Asymmetry of the ULNT1 elbow extension range-of-motion in a healthy population: Consequences for clinical practice and research

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1. Introduction

The upper limb neurodynamic test of the median nerve (ULNT1) is a physical maneuver that is used clinically in the diagnosis and treatment of musculoskeletal disorders that appear to contain a neural component (Bialosky et al., 2009; Butler, 2000; Butler & Gifford, 1989; Elvey, 1979; Shacklock, 1995, 2005). The ULNT1 consists of stabilizing the scapula, positioning the upper limb joints in glenohumeral abduction-external rotation, followed by forearm supination, wrist and finger extension, and subsequent passive movement of the elbow joint toward the final elbow extension range-of-motion (EE-ROM) (Fig. 1A).

There are several key indicators of abnormal responses in the ULNT1, some of which are considered to be reproduction of the patient’s clinical symptoms, physical responses such as abnormal muscle contraction, or restriction in the EE-ROM (Coppieters, Stappaerts, Everaert, & Staes, 2001; Coppieters, Stappaerts, Wouters, & Janssens, 2003a; Hall, Zusman, & Elvey, 1998). When at least one of these responses is also influenced by a maneuver that affects the neural tissues mechanically by altering tension in the upper limb nerves (i.e. a differentiating maneuver such as cervical spine contralateral lateral flexion) (Fig. 1B), it is inferred that there may be a neurodynamic dysfunction in the patient (Butler, 1996; Butler & Gifford, 1989; Elvey, 1979; Hall et al., 1998). Clinically, the solitary objective measurement of the ULNT1, the EE-ROM, can only be correctly interpreted by comparison between the left and right sides, a procedure which assumes natural symmetry in the EE-ROM. In daily clinical practice, this premise seems generally accepted, despite the lack of any scientific evidence. If variables possibly affecting the EE-ROM are not taken into account, however,
erroneous conclusions could result in both clinical practice and research scenarios.

In clinical practice, a restricted EE-ROM can have a decisive diagnostic role in specific circumstances of ‘covert abnormal response’, a situation in which one or more aspects of the ULNT1 results are abnormal, although the patient’s complaint itself is not reproduced (Butler, 2000; Shacklock, 2005). This typically occurs in the physically active who are experiencing mild symptoms, with neurogenic involvement, during sports or professional activity with a repetitive nature.

Restricted EE-ROM is an even more essential parameter in clinical research. Several important research papers focusing on neurodynamics use restricted EE-ROM as an independent key criterion to determine a positive ULNT1 (Byng, 1997; Greening, Lynn, Leary, Warren, O’Higgins & Hall-Craggs 2001; Greening et al., 1999; Selvaratnam, Matyas, & Glasgow, 1994; Wainner et al., 2003; Wainner et al., 2005), while others use range-of-motion to evaluate treatment progression (Coppieters et al., 2003a; Coppieters, Stappaerts, Wouters, & Janssens, 2003b; Vicenzino, Collins, & Wright, 1996).

Interest in impaired nerve movement and nerve biomechanics has increased in the last several years (Coppieters & Alshami, 2007; Coppieters & Butles, 2008; Coppieters, Hough, & Dilley, 2009; Sucher, 2009; Yayama et al., 2010). However, several issues regarding nerve movement in relation to peripheral neuropathies require further investigation. For example, the biomechanical mechanisms behind restricted nerve movement and increased nerve elongation and their clinical consequences still remain unresolved research questions (Julius, Lees, Dilley, & Lynn, 2004; Van Hoof et al., 2008). Future research should also investigate if restricted nerve movement and/or range of motion is rather a consequence or a causative factor in neurogenic related pain syndromes as for example CTS and NSAP (De-La-LLave-Rincón, Fernández-De-Las-Peñas, Palacios-Ceña, & Clelnad, 2009; Hough, Moore, & Jones, 2007; Julius et al., 2004). The ULNT1 is a promising tool for the resolution of these issues.

The ULNT1 is designed to move and load the upper limb nervous system with bias toward the median nerve and its origins in the brachial plexus (Kleinrinsink et al., 2000; Lewis, Ramot, & Green, 1998; Selvaratnam, Glasgow, & Matyas, 1988). It is therefore appropriate as a basic test to investigate nerve movement. In the study of normal nerve biomechanics, range-of-motion measures are essential, and more informative than sensory responses (Coppieters, Stappaerts, Staes, & Everaert, 2001; Coppieters, Van De Velde, & Stappaerts, 2002). In these types of studies with healthy participants, the onset of ‘normal’ sensory responses evoked by the ULNT1 is only used as a limit to determine the end of the test. Different neurodynamic test protocols are then performed with focus on end range of motion to study neurobiomechanical behavior. This emphasis provides the rationale for the establishment of standards for bilateral ULNT1 EE-ROM measurements in healthy, physically active subjects.

A considerable amount of variability can be found in ULNT1 EE-ROM in a normal population, ranging from full elbow extension to up to 60° short of full extension (Pullos, 1986). Consequently, no normative data of the EE-ROM is available for the purpose of determining normality, which explains why clinicians and researchers compare the EE-ROM of the affected side to the least, or non-involved, side. The side-by-side comparison of the EE-ROM has developed into a common clinical practice, based on the assumption that healthy subjects will inevitably show symmetry in the EE-ROM. No study exists, however, which proves the symmetry of ULNT1 EE-ROM in normal subjects, nor which investigates the possibility of small but significant asymmetries in the EE-ROM resulting from natural phenomena, in the absence of musculoskeletal disorders or neuropathy.

In the current study, we will analyze three variables that have the potential of influencing EE-ROM symmetry. First, the possible effect of significant muscular variance is investigated. For this purpose, Langer’s axillary arch (LAA) (Fig. 2A,B) is introduced as a single muscular variant (incidence 2–7%) between the insertion tendons of the latissimus dorsi and the pectoralis major, crossing the neurovascular bundle in the axilla (Bonastre, Rodríguez-Niedenfuhr, Choi & Sañudo, 2002; Üçerler, Ików, & Pinan, 2005). Previous studies have shown that LAA is capable of interfering with the biomechanics of the axillary neurovascular bundle, particularly the distal portion of the brachial plexus and the median nerve (Besana-Ciani & Greenall, 2005; Clarys, Barbaix, Van Rompaey, Caboor, & Van Roy, 1996; Lama, Potu, & Bhat, 2010; Mérida-Valesco, Rodríguez Vázquez, Mérida Valesco, Sobrado Pérez, & Jiménez Collado, 2003; Üçerler et al., 2005). Secondly, the variable of side will be examined in a traditional left–right comparison, as the possibility exists of the examiner exhibiting a detectable preferential side in performing the ULNT1. Finally, hand dominance will be analyzed as a variable that is known to affect the muscle fiber composition and neurophysiological functioning of the upper limb (Farina, Kallenberg, Merletti, & Hermens, 2003; Tanaka, McDonagh, & Davies, 1984).

Differences attributed to one or more of these concealed variables, if unrecognized, may have a considerable impact on the interpretation of the ULNT1 for both clinicians and researchers.
Therefore, the present study will investigate whether these variables have a significant effect on the ULNT1 EE-ROM measurements, which would result in the necessity of including EE-ROM asymmetry as a basic principle in ULNT1 interpretation.

2. Material and methods

2.1. Subjects

The present study was approved by the institutional ethics committee of Ghent University and all volunteers signed an informed consent form. A total of 640 healthy students were screened for the presence of LAA (Fig. 2A). Each arm was placed consecutively on the examiner’s shoulder with the elbow extended, wrist neutral, and shoulder flexed at 90°. The subject then adducted the shoulder isometrically with submaximal force while the examiner palpated the medial border of the latissimus dorsi toward the humeral insertion of the pectoralis major. In most of the cases, the presence of LAA was clearly visible as an anomalous axillary mass. Participants thus diagnosed as having LAA were subjected to an ultrasound investigation performed by an experienced physician to confirm the authenticity of the anomaly (Clarys et al., 1996). A Sonoline Sienna ultrasound machine (Siemens, Erlangen, Germany) with a 7.5 MHz linear probe was used, and LAA was imaged in cross-sectional and longitudinal view, both contracted and relaxed.

Fig. 2. (A) Right-sided LAA in vivo. (B) Right-sided dissection of LAA. (1) LAA (outlined in red); (2) pectoralis major; (3) biceps brachii; (4) insertion tendon of latissimus dorsi; (5) subscapularis; (6) pectoralis quartus (variation); (a) axillary artery; (b) neurovascular bundle; (c) musculocutaneous nerve; (f) lateral cord; (u) ulnar nerve; (m) median nerve. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Excluded from the study were subjects with a history of an upper quadrant musculoskeletal disorder within the previous 6 months, as well as subjects who reported diseases closely associated with neuropathy, or who had central or peripheral nervous system disease. Each subject underwent a physical examination and had to show a pain-free full ROM of the upper limb joints, including the cervical spine, in order to be included in the study. Using the same criteria, a matched control group was created, composed of subjects without LAA, as determined by physical examination of the axilla.

Hand dominance was determined as the side used for fine motor skills. In cases of cross-dominance, being able to do different tasks better with different hands, the dominant side was determined on the basis of the hand used for writing.

Of the 640 volunteers, 19 subjects participated in the group with LAA (8 males, 11 females; age (mean ± SD): 20.55 ± 0.65 years; body mass index, 21.87 ± 0.52; total of 26 LAA sides, further classified in subgroup u of unilateral LAA’s (n = 12; 12 sides) and subgroup b of bilateral LAA’s (n = 7; 14 sides). Seventeen subjects without LAA comprised the control group, defined as subgroup c (5 males, 12 females; age: 22.44 ± 0.33 years; body mass index, 21.40 ± 0.34). To investigate the effect of the variables of side and hand dominance, both the test and the control group were pooled for statistical analysis (n = 36, 13 males, 23 females; age: 21.44 ± 0.29 years; body mass index: 21.64 ± 0.32) (Fig. 3). Of the 36 participants, five were left-handed (14%); this distribution is a realistic reflection of the population, as 8%–15% of people are left-handed (Hardyck & Petrinovich, 1977).

2.2. Test description and procedures

The ULNT1 was performed bilaterally on each subject in two different test positions: cervical spine in neutral position (NL) and cervical spine in submaximal contralateral lateral flexion (CLLF), the maximal passive range of lateral flexion without provoking discomfort (Fig. 1A,B). For each position, the test was repeated three times. Prior to the test, the wrist was submaximally extended (total wrist extension minus 10°, determined with a manual goniometer) through an individually customized thermoplastic splint.

The head and cervical spine were gently placed in position and, by means of a custom-made device, a pad was positioned against the side of the head to prevent lateral flexion of the cervical spine toward the limb being tested (Fig. 1A,B). The glenohumeral joint was then abducted until the scapula was observed to begin elevation. At this point, a second adjustable pad was placed on the superior border of the acromion, without applying any additional caudal pressure in order to prevent further scapular elevation (Reisch, Williams, Nee, & Rutt, 2005; Shacklock, 2005). Subsequently, glenohumeral abduction followed by external rotation was performed passively to end range. Finally, the forearm was supinated, followed by passive elbow extension, the ROM of which was the principal measurement of the test (EE-ROM) (Fig. 1A, B). The EE-ROM was terminated by the examiner at the maximal end resistance (R2), when no further extension was possible (Grant, Forrester, & Hides, 1995; Reisch et al., 2005; Yaxley & Jull, 1991, 1993).

The participants were initially familiarized with the normal responses (Kenneally, Rubenach, & Elvey, 1988) to the test. They were thus well informed about having the option to interrupt and end the test whenever “submaximal discomfort or pain” occurred, which was defined according to Coppieters, Stappaerts, Janssens, and Jull (2002), Coppieters, Van De Velde et al. (2002) as “the maximal tolerance level for the test in view of the subject’s knowledge that the test has to be performed repeatedly.”

The VICOM optoelectronic system (Video CONvector; Oxford Metrix, Oxford, UK) measured the EE-ROM between the axis of the
forearm and the imaginary extension of the humeral axis. This angle was then converted into the complementary angle, yielding the actual EE-ROM measurement used throughout the study.

To prevent any test bias, the order of the starting position was randomized between the NL and CLLF positions. A 1-min and a 3-min interval were imposed between the test repetitions and change of the test (cervical) position, respectively. All tests were administered by the same tester, who was blind to hand dominance and the exact value of the EE-ROM displayed on the computer screen.

2.3. Data analysis

The intraclass correlation coefficients (ICCs) were calculated from the three repetitions in each test position at both sides to measure the intra-examiner reliability. The statistical full mixed model used was designed to analyze: i) the main effect of LAA by means of interactive effects of side and subgroups, thus whether differences between sides (in particular LAA and non-LAA) differed between subgroups (subgroup u, unilateral LAA; subgroup b, bilateral LAA; subgroup c, controls), ii) the main effect of side (difference in the EE-ROM between left and right sides - from the pooled group), iii) the main effect of hand dominance (difference in the EE-ROM between dominant and non-dominant sides - also from the pooled group) (Fig. 3).

Additional analyses (post-hoc) were conducted to evaluate at the individual level the significance of a possible relationship of the variables with EE-ROM. Therefore, the smallest detectable difference (SDD) at both sides was used in order to have an indication about the smallest significant amount of difference in the EE-ROM perceptible between opposite sides. SDD was determined at the 0.05 significance level for both sides in each test position [SDD = SEM × √2 × 1.96] and was based on the standard error of measurement (SEM), which was calculated from the pooled standard deviation (SDpooled) and the ICC [SEM = SDpooled × √(1−ICC)] (Table 1). The mean SDD of both sides was

![Fig. 3. Summary of recruitment, group and subgroup composition, test procedure and data analysis.](image-url)
calculated and used as a minimal threshold measure for significance. Subsequently, for each subject the EE-ROM of one side was subtracted from the opposite side, in accordance with the specific variable [e.g., dominant – non-dominant; this procedure will only be performed for the variables showing a significant relationship with EE-ROM as a result from the mixed model], and compared to the mean SDD. Differences in the EE-ROM between sides that exceeded or equaled the mean SDD represented clinically detectable differences, indicating for that individual a significant Bilateral LAA EE-ROM asymmetry.

To assess the effect of the unbalanced design of hand dominance on our analysis we performed post-hoc simulations. We sampled 1000 datasets from a distribution with both EE-ROM values (EE-ROM in NL and CLLF) and variance equal to those observed in our study under the assumption of no effect of hand dominance. All datasets had an unbalanced design similar to the one used in our experiments, and the proportion of significant tests was subsequently determined.

The level of significance was determined using a linear mixed model corrected for multiple measures from the same individual. To identify the most important variables we performed a stepwise-exclusion method based on likelihood-ratio tests.

The EE-ROM was always assessed in both test positions, NL and CLLF. The results below are presented as mean angle ± SEM, and the level of significance was set at \( p < 0.05 \).

### 3. Results

The mean intra-examiner reliability for measurement of the EE-ROM among the four tests (NL left & right, CLLF left & right) was 0.97 (range 0.96–0.98), with a mean SEM of 1.9° (range 1.6°–2.3°) (Table 1). The R2 EE-ROM was reached by each participant in each test, without interruption for submaximal discomfort/pain.

In general, the mixed model showed no interaction effect for the EE-ROM between side and subgroups tested in NL and CLLF (NL: \( F_{2,32} = 1.63, p = 0.21; \) CLLF: \( F_{2,32} = 2.63, p = 0.088 \)) (Fig. 4). Specifically, in the subgroup diagnosed with unilateral LAAAs (Fig. 4), no significant difference was found for the EE-ROM between the LAA side and the non-LAA side (NL: \( t_{32} = 0.99, p = 0.92; \) CLLF: \( t_{32} = 1.32, p = 0.77; \) adjusted for multiple comparison by Tukey test), which indicates that the muscular variance variable, LAA, had no effect on the EE-ROM. The mixed model also showed no main effect of side, indicating no significant difference in the EE-ROM between the left and right side in both test positions (NL: \( F_{1,32} = 1.99, p = 0.16; \) CLLF: \( F_{1,32} = 0.01, p = 0.97 \)) (Fig. 5).

In contrast, the mixed model disclosed a significant difference in the EE-ROM between the dominant and non-dominant side in both test positions (NL: non-dominant side = 158.64° ± 1.60°; dominant side = 155.80° ± 1.60°, \( F_{1,32} = 13.26, p = 0.0004 \); CLLF: non-dominant side = 153.76° ± 1.98°; dominant side = 150.71° ± 1.98°, \( F_{1,32} = 9.01, p = 0.003 \)). The mean difference between the dominant and non-dominant side was \( 2.84° ± 1.60° \) for NL and \( 3.05° ± 1.98° \) for CLLF (Fig. 5).

The unbalanced distribution of hand dominance in the dataset had no significant influence on the present findings. Simulations revealed that only 48 of 1000 (0.048 in NL) and 54 of 1000 samples (0.054 in CLLF) had significant differences between the dominant and non-dominant side, assuming no effect of the unbalanced distribution.

In both test positions, comparable SDD values were found for the left and right side (Table 1) and the mean of both sides was used as a minimal threshold measure for clinical significance at individual level (mean SDD in NL = 4.54°; mean SDD in CLLF = 5.87°). The post-hoc analysis was conducted with hand dominance as the only variable having an effect on the EE-ROM (Fig. 3); in the NL position, 33.3% of the subjects showed a significant (clinically detectable) restriction of the dominant side EE-ROM in comparison to the non-dominant side, exceeding the SDD (mean deficit = 8.7°). In the CLLF position, with a slightly higher SDD (5.87°), 27.8% of the subjects showed significant (clinically detectable) restriction of the EE-ROM on the dominant side (mean deficit = 11.0°; mean deficit over both test positions = 9.9° ± 10°).

### 4. Discussion

The present study investigated the effects of three variables on ULNT1 EE-ROM. No significant effects were found on the EE-ROM

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**Table 1** Overview of the main statistical properties of the current data.

<table>
<thead>
<tr>
<th>Test position</th>
<th>Side</th>
<th>ULNT1 EE-ROM</th>
<th>ICC</th>
<th>SD°</th>
<th>SEM°</th>
<th>SDD°</th>
</tr>
</thead>
<tbody>
<tr>
<td>NL Left</td>
<td>156.67</td>
<td>0.98</td>
<td>10.01</td>
<td>1.67</td>
<td>1.58</td>
<td>4.38</td>
</tr>
<tr>
<td>NL Right</td>
<td>157.77</td>
<td>0.97</td>
<td>9.57</td>
<td>1.60</td>
<td>1.70</td>
<td>4.70</td>
</tr>
<tr>
<td>CLLF Left</td>
<td>152.22</td>
<td>0.98</td>
<td>12.63</td>
<td>2.11</td>
<td>1.97</td>
<td>5.46</td>
</tr>
<tr>
<td>CLLF Right</td>
<td>152.26</td>
<td>0.96</td>
<td>12.04</td>
<td>2.01</td>
<td>2.26</td>
<td>6.28</td>
</tr>
</tbody>
</table>

NL, neutral test position; CLLF, contralateral lateral flexion cervical spine test position; ULNT1 EE-ROM, elbow extension range-of-motion of the median nerve upper limb neurodynamic test; ICC, intraclass correlation coefficient; SD, standard deviation; SEM, standard error SEM; SDD, smallest detectable difference.

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**Fig. 4.** Histogram of results for the general mixed model for sides and subgroups. ULNT1, median nerve upper limb neurodynamic test; LAA, Langer’s axillary arch; EE-ROM, elbow extension range-of-motion; Control, controls without LAA (subgroup c); Bilat LAA, bilateral LAAs (subgroup b); Unil LAA, unilateral LAAs (subgroup u). Unilateral right sides LAAs are converted into left sides LAAs, meaning that the LAA sides are on the left.

**Fig. 5.** Histogram of the results of the mixed model for side and hand dominance. ULNT1, median nerve upper limb neurodynamic test; EE-ROM, elbow extension range-of-motion; L, left; R, right; D, dominant; ND, non-dominant. *\( p < 0.05 \).
measurements from LAA, a single muscular variation known to interfere biomechanically with the neurovascular bundle in the axilla (Clarys et al., 1996; Lama et al., 2010; Mérida-Valesco et al., 2003). We also found no significant difference in the EE-ROM between the left and right sides, analyzed as such. However, when the variable of hand dominance was integrated into the analyses, a significant restriction of the EE-ROM was found on the dominant side in comparison with the non-dominant side for both the NL and CL LF test positions. The mean difference of the EE-ROM between the dominant and the non-dominant side was 2.84° ± 1.60° for NL and 3.05° ± 1.98° for CL LF. To determine the clinical significance of this, small effect post-hoc analyses were conducted. These analyses revealed that, in approximately one third of the participants, a mean significant restriction of ULNT1 EE-ROM of 10° occurred on the dominant side.

In this study, LAA was used as a model for a single muscular variance with the potential to interfere with the biomechanical behavior of the enclosed neural tissue. The present findings indicate that a significant single muscular variant may be unable to affect ULNT1 neurobiomechanics, as illustrated by the findings of unaltered EE-ROM. Furthermore, it can be inferred that the variable of side also has no effect on the EE-ROM. From the symmetry we found between the left and right sides, we conclude that there were no effects of the examiner’s preferential test side, or other side-dependent variables.

To our knowledge, the present study is the first to report the restrictive effect of hand dominance in healthy subjects resulting in asymmetry of the ULNT1 EE-ROM. This finding calls into question the standard procedure of comparing the patient’s EE-ROM to the least affected, or unaffected, side.

Reisch et al. (2005) is the only report that we know of, which explicitly considered the variable of hand dominance into an investigation of range-of-motion in a neurodynamic context. However, a modified version of ULNT1 (ULNT2, median nerve bias) was used in this study. In ULNT2, glenohumeral abduction is the final passive movement component, of which the end range (GA-ROM) is the objective measurement. They measured GA-ROM on the dominant and non-dominant side, and had inconsistent results from two different examiners, resulting in inconclusive data concerning the effect of hand dominance (Reisch et al., 2005).

Yaxley and Jull (1991) examined GA-ROM of ULNT2 (radial nerve bias) and indirectly provided information regarding the effect of hand dominance. In this study, only right-handed subjects were included, and no significant differences were found between left and right sides, from which we can conclude that there was no effect of hand dominance on GA-ROM. An interesting finding, however, was that, for the dominant side, a significant deficit in GA-ROM was found between the test performed with wrist and finger flexion (radial nerve bias) and with wrist and finger extension (median/ulnar nerve bias). No such deficit was found for the non-dominant (left) side, which may indicate a decreased compliance of the radial nerve to these specific biomechanical alterations on the dominant side.

Grant et al. (1995) also investigated the ULNT2 (radial nerve bias) and reported a significant restriction of GA-ROM on the right side in healthy professional keyboard users. Hand dominance was not included as a separate variable in their analyses. Only one subject was left-handed, however. Their findings of a restrictive influence of hand dominance on range-of-motion during neurodynamic testing contradict the findings of Yaxley & Jull (1991). With the exception of the study of Reisch et al. (2005), hand dominance has not been taken into account during analysis, or deliberately controlled for, in previous reports concerning neurodynamics.

Hough, Moore, and Jones (2000), using spectral Doppler ultrasound, demonstrated a slight decrease of median nerve excursion on the dominant side, measured at the elbow following wrist extension. Although this restriction was not significant, it was concluded that a classical comparison between limbs (left-right) might be of limited value, as further analysis indicated a weak intra-subject between-limb correlation. In a later study, the same authors (Hough et al., 2007) reported significantly reduced nerve/tendon excursion ratios of the median nerve in 58% of patients with carpal tunnel syndrome. Interestingly, a significantly greater number of subjects in that study who were classified with low nerve/tendon excursion ratios had their dominant hand tested, compared with patients classified as having high nerve/tendon excursion ratios. These ultrasound measurements of restricted median nerve excursion lend support to our present conclusion of limited ULNT1 EE-ROM on the dominant side. Unlike ultrasound, the ULNT1 does not directly measure nerve excursion. Nevertheless, evidence has been provided that ULNT1 EE-ROM is associated with decreased nerve movement (Greening et al., 2001, 1999) and that it distinctly reflects alterations in nerve biomechanics (Coppieters, Stappaerts, Everaert et al., 2001, Coppieters, Van De Velde et al., 2002b).

A more in-depth focus on morphological variables reveals that LAA is closely related to the axillary neurovascular bundle, and that it is tightened during glenohumeral abduction-external rotation, a main postural component of the ULNT1 (Boonstra, 1979; Clarys et al., 1996; Daniels & Oakes, 2000; Sacchetto, 1977). LAA thus occurs at a critical location (brachial plexus, origin median nerve) and the effectuating mechanism is amplified by the starting posture of ULNT1. However, according to the present results, the presence of this single muscular variation is not likely to influence local nerve biomechanics, which would be reflected in a restricted EE-ROM. If LAA can serve as representative for a single muscular variant with proven interference on the enclosed neural tissue, it may be suggested that, in healthy individuals, isolated significant morphological variance will not contribute to ULNT1 EE-ROM asymmetry.

The fact that hand dominance influences the EE-ROM, while a significant morphological variation such as LAA does not, may be explained by the fact that hand dominance involves the entire upper limb, in contrast with LAA, which only interferes at one specific location. Recent studies show that stiffness regulation of the upper limb is a physiological mechanism that functions to maintain acceptable levels of fine motor performance during various physical, spatial, and mental task requirements (Bloemsaat, Meulenbroek, & Van Galen, 2005; Gribble, Mullin, Cottho, & Mattar, 2003; Meulenbroek, Van Galen, Hulstijn, Hulstein, & Bloemsaat, 2005; Van Gemmert & Van Galen, 1997), changing the upper limb functional dynamics in the distal executive unit (forearm/hand) as well as the proximal postural unit (shoulder region) (Milner, 2004). It may be assumed that the dominant side is likely to be more active during daily activities, which often consist of (repetitive) fine motor tasks requiring high-level accuracy (e.g., writing, keyboarding, computer mouse operating, playing a musical instrument). This means that, over time, the dominant side is more exposed to upper limb stiffness regulation than the non-dominant side.

The long-term preferential use of muscles of the dominant side of the body results in changes of muscle fiber composition, with a higher prevalence of slow twitch type I fibers in the dominant muscle (Fugl-Meyer, Erickson, Sjostrom, & Sodestrom, 1982). Several authors have reported differences in myoelectric manifestations of muscle fatigue between the two sides, with the dominant side showing less fatigue for the distal limb and hand muscles (De Luca, Sabbahi, & Roy, 1986; Tanaka et al., 1984; Zijdewind, Bosch, Goessens, Kandou, & Kernen, 1990). These effects are also found more proximally in the upper trapezius muscle (Farina et al., 2003) and in the lower back muscles (Merletti, De Luca, & Sathyam, 1994).
These reports support the hypothesis that side dominance changes muscle fiber properties in both postural muscles and muscles used for fine movements.

The musculoskeletal system also provides the peripheral nervous system a mechanical interface in relation to which it can slide, adjusting to upper limb movement. The aforementioned changes in tissue characteristics and long periods of up-regulated upper limb stiffness may cause an increase in frictional coefficients on the dominant side. Increases in the frictional forces between the nerve and its surroundings, perhaps in several locations simultaneously, may decrease the overall capacity of the nerve to comply with limb movement through sliding, which would be reflected in limited ULNT1 EE-ROM. In contrast, LAA can only influence the nerve at a single location, which may explain why the EE-ROM is not restricted by LAA.

In our study, the mean difference of EE-ROM between the dominant and non-dominant side was 2.84° for the NL and 3.05° for the CLLF test positions. Although this effect may initially seem minor, even a small change in the EE-ROM may have considerable consequences for clinical practice and, particularly, for clinical research. Post-hoc analyses revealed that, in one third of the healthy test population, the restrictive effect of hand dominance on the EE-ROM (10°) is likely to be appreciated by a clinician or examiner familiar with neurodynamic testing. This insight underscores the idea that, if limited EE-ROM is the only finding of ULNT1, this should be interpreted carefully (Butler, 2000; Coppieters, Stappaerts, Everaert et al., 2001). Our results also further question the practice of using the less-involved, or uninvolved, side as a relative control, as well as the use of the EE-ROM deficit between both sides as an independent inclusion or exclusion criterion in clinical research. Wainner et al. (2003, 2005) used a lower threshold of a 10° deficit of ULNT1 EE-ROM between both sides as an independent criterion for inclusion of subjects in carpal tunnel syndrome and cervical radiculopathy groups for two separate studies. In light of our results, this modus operandi regarding the interpretation of ULNT1 increases the probability for an increased inclusion of false positive subjects in the test group, which may contaminate subsequent analyses and overall outcome. Our findings emphasize the key importance of the effect of hand dominance in clinical research.

There are several reports in the literature in which the ROM from neurodynamic tests revealed no significant differences when compared between the left and the right sides, leading to the suggestion of ROM symmetry (van der Heide, Allison, & Zusman, 2001; Yaxley & Jull, 1991). Accordingly, in the present study, no significant differences were found in a traditional left-right comparison as illustrated in Fig. 5. Only when analyses of the EE-ROM between both sides were performed as a function of hand dominance did a restrictive effect and, as a consequence, asymmetry occur (Fig. 5).

When only a traditional left-right comparison is included in a research design, therefore, the confounding effects of hand dominance can confuse results, and even lead to erroneous conclusions. For example, the effect of hand dominance, if unrecognized, may lead to an over- or underestimation of the extent to which an existing neurogenic problem affects the ULNT1 EE-ROM. Both in clinical and in research settings, the ULNT1 is frequently used as a tool for assessing the effectiveness of treatment (Coppieters et al., 2003a; Vicenzino et al., 1996). During such an assessment, a persistent limited EE-ROM on the dominant side may be misinterpreted as a delay or an arrest of further treatment progression if the effect of hand dominance is not taken into account. Clinicians and researchers should be advised to take the effect of hand dominance into consideration, and to correct for it in their statistical analyses.

The sample size used in the current study (n = 38) was rather small, and not properly balanced (right versus left-handed subjects) for hand dominance. In order to investigate the effect of this unbalanced design upon our dataset, we performed post-hoc simulations for unbalanced data. The results of these simulations (0.048 in NL and 0.054 in CLLF) illustrate that the unbalanced design did not increase the type I error, the false rejection of the null hypothesis. This means that the significant restriction of ULNT1 EE-ROM is indeed, caused by an effect of hand dominance, and is not induced by the unbalanced design of the dataset.

The present unbalanced data does, however, reflect a representative distribution of hand dominance: 14% of the participants were left-handed, which corresponds to the 8–15% left-handedness in the general population (Hardyck & Petrinovich, 1977). This distribution can therefore be expected in any research design where subjects are not specifically selected based on hand dominance. Consequently, corrections for hand dominance, also in unbalanced conditions, should be made.

The range of age in the present test and control group was rather small (20.55 ± 0.65(SD) years and 22.44 ± 0.33(SD) years respectively) because recruitment occurred in a student population. Therefore, the sample groups were not fully representative of the wider adult population. However, the authors anticipate that any effects of hand dominance on ULNT1 EE-ROM would become more pronounced with increasing age, although this expectation remains to be verified experimentally.

Further study on the effect of dominance in general may also be indicated in order to determine its role in other commonly-used neurodynamic tests, such as the radial and ulnar nerve biased ULNTs and, for example, the straight leg raise test for the lower limb.

5. Conclusion

In conclusion, the present study demonstrates that the ULNT1 EE-ROM is not affected by the presence of LAA, a model for an isolated muscular variance surrounding the neural tissue. Traditional left-right comparisons revealed no significant differences of the EE-ROM suggesting, in accordance with the literature, symmetry of the ULNT1 EE-ROM. However, when the analyses were performed with an enhanced statistical model, which integrated the distribution of hand dominance, a significant restriction of the EE-ROM was found on the dominant side. Post-hoc analysis illustrated that, in approximately one third of the asymptomatic subjects, the EE-ROM showed an average deficit of 10° on the dominant side. This indicates that the restrictive effect of hand dominance resulted in a clinically significant asymmetry of ULNT1 EE-ROM, which renders questionable the clinical procedure of comparing the patient’s EE-ROM to the least, or unaffected, side.

Conflict of interest
None declared.

Ethical statement
The study was approved by the institutional ethics committee of Ghent University and all volunteers signed an informed consent form.

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References


