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Reliability of muscle function and sensory perception measurements of the wrist extensors

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ABSTRACT

This study determined the reliability of muscle function and sensory perception measures of the wrist extensors. The test-retest reliability of the measurements was determined by an intraclass correlation coefficient (ICC), coefficient of variation (CV), standard error of measurements (SEMs), and one-way repeated measures ANOVA using the values collected from 25 young (20.6 ± 1.3 years) healthy male volunteers on two occasions separated by 1 day. The measures consisted of grip strength, wrist extension strength (WES), range of motion in active and passive wrist flexion and extension, choice reaction time (CRT), vibration sense (VIB), joint position error sense (JPE), cold pain (CP) and heat pain threshold, and pressure pain threshold. An acceptable reliability was determined as the ICC values greater than 0.85, CV less than 15%, and SEMs less than 5%. ICC of all measures except for JPE were greater than 0.85, only CV of JPE, CP, and VIB exceeded 15%, SEMs were higher than 5% only for JPE and CP, and the ANOVA showed a significant time effect for CRT and WES. It is concluded that most of the measurements except JPE are reliable and can be used to investigate effects of a physiotherapy intervention on the wrist extensors.

INTRODUCTION

Assessing muscle function and sensory perception is important in physiotherapy to diagnose a symptom and examine effectiveness of an intervention in both clinical and research settings. Commonly used muscle function assessments include maximal voluntary contraction (MVC) strength during isometric or dynamic contraction and active range of motion (Clarkson, Nosaka, and Braun, 1992; Leger and Milner, 2001). Some of the sensory perception assessments include pain intensity using a visual analog scale (VAS) and pressure pain threshold using an algometer (Slater, Arendt-Nielsen, Wright, and Graven-Nielsen, 2003; Slater, Arendt-Nielsen, Wright, and Graven-Nielsen, 2005). Other measures such as reaction time, vibration sense, and joint position error sense have been also used in some studies to evaluate musculoskeletal conditions (Bisset et al, 2006; Brockett et al, 1997; Weerakkody et al, 2001). However, the majority of the previous studies investigated muscle function and sensory perception for the elbow flexors (Hubal, Rubinstein, and Clarkson, 2007; Nosaka, Newton, and Sacco, 2002), knee extensors (Byrne, Eston, and Edwards, 2001; Paschalis et al, 2007) and calf muscles (Webster et al, 2002; Weerakkody et al, 2001). Little attention has been given to the forearm and wrist muscles.

The forearm and wrist muscles are important for daily activities such as eating, cooking, and writing, as well as for sporting activities such as racket sports. The number of research studies on the wrist extensors was limited, thus assessing muscle function and sensory perception of these muscle groups was focused on in this study. In the previous studies investigating exercise-induced muscle damage, only pressure pain threshold and Likert pain scale were used to assess muscle

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damage in the wrist extensors (Slater, Arendt-Nielsen, Wright, and Graven-Nielsen, 2003; Slater, Arendt-Nielsen, Wright, and Graven-Nielsen, 2005). MVC strength of the wrist extensors and range of motion of the wrist joint were included in a study (Leger and Milner, 2001); however, other measures such as reaction time, vibration sense, and joint position error sense have never been included in the previous studies of the wrist extensors. To include these measures in a study, it is necessary to establish the reliability of the measurements.

At present, little information is available for the reliability of muscle function and sensory perception measures of the wrist extensors. Therefore, the purpose of this study was to investigate the test-retest reliability of some muscle function and sensory perception measures that could be used to assess effects of a prophylactic or therapeutic intervention on the wrist extensors.

METHODS

Participants

Twenty-five healthy young men (20.6±1.3 years) volunteered to participate in this study. Their average (±SD) height and body mass were 172.0±4.6 cm and 62.3±7.4 kg, respectively. The subjects had no history of neuromusculoskeletal disorders in upper limbs, and had no experience of arm resistance training in the last 3 months before attending this study. The study was approved by the institutional ethics committee, and a written consent was obtained from each individual.

Measures

All of the measurements were taken from the nondominant arm considering possible effects of daily activities on the measures. The measures consisted of grip strength (GS), wrist extension strength (WES), range of motion in active wrist flexion (ROM-AF), active wrist extension (ROM-AE), passive wrist flexion (ROM-PF), and passive wrist extension (ROM-PE), choice reaction time (CRT), vibration sense (VIB), joint position error sense (JPE), and pain thresholds including thermal pain threshold [cold pain (CP) and heat pain (HP)] and pressure pain threshold (PPT). The order of the measurements was standardized as follows: CP, HP, VIB, PPT, ROM-AF, ROM-AE, ROM-PF, ROM-PE, and CRT followed by GS and WES, to consider possible carryover effects from other measures. The order of the muscle strength measures (GS and WES) were randomized to minimize bias from measuring the muscle performance. The interval between different measures was at least 5 minutes, and the rest period between trials in the same measure was 30–60 seconds as indicated in each test protocol shown below. One day prior to the study, all participants underwent a complete series of familiarization trials. The reliability assessments were based on the measures between two occasions at the same time of the day with a 24-hour interval. The subjects were advised to use the tested limb at minimal level between the testing sessions. The same investigator performed all measurements and was blinded from the previous scores. All of the instruments were calibrated before the measures according to the respective recommended procedures.

Grip strength

Grip strength (GS) was measured by using an electronic digital hand dynamometer (Model MLT003/D, Power Lab, Australia). The manufacturing resolution of the dynamometer was ±0.6 N. Subjects sat on a chair with the nondominant arm (from the elbow to the wrist joint) supported by a platform. The upper extremity was positioned according to the recommendations of the American Hand Society of Hand Therapist (Fess, 1992) so that the shoulder was adducted and neutrally rotated, forearm in neutral position, and wrist slightly extended (20°). GS was measured with the elbow in 90° flexion and comfortable grip width of each subject. Subjects were instructed to perform a sustained maximal isometric contraction for 6 seconds (Kamimura and Ikuta, 2001). The measurement was performed three times with 1 minute between trials, and the mean of three peak values from the trials was used for further analysis.

Wrist extension strength

Wrist extension strength (WES) was recorded via a force transducer (Model MLT003/D, Power Lab, Australia). The manufacturing resolution of the dynamometer was ±0.6 N. Each subject sat on a chair with his forearm in full pronation with 45° elbow flexion supported on an armrest of the chair, and his wrist was set in 20° extension with the 3rd knuckle placed to the centre of the force transducer. Subjects were instructed to maximally extend the wrist by pushing the dorsal surface of the hand against the plate of the force transducer and sustained a maximal isometric contraction for 6 seconds (Kamimura and Ikuta, 2001). Subjects performed the maximal contraction three times with a 1-minute rest between the trials. Peak value was determined for each trial, and the mean of the three trials was used for further analysis.

Range of motion (ROM)

ROM was evaluated by using a universal goniometer with the resolution of within 1° for wrist extension and flexion to determine the pain-free active and passive range of motions. Subjects sat on an arm supporting chair and were asked to rest the arm on the support. The bony prominences, including triquetrum, olecranon, and the fifth metacarpal head, were marked with the permanent marker to identify the reference points clearly. The center of the goniometer was placed at the center of the axis of the wrist joint (triquetrum bone) with a stationary arm of the goniometer placed paralleled to the lateral midline of the ulna toward olecranon process, and a moveable arm of the goniometer was placed to the lateral midline of 5th metacarpal bone toward the metacarpal head (Reese and Bandy, 2002). The pain-free active range of motion was performed by instructing the subject to move the wrist into flexion and extension directions; the subject was requested to stop the movement when he perceived pain of the wrist extensor muscles or at the end of the range. For the pain-free passive range of motion, the subject was asked to relax the hand during passive movement of the wrist joint into flexion and extension directions by the investigator. The subject signaled the investigator for a position of the wrist when he felt initial perception of pain of the muscles or at the end range of motion. The measurements were taken three times with a 30-second interval. The mean of the three trials was used for further analysis.

Joint position error

Joint position error (JPE) was randomly measured by using the universal goniometer in the same setting as the ROM assessment. The target points were set at 45° wrist flexion and 45° wrist extension, which was about the middle range of the full wrist flexion and extension. Subjects were blindfolded to eliminate any visual cues and were told to concentrate on the position of the hand "in space." The investigator passively moved the subject's hand to a target angle as referenced by a universal goniometer and held it for 3 seconds before returning the wrist to the neutral position. As soon as returning to the neutral position, subjects were asked to immediately reposition the hand back to the target angle and inform the investigator when they felt the position was achieved. The investigator recorded the angle, and the absolute difference between the target angle and the recorded angle was determined (Dover and Powers, 2003). The test was repeated three times for both flexion and extension positions with a 30-second rest between trials, and the mean of the three trials was used for the further analysis.

Reaction Time

In this experiment we used three choices reaction time (CRT) with three lighting stimuli. The reaction time was measured by a reaction timer (Thai Phan, Thailand) with the resolution of 1 millisecond. Each subject sat on a chair and placed the testing hand on a mark located on the center of a table, and faced to a box on which three buttons are located 30 cm between them. The distance from the mark on the table to the middle button was 20 cm. The subject was asked to reach out toward the button responding to the light as soon as a randomly selected lighting stimulus was given in 0–3 seconds. Each standard test consisted of 12 trials with 30-seconds rest between trials, and six middle values of the 12 trials were averaged and used for further analysis (Bisset et al, 2006; Hoeger and Hoeger, 1999).

Vibration sense

Vibration sense (VIB) was assessed on two sites of the wrist extensor muscles: 1) common extensor origin at the lateral epicondyle (O); and 2) belly of extensor muscles located at the prominent point over the extensor carpi radialis brevis muscle (M) using a vibration neurosensory analyzer (Medoc Ltd., Neuro Sensory Analyzer Model TSA-II, Israel). The vibration is factory calibrated to $\pm 0.1\,\mu m$ with a control resolution of $\pm 1\%$. Vibration stimulus was applied to the sites (i.e., origin site, muscle site) in progressive magnitude of $0.1\,\mu m\,s^{-1}$ with a fixed frequency of 100 Hz. Each subject lay down on his back, and the elbow was flexed at 90° and rested his hand above the umbilicus for the test of the origin site, and his arm was placed by his side in 0° elbow extension and 90° pronation for the muscle site test. The subject held a control switch in the other hand and was asked to press a control switch when he started to feel the vibration (Weerakkody et al, 2001). The magnitude (mA) of the vibration to be sensed (threshold) was assessed three times with a 30-second interval between trials. The mean value of the three trials was used for further analysis.

Thermal pain threshold

Thermal pain threshold (TPT) was the level of temperature that induces initial pain and was assessed by using a Thermal Sensory Analyzer (Medoc Ltd., Neuro Sensory Analyzer Model TSA-II, Israel) for cold and heat pain threshold. The system was calibrated in accordance with the instruction manual, and a control resolution was 0.3°C. The measurement sites were the same as those for the vibration sense: (1) common extensor origin at the lateral epicondyle (O); and (2) belly of extensor group muscles located at the prominent point over the extensor carpi radialis brevis muscle (M). The temperature of the thermode ($5\,cm^2$) was increased or decreased at a controlled rate ($2^{\circ}\,C \cdot s^{-1}$ for cold pain and $1^{\circ}\,C \cdot s^{-1}$ for heat pain). Each subject lay down on this back with arm by his side (0° elbow extension and 90° pronation), and the

thermode was applied on the marked areas with Velcro strap. According to the previous standard protocol for evaluating TPT in the wrist extensors (Paungmali, O'Leary, Souvlis, and Vicenzino, 2003; Wright, O'Callaghan, Smith, and Vicenzino, 1994; Wright, Thurnwald, and Smith, 1992), the initial temperature for testing of cold pain threshold (CP) was set at 32°C, and the thermode temperature gradually decreased at a rate 2° C · s^{-1} to a minimum cutoff temperature of 0° C. The subject held a control switch and was instructed to press the button when he felt the sensation changing from cold to pain. For the heat pain threshold (HP), which was conducted 1 minute after the cold pain threshold, the initial temperature was also set at 32°C, and the temperature of the thermode was gradually increased at a rate of 1° C · s^{-1} up to a maximum cutout temperature of 50°C to avoid heat injury on the skin. The subject was asked to press a control switch when he felt the sensation changing from hot to pain. The subject received a verbal instruction approximately 1–2 seconds before the initiation of each test, and each pain threshold was assessed three times with a 30-second interval between trials. The mean value of the three trials was used for further analysis.

Pressure pain threshold

Pressure pain threshold (PPT) was measured by an algometer (Somedic Production, Algometer type II, Sweden) with a probe of 1.0 cm^2. The algometer is factory calibrated to ±3% of readout and is regularly recalibrated in the laboratory with a 100-kPa calibrating weight before experimentation. PPT was assessed at the two sites: (1) common extensor origin at the lateral epicondyle (O); and (2) belly of extensor group muscles located at the prominent point over the extensor carpi radialis brevis muscle (M), respectively. Each subject lay down on the back with his arm by the side (0° elbow extension and 90° pronation). The probe was placed at the reference site, and the pressure was increased at a rate of 30 kPa · s^{-1} until the subject felt the sensation changing from the pressure to pain, which was indicated by the subject pressing a button. PPT was assessed three times for each site with 30-second rest between trials, and the mean of the three trials was used for further analysis.

Reliability analysis

The test-retest variability was determined by an intraclass correlation coefficients [ICC(3,3)] for all measures except for CRT [ICC(3,6)], coefficient of variation (CV), and standard error of measurements (SEMs). The presence of systematic bias between trials was analyzed by using a one-way repeated measures ANOVA. The statistical significance was set at the alpha level of 0.05. The results of ICC and one-way repeated measures ANOVA were obtained from the SPSS statistical package, and CV and SEMs values were calculated from the following formula:

$$CV = (SD/\overline{X})100$$

$$SEMs = SD\sqrt{1 - ICC}$$

where $\overline{X}$ is the mean of the data, SD is the standard deviation of observed test scores, and ICC is the reliability coefficient for that measurement.

For SEMs interpretation, the percent value of the actual SEMs was determined by the proportion in percentage of SEMs value to the mean of data (Atkinson and Nevill, 1998; Portney and Watkins, 2000). The ICC values less than 0.70, 0.70–0.79, 0.80–0.89, and greater than 0.90 were considered as poor, fair, good, and high in reliability, respectively, and an ICC value greater than 0.85 was considered as an acceptable reliability (Portney and Watkins, 2000). A measure is also considered to be reliable if CV is less than 15% and SEMs is less than 5% (Atkinson and Nevill, 1998; Portney and Watkins, 2000).

RESULTS

Table 1 shows the Intraclass correlation coefficients (ICC), coefficient of variation (CV), standard error of measurement (SEMs), and analysis of systematic error (ANOVA) for all measures. All muscle function measures, including grip and wrist extension strength, ROM (ROM-AF, ROM-AE) and CRT, were considered to be reliable. Sensory perceptions (ROM-PF, ROM-PE, VIB, CP, HP, and PPT) were also reliable (ICC $>$ 0.85); however, VIB and CP over the origin site were greater in CV compared to that of the other measurements. ICC, CV, SEMs, and ANOVA all indicated that the reliability of JPE was low.

DISCUSSION

This study used ICC, CV, SEMs, and one-way repeated measures ANOVA to assess the reliability of muscle function and sensory perception measures of the wrist extensors in an attempt to use the measures to examine effectiveness of an intervention in both clinical and research settings such as investigating the effect of a physiotherapy intervention on eccentric exercise-induced muscle damage. The results showed that all measures except for JPE were reliable (Table 1).

TABLE 1 Intraclass correlation coefficients (ICC), coefficient of variation (CV), standard error of measurements (SEMs), and F and P values of one-way analysis of variance (ANOVA)

Measurement	ICC	CV (%)	SEMs	ANOVA
GS	0.86	6.7	7.39 (2.4%)	0.90, 0.351
WES	0.95	10.5	1.70 (2.0%)	11.87, 0.002
ROM-AF	0.95	2.0	0.35 (0.4%)	2.79, 0.108
ROM-AE	0.95	2.1	0.34 (0.4%)	2.66, 0.116
ROM-PF	0.95	1.5	0.35 (0.4%)	0.50, 0.487
ROM-PE	0.97	1.0	0.18 (0.2%)	0.11, 0.744
CRT	0.92	5.3	0.01 (1.5%)	10.02, 0.004
VIB-O	0.94	17.7	0.26 (4.4%)	3.16, 0.088
VIB-M	0.93	14.0	0.39 (4.2%)	1.14, 0.296
JPE-F	−0.11	79.4	3.01 (72.9%)	1.03, 0.320
JPE-E	0.58	62.0	1.24 (40.1%)	0.00, 0.967
CP-O	0.94	27.2	0.54 (7.3%)	1.40, 0.249
CP-M	0.98	12.2	0.14 (1.6%)	0.43, 0.517
HP-O	0.88	2.7	0.40 (0.9%)	0.01, 0.936
HP-M	0.97	1.8	0.14 (0.3%)	0.01, 0.912
PPT-O	0.92	7.8	7.03 (2.2%)	0.00, 0.991
PPT-M	0.96	5.1	2.64 (1.0%)	1.78, 0.195

GS = grip strength; WES = wrist extension strength; ROM-AF = range of motion for active wrist flexion; ROM-AE = range of motion for active wrist extension; ROM-PF = range of motion for passive wrist flexion; ROM-PE = range of motion for passive wrist extension; CRT = choice reaction time; VIB-O = vibration sense at lateral epicondyle; VIB-M = vibration sense at the belly of the carpi radialis brevis muscle; JPE-F = joint position error or wrist flexion; JPE-E = joint position error for wrist extension; CP-O = cold pain at lateral epicondyle; CP-M = cold pain at the belly of the carpi radialis brevis muscle; HP-O = heat pain at lateral epicondyle; HP-M = heat pain at the belly of the carpi radialis brevis muscle; PPT-O = pressure pain threshold at lateral epicondyle; PPT-M pressure pain threshold at the belly of the carpi radialis brevis muscle.

Muscle function

The measurements of muscle function in the present study included grip strength, wrist extensor strength, choice reaction time, and active range of motion of the wrist joint. Previous studies have shown that the position of arm and hand, wrist angle, and grip span affect the grip strength (Fransson and Winkel, 1991; Kattel, Fredericks, Fernandez, and Lee, 1996; Morse, Jung, Bashford, and Hallbeck, 2006). The grip strength measurement protocol in the present study was based on that recommended by the American Society of Hand Therapists (Fess, 1992) in which the arm and hand were standardized in one position. The study by Bohannon (2006) used the same protocol to that used in the present study and reported that the test-retest reliability of a hand-grip dynamometer (MicroFET 4 hand-grip dynamometer) was high (ICC=0.97–0.99) when the test was conducted on two consecutive days for the left and right hands. The ICC values of the present study were not as high as those reported by Bohannon (2006), which was probably due to the difference in the instrument used in the studies. Regarding the wrist extension strength, it has been demonstrated that the wrist angle affects wrist extension strength (Morse, Jung, Bashford, and Hallbeck, 2006). In the present study, the wrist joint was set at 20° extension, so the reliability of other angles should be investigated, if a different angle is used.

It should be noted that the ANOVA showed a significant difference in the wrist extension strength between days, although the ICC, CV, and SEMs showed that the measure was reliable (Table 1). When comparing the values, the WES on the second day (88.8±26.7 N) was significantly greater that that of the first day (80.6±27.7 N). It seems likely that this was due to a learning effect. Compared with the grip strength measure, it appears that factors contributing to learning effect were greater for wrist extension strength, because the measure was less familiar to the subjects. It may be necessary to have more practice trials in the familiarization session to minimize the learning effect, or the magnitude of the effect should be taken into account when the test is used in a study.

Choice reaction time in the present study was defined as the response time, including the reaction time (the time taken between a light stimulus and the initiation of hand movement) and movement time (the time taken to move the hand to the target button). The same measure was shown to be acceptable for determining reaction time in healthy women aged between 25 and 53 years with ICC value of 0.75 and standard error of measurement (SEMs) of 17.4 ms in a previous study (Kauranen and Vanharanta, 1996). The ICC, CV, and SEMs of choice reaction time in the present study were better to those reported by Kauranen and Vanharanta (1996) possibly due to a difference in subjects' age range (Hoeger and Hoeger, 1999). However, the ANOVA data suggested a possible systematic error between trials for this measurement showing better reaction time in the second day (0.661±0.098 s) compared with the first day (0.695±0.094 s). This seems likely to indicate a learning effect as found in the wrist extension strength. To minimize this effect, increasing the number of practice trials in familiarization session or including more familiarization days may be necessary.

Regarding the active range of motion measures (ROM-AF and ROM-AE), Horger (1990) examined the reliability of goniometric measurements of active wrist motions in flexion and extension using 48

subjects (33 men, 15 women) and reported that the intrarater reliability coefficients exceeded 0.95. This value is similar to that obtained in the present study. However, the SEMs (3.6–4.5°) in Horger's study are larger than those in the present study (0.34–0.35°). This may be due to the heterogeneity of the participants in Horger's study with larger ranges in age (18–71 years) with various hand disorders.

Sensory perception

The measurements of sensory perception consisted of passive range of motion (ROM-PF and ROM-PE), vibration sense, joint error position sense, and several pain assessments. The reliability of ROM-PF and ROM-PE found in the present study were similar to those reported by Horger (1990), who examined the intrarater reliability coefficients of goniometric measurements of passive wrist flexion and extension. The vibration sense has been used to represent the proprioceptive sense via large-fiber mechanoreceptors. The vibration sense showed that the reliability was suitable; however, it should be noted that the CV of vibration sense was relatively large (13.9%–17.7%). Peters, Bienfait, de Visser, and de Haan (2003) showed that the intraobserver reliability for vibration perception threshold on the dorsum of the distal end of the second metacarpal bone (within 24-hour interval) using ICC values was 0.95 for left hand and 0.77 for right hand. The reliability of vibration sense in Peters and coworkers' study was similar to the findings of the present study, which tested the origin and the extensor muscles of the arm. It has been suggested that adipose tissue deposits over the measurement sites and the length of limb affect vibration sensation (Hodge et at, 1995; Wiles, Pearce, Rice, and Mitchell, 1991). In the present study, it seemed unlikely that a large variability in the adipose tissue thickness over the wrist extensors existed among subjects; however, individuals should be cognizant of potential factors such as body composition and height that might affect the reliability.

ICC values of joint position error in flexion (JPE-F) and extension (JPE-E) were less than 0.85 with high variation (CV=79.4%, and 62.0%, respectively), and SEMs were more than 5%. Thus, the reliability of JPE-F and JPE-E measures were not within the acceptable ranges. Joint position error is a sensory perception influenced by the afferent information from peripheral mechanoreceptors located in the skin, muscle, and surrounding joint structures (Voight et al, 1996). The control of this kind of sense is most likely a combination of afferent information, efferent response, and central control (Dover and Powers, 2003), and these factors may make this type of measurement more complicated. The measurement protocol of JPE may account for the lack of its reliability in that JPE was measured at the middle range, because it has been reported that it is difficult to detect a small change in JPE at a middle range due to the lower firing rate of joint mechanoreceptors compared to the end range (Janwantanakul, Magarey, Jones, and Dansie, 2001). However, we followed the standard protocol of measurement identifying the reference points prior to the measurement. The high variation and error of the JPE tests may also be caused by the nature of the test in which the subjects have to pay attention closely during the period of testing. Therefore, usage of the JPE should be considered with caution when applied for clinical investigation.

The measurements of pain in the present study included thermal pain threshold for cold and heat stimulus and pressure pain threshold. A distinction between heat and cold pain thresholds was less evident (Neddermeyer, Fluhr, and Lotsch, 2008); however some researchers have highlighted that cold pain is a sensitive tool for detecting characteristics of hyperalgesia (Chien, Eliav, and Sterling, 2009; Frost et al, 1991). The results of cold and heat pain threshold showed that the reliability was suitable. However, the cold pain threshold demonstrated more variability compared with the heat pain threshold. This might be due to a difference in transmitted signal of cold and warmth receptors. Warmth signals are transmitted mainly over unmyelinated C-nerve fibers, whereas cold signals are transmitted via the complicated pathways including C- and A-delta myelinated nerve fibers (Guyton, 1991). In addition, the range of perceiving cold pain threshold is greater than heat pain threshold, for example, the receptors of cold pain are stimulated from 15°C and to the limit of protocol (0°C), but the range of heat pain is narrower (from 45°C to the limit of protocol at 50°C) (Guyton, 1991). These factors may be associated with the difference in variation between the thermal pain measurements. Cathcart and Pritchard (2006) examined the reliability of cold pain threshold in the wrist by assessing it twice 10 minutes apart, and reported that ICC and CV were 0.76% and 21.2%, respectively, for the left wrist, and 0.94 and 12.6%, respectively, for the right wrist. The results of the present study showed similar values for the test-retest reliability for 1 day apart.

Slater, Arendt-Nielsen, Wright, and Graven-Nielsen (2003; 2005) used pressure pain threshold on delayed-onset muscle soreness (DOMS) studies in the wrist extensors; however, no reports of the reliability of pressure pain threshold were included in their study. Jones, Kilgour, and Comtois (2007) showed the test-retest reliability of pressure pain threshold for the biceps brachii and reported that the ICC was 0.96–0.97. The

result of the present study verified the reliability of pressure pain threshold measures for the wrist extensors.

These pain measurements are useful for evaluating the clinical signs of tissue hyperalgesia. Hyperalgesia has been categorized into two distinct forms. Primary hyperalgesia is characterized by sensitivity to both thermal and mechanical stimuli (e.g., PPT), whereas secondary hyperalgesia is characterized by sensitivity mainly to mechanical stimulus, suggesting that central sensitization is mediated by neural input via myelinated afferent nerve fibers (Wright, Thurnwald, and Smith, 1992).

In conclusion, the present study assessed the reliability of muscle function and sensory perception measures that could be used in a study to investigate neuromuscular function of the wrist extensors. However, this study may have some limitations such that only healthy young male subjects were included, and the duration of the follow-up was within a 1-day interval. It is interesting to investigate how exercise of the wrist extensors affects these measures and whether these measures are valid to assess the effect of an intervention on muscle damage of the wrist extensors.

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