

Protocol for Forearm Pronosupination Strength Measuring in Different Postures: Reliability and Influence of Relevant Factors

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Abstract

Importance: Pronosupination strength can be affected by different pathologies, limiting the performance of many daily activities. A functional evaluation of those pathologies should include pronation and supination strength assessment with a reliable and valid device and protocol. Although there are assessment methodologies, there is disparity both in the protocols proposed and in the results regarding the influence of gender, age, upper limb dominance, and forearm posture on strength.

Objective: To design a device and standardized protocol to measure pronation and supination torques in different positions of the forearm, focusing on its reliability and the influence of gender, age, and upper limb dominance on the forces.

Method: Pronation strength and supination strength in 39 healthy subjects were studied in five forearm positions: 30° and 60° of supination, neutral rotation, and 30° and 60° of pronation. The influence of gender, age, and upper limb dominance was studied using repeated-measurements analysis of variance. Intrarater and interrater reliabilities were studied in 17 of those subjects, with the intraclass correlation coefficients (ICCs) from three measurement sessions.

Results: Except for pronation exerted at 60° of pronation, all ICCs ranged from 0.72 to 0.97. Sex, limb dominance, and posture significantly affected pronosupination strength ($p < .05$), with the highest supination strength found at 60° of pronation and the highest pronation strength at 60° of supination.

Conclusions: A reliable pronosupination torque assessment device and standardized protocol were developed. In considering their use in the clinical setting, the influence of gender, limb dominance, and forearm posture must also be considered.

What This Article Adds: In this study, the reliability of a device for measuring the strength of pronation and supination of the forearm has been verified through a standardized protocol suitable for its use in a clinical environment, both for the total time of measurement and for its simplicity. Several positions of the forearm are included within a functional range to allow the evaluation of how the structures behave in each case and thus

identify limitations in specific activities, better focus therapy, and identify patterns related to different pathologies. In addition, the effects of relevant factors such as gender, limb dominance, and forearm posture itself have been studied to allow a subsequent correct evaluation of the results that were found by using this protocol.

Pronosupination, or rotation of the forearm around its longitudinal axis, provides an extra degree of freedom to the wrist that, in turn, allows the hand to be oriented at any angle. Although the maximum arc of pronosupination oscillates approximately between 71° of pronation and 81° of supination, most activities are conducted within a functional range of about 100°, between 50° of pronation and 50° of supination (Kapandji, 2001).

In addition to motion, the exertion of rotational strength in various positions or angles of rotation of the forearm is required in common activities such as using a screwdriver, turning a knob, or activating a lever. Many ligamentous (Hwang et al., 2018), osteological (Melamed et al., 2015), or musculotendinous (Citak et al., 2011; Inagaki, 2013) pathologies may affect pronosupination strength, thus interfering in the execution of those activities. A deep knowledge not only of the kinematics but also of the stability and forces acting at the elbow will be paramount for a proper monitoring, design, and treatment selection (Inagaki, 2013; Lees, 2009).

A complete evaluation of the elbow should ideally include the measurement of pronosupination strengths with reliable and valid devices and protocols, including forces exerted in different functional postures of the forearm. This would involve diverse configurations of the radius, ulna, and carpal structures and, therefore, changes in the lever arm, the stability of structures, and the transmission of forces, which seems to be maximal at 60° of supination (60SUP) of the forearm (Lees, 2009). Moreover, a comprehensive assessment of the different functional positions of the forearm is more representative of the diverse functional requirements of everyday activities. Also, the degree of elbow flexion influences the range of forearm pronation and supination: The greatest pronation is achieved when the elbow is fully extended, whereas the greatest supination is achieved with full flexion (Lees, 2009). The degree of elbow flexion also influences strength; therefore, 90° of flexion, the position where the biceps brachii has the maximal impact on supination, is the most advantageous position for this strength (Güleçyüz et al., 2017). Hence, it seems appropriate to consider an intermediate level of elbow flexion (90°) as the ideal posture to assess the pronosupination range of motion and isometric strength (Kapandji, A., 2007). However, authors often measure pronosupination strength at 90°, and also at 45°, of elbow flexion (Kotte et al., 2018).

Few studies have assessed both pronation and supination strengths *in vivo* by considering different rotation postures of the forearm (Ellenbecker et al., 2006; Gordon et al., 2004; Matsuoka et al., 2006; Ploegmakers et al., 2015). Of those, very few do it in 90° of elbow flexion (Gordon et al., 2004), and no one has analyzed the influence of relevant factors on strength, including gender, age, and upper limb dominance (Kotte et al., 2018), as well as the correlation between those factors in the same study.

In this study, we propose a new protocol for measuring pronosupination strength, with the elbow flexed at 90°, in five different functional postures of the forearm (within a range of 120° of forearm rotation). Additionally, we studied the influence of gender, upper limb dominance, age, and forearm posture on pronosupination strength. Our ultimate goal was to validate a

Method

We used a static, square-headed, torque load–weighing sensor with a sensitivity of >0.01 Nm and a range of ± 10 Nm to measure the rotational torque strength. A least squares regression was performed to ensure the adjustment of the sensor (Kullaa, 2010).

An external framework was designed that includes a cylindric grip handle. This handle, with a length in the vertical direction of 192 mm and a diameter of 29 mm, has been specifically designed to allow a firm and comfortable grip, regardless of the size of the evaluated hand, including a nonslip material to facilitate the generation of force. This adds 2 mm to the original diameter of the handle, which makes it similar to some commercial hand dynamometers aimed at measuring grip strength (Hogrel, 2015; Lorenzo-Agudo et al., 2007).

Handle orientation could be adjusted to 60SUP, 30° of supination (30SUP), 0° of pronosupination (NEU), 30° of pronation (30PRO), and 60° of pronation (60PRO) of the forearm. This allowed us to measure the torque (in Newton meters) in each posture during isometric pronation and supination. In line with authors such as Ploegmakers et al. (2015), we chose these rotation angles as representative of the force exerted within a functional range, avoiding an excess of positions so as not to lengthen the test, as well as measurement in extreme positions that would prevent many subjects with upper limb pathologies from performing it.

A convenience sample of 39 healthy men and women between 18 and 65 yr old participated in the study. The main exclusion criterion was the presence of any discomfort or pathology in the upper limbs that could affect the measurements.

Measurements were performed with the subjects in a sitting posture, elbow flexed at 90°, and relaxed shoulder. A foam pad was placed between the medial surface of the arm (just above the medial epicondyle) and the trunk. To prevent compensatory shoulder movements, we asked the patient to keep the foam from falling, which, in turn, prevented substitution from the shoulder. Both the dominant and nondominant upper limbs were assessed, always starting with the dominant side. The subjects were requested to exert as much force as they could in each posture, during 2 to 3 s, in the following order: isometric pronation at 60SUP, 30SUP, NEU, 30PRO, and 60PRO; and isometric supination at 60PRO, 30PRO, NEU, 30SUP, and 60SUP.

The evaluators made sure that the subjects understood the instructions correctly, allowing them to practice before the measurements without exerting the maximum force.

The interrater and intrarater reliabilities of the system and the protocol were evaluated with a subsample of 17 subjects chosen by means of convenience sampling. Two physiotherapists who were trained in the procedure participated as Evaluators A and B. During the first session, which was conducted in a single day, each evaluator performed the whole measurement, with a 5-min resting period between measurements to avoid muscle fatigue. To reduce a potential bias in the interrater reliability study, during the first session, Evaluator A or B was chosen randomly for each subject. In an attempt to avoid the “learning effect” (Bellace et al., 2000; Innes, 1999) to influence our test–retest study, we established a minimum interval of 24 hr before Evaluator A

reassessed each subject. All measurements were performed in accordance with the previously described protocol, but in the second (interrater) and third (intrarater) measurements, only the dominant limb was assessed. In the specific case of the reliability study, we chose to perform measurements only of the dominant hand to simplify repeated measurements and avoid intrasubject variability.

We recorded the participants' gender, age, and upper limb dominance as independent variables. Participants were classified into four age groups: A0 (18–29 yr old), A1 (30–39 yr old), A2 (40–49 yr old), and A3 (50–65 yr old).

Strengths were characterized as the maximum supination and pronation torques (in Newton meters) for each forearm posture and side (dominant and nondominant), so that the following 10 values per limb were recorded (20 per participant): Pro_60SUP, Pro_30SUP, Pro_NEU, Pro_30PRO, Pro_60PRO, Sup_60PRO, Sup_30PRO, Sup_NEU, Sup_30SUP, and Sup_60SUP; the first three characters (Pro and Sup) represent the type of isometric strength recorded (pronation and supination, respectively), and the remaining characters correspond to the orientation of the forearm as previously described.

For the strengths for each direction, posture, and side, values were expressed as means and standard deviations. We used the intraclass correlation coefficient (ICC) (2,1) to measure the interrater and intrarater reliabilities of strengths for the dominant side (Gisev et al., 2013; Shrout & Fleiss, 1979). The standard error of measurement (*SEM*), values, calculated as a further measure of reliability, were expressed as percentages of the mean score, which were considered acceptable when less than 20% (Barbado et al., 2020).

The influence of the participants' characteristics and of forearm posture on measured strengths was analyzed by a repeated-measurements analysis of variance (ANOVA), using a mixed linear model with gender, age, upper limb dominance, and posture of the forearm as fixed factors and the participant as the random effect. The relevant interactions between fixed factors were selected using a stepwise algorithm (Venables & Ripley, 2002) and analyzed using a simple effects test (Schabenberger et al., 2000).

Statistically significant differences were defined considering a Type I error of $\alpha = .05$ ($p < .05$). All the analysis was conducted with the RStudio package 2021.09.1.372 for statistical computing (R Foundation for Statistical Computing, 2014).

The study was approved by the Universitat Politècnica de València Ethics Committee in Human Research. All participants agreed to participate after being informed of the purposes and methodology of the research, and signed an informed consent.

Results

A total sample of 39 participants participated in the study, and a subsample of 17 participants also took part in the reliability study. In both cases, the samples were evenly distributed by gender and age. All participants were right-handed except for one, who did not take part in the reliability study.

Test–Retest and Interrater Reliabilities

The ICCs and *SEMs* that were obtained for test–retest and interrater reliabilities are presented in Table [ID]TBL1[/ID]1. In all cases except pronation strength at 60PRO (Pro_60PRO), ICCs were more than 0.70, and *SEMs* were less than 20%.

Influence of Participant's Characteristics on Strength

The stepwise selection algorithm left the four main factors (gender, age, limb dominance, and forearm posture) and the interaction between dominance and age as influential factors of the statistical model. The ANOVA showed a significant effect of gender, dominance and posture of the forearm on strength (see Table [ID]TBL2[/ID]2).

Although age itself did not have a significant effect on strength, we found a significant interaction between this factor and limb dominance, specifically for Group A1, as seen in the post hoc analysis (see Table [ID]TBL3[/ID]3 for specific strength values).

The greatest supination force was achieved at 60PRO, and the greatest pronation force was achieved at 60SUP (see Figure [ID]FIG1[/ID]1). In the post hoc test, it was found that those two forces were greater than those made in the rest of the postures for supination and pronation, respectively ($p = .000$).

Discussion

Although the gold standard for the measurement of strength is isokinetic dynamometry (Ellenbecker et al., 2006; Pienimäki et al., 2002), those systems are generally complex and overall unfit for routine clinical practice (Wong & Moskovitz, 2010). Alternatively, there are simpler devices, such as the Baseline dynamometer (Fabrication Enterprises, White Plains, NY), which allows the recording of isometric strength at one or various rotation postures (Axelsson et al., 2020; Kerschbaum et al., 2017; Ploegmakers et al., 2015). Even if the results of validity and reliability of the latter are good, studies with them are scarce (Axelsson & Kärrholm, 2018; Wong & Moskovitz, 2010), and there is no consensus regarding which specific protocol and posture of the upper limb are optimal for measuring with such system.

Some researchers have developed noncommercial devices for measuring pronosupination isometric strength, with different protocols and dissimilar findings (Gordon et al., 2004; Güleçyüz et al., 2017; Matsuoka et al., 2006). In line with those, we have developed a measuring device, but we have also defined a standardized protocol that we believe to be useful for research purposes and within clinical contexts such as hand and wrist specialty settings, where it is paramount to evaluate isometric pronation and supination strength. To do so, as proven by our results, clinicians must consider different functional rotation angles of the forearm where forces may vary and place the elbow at 90° flexion, which is considered the most appropriate posture (Kapandji, 2007).

We have studied the influence of different factors on strength and verified the reliability of both the device and the protocol in the same study. To do so, we studied a convenience sample of 39 healthy people (17 in the reliability study) that was comparable with or greater than those of previous studies such as Ellenbecker et al. (2006), Wong and Moskovitz (2010), and Gordon et al. (2004), which had 32, 18, and 14 participants, respectively.

The results of our study confirm that the relative reliability of the device and protocol is either good or excellent; most of the ICCs ranged from 0.72 to 0.97 (Koo & Li, 2016). Overall, test–retest intrarater reliability seems to be higher than interrater reliability, with most of the ICCs higher than 0.9 (excellent agreement). This seems logical, because in interrater reliability, factors related to the experience and capabilities of each evaluator come into play (Tuijn et al., 2012). The ICCs found were either equivalent to or higher than the correlation coefficients found by Kramer et al. (1994) for forearm rotation torques measured with the BTE (WS20) and the Cybex (340) dynamometers (ICCs ≥ 0.75).

Our results are also similar to those found by authors such as Axelsson and Kärrholm (2018) or Wong and Moskovitz (2010), with ICCs ranging from 0.88 to 0.96 for pronation and supination torques and between 0.85 and 0.97 for interrater reliability and intrarater reliability, respectively. These ICCs seem to be a bit higher than ours, but we need to consider a few relevant methodological differences that may justify this. First, both of the aforementioned studies considered only strength for neutral rotation of the forearm, whereas, in this study, we analyzed reliability at six different postures. The ICCs that we obtained for neutral posture were also higher than 0.8 in our study. Second, previous authors analyzed the reliability of the devices being studied, but we also studied the reliability of the measurement protocol. Given that we tried to keep this protocol as short as possible to maximize its clinical usability, we only obtained one value for each position, whereas the previous authors used either the peak or the mean value out of three trials. Third, there were also other differences in the protocol, such as the elbow flexion (45°) or the handle shape (doorknob; Wong & Moskovitz, 2010), which could have somehow influenced results.

We have obtained *SEM* values less than 20%, which confirms that the test provides reliable parameters (Barbado et al., 2020). Only Pro_60PRO obtained a lower intrarater ICC (0.57) and an *SEM* more than 20%, coinciding with the lowest strength found and the posture that the participants referred to as the most difficult one. This posture produces discomfort (Mukhopadhyay et al., 2007), which might relate to the increased variability, and it is disadvantageous from an anatomical point of view, with little to no lever arm when it comes to exerting pronation force (Kapandji, 2001).

Regarding normative strength values and the effects of different intrinsic factors on those values, there are discrepancies in the available studies. There is no consensus on the protocols to determine those values, which should be interpreted with caution (Kotte et al., 2018). What does seem clear, however, is that gender significantly affects pronosupination strength (Kerschbaum et al., 2017), which is higher in men, and this has also been confirmed in our study.

Concerning limb dominance, although some authors have found a clear effect (Gallagher et al., 1997), others have found it only for pronation or supination (Ellenbecker et al., 2006; Ploegmakers et al., 2015) or only in part of the population studied (Güleçyüz et al., 2017; Kerschbaum et al., 2017). In our study, we have found a statistically significant difference for dominance.

There are few reported data in the literature regarding the effect of age. In our study, we found no effect of age on strength. However, a statistically significant interaction between limb dominance and age has been found, occurring mainly in Group A1 (30–39) yr and decreasing at older ages. This could be related to higher peak forces reached by people younger than 39 yr old,

which led to a bigger difference between the dominant and nondominant sides (Güleçyüz et al., 2017).

We also found that the forearm posture significantly affected the results and that both pronation and supination strengths were greater when exerted against the adopted posture. Regarding pronation, the greatest force was generated at 60SUP. This aligns with the findings of Matsuoka et al. (2006), Gordon et al. (2004), and O'Sullivan and Gallwey (2002), who also found greater pronation forces around midsupination of the forearm. Unlike the latter authors, we did not find that pronation forces were clearly greater than those generated at 60SUP in the opposite posture.

In contrast to our findings, Haugstvedt et al. (2001) found greater generation of forces by the pronator quadratus and pronator teres between the neutral posture and 30SUP of the forearm; we think that those differences are justified by the absence of grip in their study (eliminating the effect of wrist and finger tendons that cross the wrist) and by the fact that it was performed *in vitro*, ignoring the agonist-antagonistic actions of the movement *in vivo*. Supination strength was highest at 60PRO in our study, which coincides with Gordon et al.'s (2004) findings. Also, Haugstvedt et al. (2001) found that the biceps, the most powerful counterresistance supinator, generates up to four times more torque between 10° and 30° of forearm pronation, compared with other postures. We think that, in our study, the greatest forces were found at 60° and not at 30° or in a neutral posture, such as in previous studies (e.g., O'Sullivan & Gallwey, 2002), because of the added action of the wrist and finger tendons crossing the wrist that involves a cylindrical grip like ours (Gordon et al., 2004). These muscles, mainly the extensor and flexor carpi radialis, have relevant involvement in postures of maximum rotation of the forearm (Haugstvedt et al., 2001).

Last, we present here some methodological considerations regarding our study. First, some authors (Gordon et al., 2004) have considered that, in an evaluation solely of the action of the pronating and supinating musculature of the forearm, the added movement of the wrist should be blocked by using a wrist clamp, ruling out any added grip force. Our intention was to replicate a real-life functional movement, in which the hand also participates by grasping the object. Therefore, we used a cylindrical grip, which means the involvement of wrist and finger musculature and tendons with a complementary action on pronosupination.

Second, our goal was to replicate the designed protocol in the clinical setting; therefore, we tried to avoid making it unnecessarily lengthy. With the aim of checking the reliability of the protocol, and not just that of the device, a single repetition was made for each force and posture, following the same standardized order of postures. This could have negatively affected the results of our reliability study.

Third, only one person in our sample was left-handed. Therefore, we cannot ensure that the effect of limb dominance that we found would be equivalent in these participants.

Finally, the sample of participants who participated in the reliability study was chosen through convenience sampling, because of their accessibility and the availability of the measurement equipment and the evaluators. Although it was not big, the sample was similar to that of other studies (e.g., Wong & Moskovitz, 2010), and we consider it sufficient to infer a high reliability of the methodology developed.

Implications for Occupational Therapy Practice

The influence of relevant factors (gender, limb dominance, age, and forearm posture) and the reliability of the protocol and device designed have been studied. The findings of this study have the following implications for occupational therapy practice:

- The device and protocol can be used in a clinical setting for the evaluation of pronation and supination strength in different postures, helping to enhance the treatment and strength training in these postures and to identify patterns of deficit.
- The results obtained should be evaluated with consideration of the effects of the factors studied, thus improving the interpretation.
- The identification of the opposite postures (60PRO or 60SUP) as more advantageous for the exertion of force leads to the adaptation of certain daily activities, facilitating the action of the musculature by modifying the axis of rotation of the forearm. These findings also indicate that clinicians should measure pronation and supination using the most biomechanically appropriate postures.
- Whereas classical functional assessment methodologies such as scales are used to measure different aspects of upper limb functioning, this methodology provides accuracy and specificity, which is especially key in research settings.

Conclusion

The device, developed through the proposed protocol, allows the reliable measurement of pronation and supination strength of the forearm in different functional rotation angles. This strongly supports its use within a research or clinical context.

We found significant differences in the forces generated according to gender and limb dominance. These differences should be considered when establishing comparisons between participants or between the dominant and nondominant sides.

The posture of the forearm influences the ability to generate force, being greater in the opposite postures: supination force in 60PRO and pronation force in 60SUP. This should be considered by clinicians when measuring these forces in patients with any kind of hand or forearm injury.

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Figure 1. Distributions of pronation (Pro) and supination (Sup) strengths at each posture of the forearm ($n = 39$).

Note. On the x axis, Pro and Sup represent the type of isometric strength recorded: pronation and supination, respectively. The remaining characters correspond to the orientation of the forearm. 30PRO = 30° of pronation; 60PRO = 60° of pronation; 30SUP = 30° of supination; 60SUP = 60° of supination; NEU = 0° of pronosupination.

Table 1. Intrarater and Interrater Reliabilities (and SEM) for Strengths at Different Postures of the Dominant Limb

Strength and Posture ^a	ICC (2,1) Reliabilities (SEM)	
	Intrarater	Interrater
Pro_60SUP	.916 (10.30)	.803 (13.84)
Pro_30SUP	.942 (7.84)	.921 (8.00)
Pro_NEU	.809 (14.26)	.890 (9.64)
Pro_30PRO	.728 (17.81)	.788 (13.74)
Pro_60PRO	.573 (36.36)	.753 (25.40)
Sup_60SUP	.893 (8.50)	.795 (13.74)
Sup_30SUP	.918 (8.09)	.881 (9.22)
Sup_NEU	.911 (9.07)	.907 (9.39)
Sup_30PRO	.948 (7.01)	.906 (9.97)
Sup_60PRO	.973 (5.77)	.942 (8.30)

Note. SEMs are presented as percentages. 30PRO = 30° of pronation; 60PRO = 60° of pronation; 30SUP = 30° of supination; 60SUP = 60° of supination; ICC = intraclass correlation coefficient; NEU = 0° of pronosupination; Pro = pronation; SEM = standard error of the mean; Sup = supination.

^aIn this column, the first three characters (Pro and Sup) represent the type of isometric strength recorded: pronation and supination, respectively. The remaining characters correspond to the orientation of the forearm.

Table 2. Analysis of Variance (Type 2) Results

Variable	<i>F</i>	<i>dfs</i>	<i>p</i>
Posture	159.68	9, 728	.000
Gender	91.71	1, 34	.000
Dominance	7.09	1, 728	.008
Age	2.07	3, 34	.102
Dominance × Age	3.61	3, 728	.008

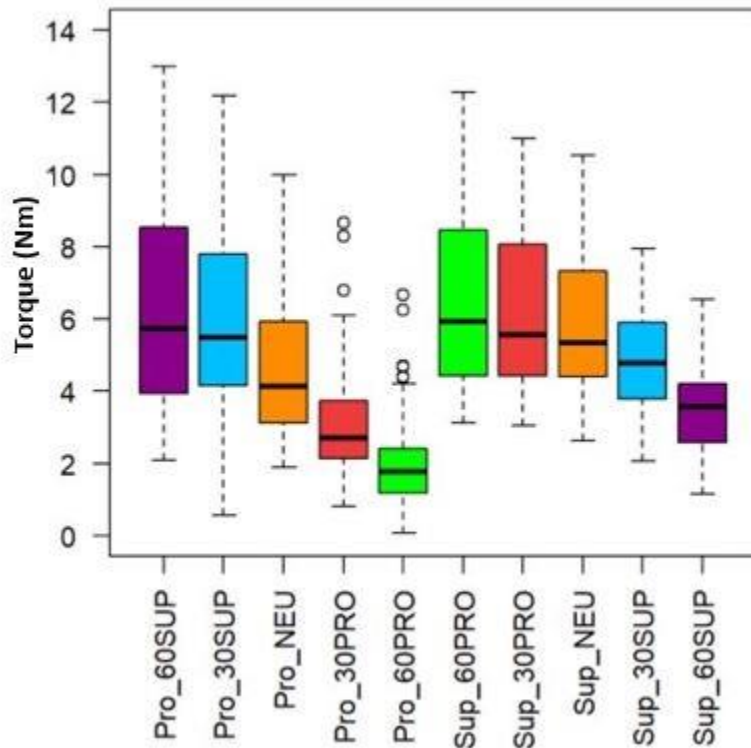
Note. *dfs* = degrees of freedom.

Table 3. Mean Values for Strength in Dominant and Nondominant Upper Limbs in Each Age Group

Age Group	Strength, <i>M</i> (<i>SD</i>)		<i>F</i>	<i>p</i>
	Nondominant Upper Limb	Dominant Upper Limb		
A0	3.97 (2.073)	4.22 (2.373)	1.88	.514
A1	4.52 (2.274)	5.15 (2.696)	15.90	.000
A2	5.29 (2.715)	5.26 (2.556)	0.04	1.000
A3	5.20 (2.554)	5.25 (2.603)	0.10	1.000

Note. Means and standard deviations are given in Newton meters. *F* values correspond to post hoc analysis of the interaction between upper limb dominance and age for each given group. four age groups: A0 (18–29 yr old), A1 (30–39 yr old), A2 (40–49 yr old), and A3 (50–65 yr old).

FIGURE 1



SUPPLEMENTAL MATERIAL

Figure A-1. Handle of the measuring device, with marks for 60° (60SUP and 60PRO), 30° (30SUP and 30PRO) and 0° (NEU) postures represented by numbers 1 to 5.



Table A-1. Characteristics of the subject samples. Age groups A0, A1, A2, and A3 as defined in the main text. The sizes of the subsample used in the reliability study is given in parentheses.

Age Sex	A0	A1	A2	A3	Total
Men	3 (2)	5 (4)	5 (2)	7 (2)	20 (10)
Women	4 (2)	5 (2)	6 (2)	4 (1)	19 (7)
Total	7 (4)	10 (6)	11 (4)	11 (3)	39 (17)