximum tolerable point of the test was identified (SEM = 4.2–4.8º; MDC_{95} = 11.7–13.2º). The 95% LoA showed a similar trend, with narrower agreement limits for the maximum tolerable point. The 95% LoA results are presented in Table 2 and Figure 2. No systematic bias was found in the measurements performed.

The precision of the inferior limit of agreement at the onset of pain was approximately ±5º, being (-11.9º, -22.1º) and (-15.9º, -26.3º) for the dominant and non-dominant limb, respectively. The same trend was found for the upper limit: (14.7º, 24.9º) on the dominant side and (11.2º, 21.6º) on the non-dominant side. The 95%CI of the bias between the two measurements were (-1.6º, 4.3º) and (-0.7º, 5.4º) for the dominant and non-dominant sides, respectively. For the maximal tolerable point, the precision of the LoA was narrower (±3º). For the inferior limit, the 95%CIs were (-8.9º, -16.1º) for the dominant side and (-8.9º, -15.3º) for the non-dominant side. For the upper limit, they were (10.4º, 17.6º) and (8.1º, 14.5º), for the dominant and non-dominant sides, respectively. The 95%CI for the bias were (-1.4, 2.9º) for the dominant side and (-2.3º, 1.5º) for the non-dominant side.

DISCUSSION

To the best of the authors' knowledge, this was the first study to investigate the intrarater agreement parameters of a smartphone application in the assessment of the EE-ROM during the ULNT1. Relatively wide agreement parameters were observed when determining the EE-ROM at the onset of pain, with narrower estimates found at the maximum tolerable point. Findings suggest that smartphone measurements may have potential for clinical purposes when considering EE-ROM and maximum pain tolerance as the assessment criterion.

In the present study, estimates of the measurement error (SEM) and the minimal amount of change necessary to assume a meaningful change in patient's performance (MDC_{95}) were relatively low at the maximum tolerable point. Previous studies assessing the EE-ROM during the ULNT1 at maximum pain tolerance, using an electrogoniometer[22, 27] or a camera-based 6 degrees of freedom motion tracking device[28], have shown even lower measurement error (SEM = 0.97º–2.59º) than the present study (Table 1). It is known that this type of equipment is paramount in providing accurate and reliable results under laboratory conditions (eg, instrumental constraint of movements of the body segments during the maneuver); however, such devices and conditions are not available or unpractical to use in most clinical settings; therefore, their usefulness in clinical practice is of questionable value. Despite that, results from the present study were comparable to the results obtained in a study performing

the same measurement with a universal goniometer[29] (SEM = 4.2º–4.8º vs. SEM = 3.91º–6.02º; MDC = 11.7º–13.2º vs. MDC = 10.93º–16.70º, respectively). These findings are encouraging, since they suggest that measurement of the EE-ROM at maximum pain tolerance during the ULNT1 can be performed in the clinical setting by either using a smartphone or a universal goniometer without a substantiated difference in the measurement error. Previous studies comparing measurements of joints ROM between smartphones and universal goniometers have found high correlations (r = 0.79–0.99[10, 16-18]) and good agreement results[15-17]. Considering the availability, portability and the reduced number of human resources needed to perform measurements (ie, it requires only one person to conduct both the test and the measurements), smartphones may have the potential to be widely used in the future for measuring the EE-ROM during the ULNT1 in the clinical context.

Regarding the onset of pain, the SEM and MDC_{95} were relatively high and the 95% LoA were wider in both sides, when compared to the maximum tolerable point. Coppieters et al[22] found a similar trend using electrogoniometer measurements in a sample of asymptomatic subjects, with the SEM of 'submaximal pain' being better than the 'onset of pain'. It is likely that these results are related to less accurate perception of a light pain, as subjects experience at "pain onset", comparatively to the more intense experience at "maximum tolerable point". Further research is needed to explore this issue. Furthermore, previous studies assessing the EE-ROM during the ULNT1 at the onset of pain using goniometers and electrogoniometers have shown a lower

measurement error than in the present study (Table 1)[22, 30, 31], with the SEM ranging from 3.0º[22] to 4.02º[30]. This finding suggests that care must be taken when using the smartphone to measure EE-ROM during the ULNT1 at pain onset. Future research is warranted to compare measurements conducted with smartphones and (electro)goniometers.

The Compass app used in the present study is the smartphone's native application primarily intended for recreational use; however, this study aimed to assess its potential applicability to measure EE-ROM during the ULNT1 based on the premise that any physical therapist using the smartphone could easily use this application to measure ROM. Nevertheless, it is not specific to measure joints ROM and thus it lacks specific features which are important for clinical practice, such as the automatic calculation of the joint ROM, the selection of the joint, side, position of the body segment, type of motion (ie, flexion, extension, abduction, etc.), or the memory of the joint ROM by date, time and patient. Currently, there are various paid applications designed to measure joints ROM on real-time (eg, *GetMyROM*[32], *Simple Goniometer*[18], *Clinometer*[10, 15, 21]). Their agreement properties have been tested while assessing the ROM of the shoulder[15, 32], knee[18] and cervical spine[21]. However, to the authors' knowledge, no study has examined the EE-ROM during the ULNT1, as performed in this study. Future research should investigate the measurement properties of goniometer-based apps in the assessment of the EE-ROM during the ULNT1.

Limitations

This study had some limitations that need to be acknowledged. First, the results cannot be generalized because the sample was composed of adults without impairments or limitations. Further research should also assess the measurement properties of smartphone measurements in populations with nerve-related pain and disability of the upper limb, since they may show a higher measurement error in EE-ROM during the ULNT1 than populations without impairments/limitations[22].

Second, in the present study, the measurements were conducted in the same day; however, a previous investigation using an electrogoniometer to measure the EE-ROM has shown that between-day agreement is frequently lower than the within-day agreement[22]. This should be explored in future studies using the smartphone. Third, the present study assessed the intrarater agreement of the smartphone to measure EE-ROM during the ULNT1 without instrumental constraint or measurement of the movements of the upper body quadrant segments, as currently performed in the clinical setting. Before the possible widespread use of this technology in the clinical environment, though, further research needs to be conducted to more definitively discern its value, specifically: (a) to compare the EE-ROM measurements from the smartphone and a clinical (eg, goniometer) and laboratorial (eg, 6 degrees of freedom motion tracking devices) '*gold standard'* under the same and other testing conditions (eg, different sequences, adding/removing structural differentiating maneuvers) to assess the concurrent validity of smartphone measurements; (b) to assess interrater agreement; (c) to explore the feasibility of using smartphone applications to measure the EE-ROM during the ULNT1 in different clinical

settings; (d) to establish the minimal clinically important difference of the EE-ROM during the ULNT1 to better interpret the range of measurement error that can be accepted for clinical purposes. Finally, the application used in the present study is native to a specific smartphone and operating system manufacturer and thus its use is restricted to this environment. However, the applicability of smartphone measurements is likely extendable to other smartphones having motion sensors and different operative systems.

CONCLUSIONS

The wide availability and portability of smartphones make them an interesting alternative to the universal goniometers commonly used in clinical practice. The results of this study, together with previous studies, has shown that smartphones (particularly those using an iOS system) may have comparable agreement parameters to goniometry to assess the EE-ROM during the ULNT1 when considering maximal pain tolerance. Nevertheless, much work still needs to be conducted before the possible widespread use of the smartphone to measure the EE-ROM during the ULNT1.

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Figure Legends

FIGURE 1. Measurement of the elbow extension range of motion during the upper limb neurodynamic test 1 using the smartphone: initial position (left image), onset of pain (center), and maximal tolerable (right image). The initial position defined the 0º of testing range of motion.

FIGURE 2. The 95% limits of agreement of the elbow extension range of motion at the onset of pain and at the maximum tolerable point of the upper limb neurodynamic test 1, for the dominant and non-dominant sides. Points represent each of the participants.

TABLE 1. Studies analyzing the intrarater agreement of the elbow extension range of motion in asymptomatic subjects during the upper limb neurodynamic test 1 (ULNT1).

Authors	Participants	Instrumentation	Intrarater agreement
Coppieters et al[33]	n = 10, 5 males, 23.4 ± 2.2 years old, all right handed	Electrogoniometer	Pain onset SEM: D = 3.0º ± 95% CI 6.0º Pain tolerance SEM: D = 2.3º ± 4.5º
Lohkamp and Small[29]	n = 20, 10 males, 27.9 ± 6.2 years old, dominance not specified	Goniometer	Pain tolerance SEM: D = 3.91º, ND = 6.02º MDC: D = 10.93º, ND = 16.70º
Oliver and Rushton[27]	n = 40, 11 males, 23.4 (18–42) years old, dominance not specified	Electrogoniometer	Pain tolerance* SEM: R = 0.97º– 2.59º MDC: R = 2.68º – 7.16º

Talebi et al[27]	n = 23, 22.3 ± 2.3 years old, sex and dominance not specified	Goniometer	Symptoms or stretching onset* SEM = 3.1º
Van Hoof et al[28]	n = 36, 13 males, 21.4 ± 0.3 years old, 31 right handed	Camera-based motion tracking device	Pain tolerance/ Maximal end resistance SEM: R = 2.26º, L = 1.97º MDC: R = 6.28º, L = 5.46º
Stalioraitis et al[30]	n = 51, 26 males, 26.7 ± 5.9 years old, all right handed	Electrogoniometer	Symptoms onset SEM: R = 3.31º, L = 4.02º MDC: R = 9.17º, L = 11.14º
Current study	n = 41, 21 males, 31.3 ± 13.3 years old, 35 right handed	Smartphone	Pain onset SEM: D = 6.6º, ND = 6.8º MDC: D = 18.4º, ND =18.8º Maximum pain tolerance SEM: D = 4.8º, ND = 4.2º MDC: D = 13.2º, ND = 11.7º

Abbreviations: D, dominant; L, left; MDC, minimal detectable change; ND, non-dominant; R, right; SEM, standard error of measurement. Notes: In studies using variations of the ULNT1, findings are only displayed for the sequence of

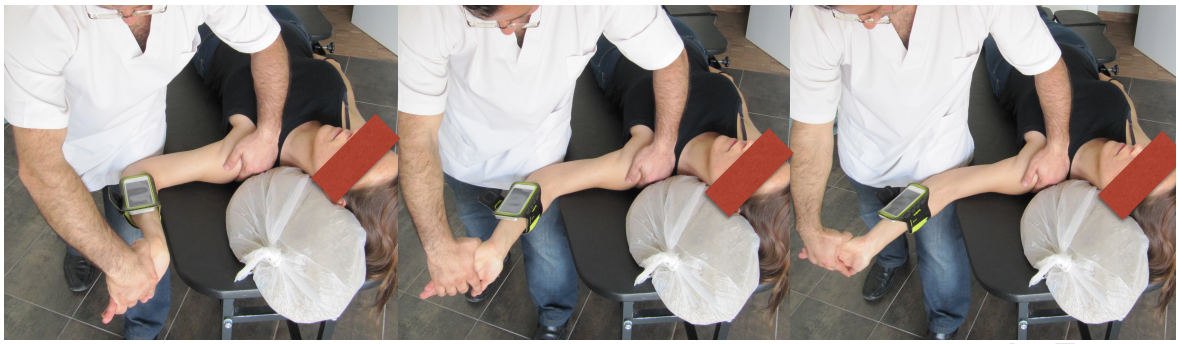
the test that was similar to that of the present study, unless otherwise indicated.

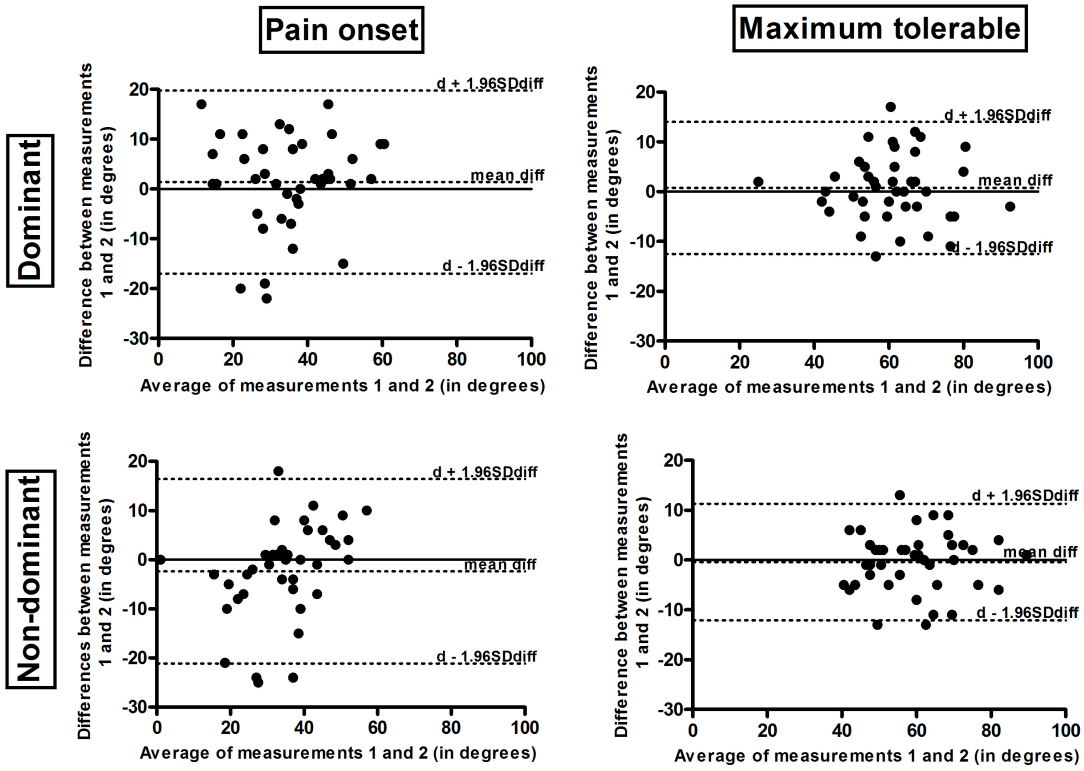
*The test was conducted with the cervical in neutral position.

TABLE 2. Descriptive statistics and agreement parameters of the elbow extension range of motion at the onset of pain and at the maximum tolerable point of the upper limb neurodynamic test 1. Values are displayed for the dominant (D) and non-dominant (ND) sides and presented in degrees (º).

	Side	**mean ± SD of measurement 1 (º)**	**mean ± SD of measurement 2 (º)**	**$\bar{d} \pm SD_{diff}$ of measurements 1 and 2 (º)**	**SEM (º)**	**MDC_{95} (º)**	**95% LoA (º)**
Onset of pain	D	36.0 ± 13.7	34.6 ± 13.1	1.4 ± 9.4	6.6	18.4	-17.0 – 19.8
	ND	33.3 ± 13.8	35.7 ± 10.4	-2.3 ± 9.6	6.8	18.8	-21.1 – 16.4
Maximum tolerable	D	61.3 ± 12.6	60.5 ± 12.8	0.8 ± 6.8	4.8	13.2	-12.5 – 14.0
	ND	59.2 ± 12.5	59.6 ± 12.3	-0.4 ± 6.0	4.2	11.7	-12.1 – 11.3

Abbreviations: 95% LoA, 95% limits of agreement; $\bar{d}$, mean of the differences; D, dominant side; MDC_{95}, minimal detectable change at the 95% level of confidence; ND, non-dominant side; SD, standard deviation; SD_{diff}, standard deviation of the differences; SEM, standard error of measurement.





Highlights:

- The smartphone app showed a relatively wide agreement of EE-ROM during the ULNT1;
- A better agreement was found at maximal pain tolerance than at the onset of pain;
- Results regarding maximal pain tolerance are comparable to those using goniometers.