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ORIGINAL ARTICLE

Electromyographic Activity of the Upper Limb in Three Hand Function Tests

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Summary *Objective/Background:* Occupational therapists usually assess hand function through standardised tests, however, there is no consensus on how the scores assigned to hand dexterity can accurately measure hand function required for daily activities and few studies evaluate the movement patterns of the upper limbs during hand function tests. This study aimed to evaluate the differences in muscle activation patterns during the performance of three hand dexterity tests.
Methods: Twenty university students underwent a surface electromyographic (sEMG) assessment of eight upper limb muscles during the performance of the box and blocks test (BBT), nine-hole peg test (9HPT), and functional dexterity test (FDT). The description and comparison of each muscle activity during the test performance, gender differences, and the correlation between individual muscles' sEMG activity were analysed through appropriate statistics.
Results: Increased activity of proximal muscles was found during the performance of BBT ($p < .001$). While a higher activation of the distal muscles occurred during the FDT and 9HPT performance, no differences were found between them. Comparisons of the sEMG activity revealed a significant increase in the muscle activation among women ($p = .05$). Strong and positive correlations ($r > .5$; $p < .05$) were observed between proximal and distal sEMG activities, suggesting a coordinate pattern of muscle activation during hand function tests.

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Conclusion: The results suggested the existence of differences in the muscle activation pattern during the performance of hand function evaluations. Occupational therapists should be aware of unique muscle requirements and its impact on the results of dexterity tests during hand function evaluation.

Introduction

Hand and upper extremity function is essential to humans as it allows for the performance of a wide range of self-care, productive, and leisure activities (Chan & Spencer, 2004). Due to its importance, impairments in the upper extremities lead to restrictions on activity performance and impacts participation in social activities and engagements in meaningful occupations, ultimately affecting overall wellbeing and quality of life (van de Ven-Stevens et al., 2016).

Treating patients with hand and upper limb injuries is a common situation for occupational therapists; hand and wrist lesions account for approximately 20% of all cases seen in hospital emergency departments (Dias & Garcia-Elias, 2006), with most patients presenting further limitations to upper extremity function due to a restricted range of motion, pain, oedema, and muscle weakness caused by the trauma (Ydreborg, Engstrand, Steinvall, & Larsson, 2015). In addition to acute situations, restricted hand function also represents one of the leading causes of limited participation in daily activities by patients with chronic diseases, such as rheumatoid arthritis (Andrade, Brandão, Pinto, & Lanna, 2016) and stroke (Dawson, Binns, Hunt, Lemsky, & Polatajko, 2013).

Although the cause of injury varies in different countries (Che Daud, Yau, Barnett, Judd, Jones, & Muhammad Nawawi, 2016), the majority of the upper limb trauma affects working adults aged between 20 years and 64 years (de Putter et al., 2016), thereby causing a significant economic impact. Studies completed in the past decade have estimated the healthcare and productivity costs of upper limb lesions to be US$ 410—740 million per year (de Putter, Selles, Polinder, Panneman, Hovius, & van Beeck, 2012; de Putter et al., 2016), with increased absenteeism and early retirement age observed among patients (Shi, Sinden, MacDermid, Walton, & Grewal, 2014; Tiippana-Kinnunen, Paimela, Peltomaa, Kautiainen, Laasonen, & Leirisalo-Repo, 2013).

Assessment procedures that allow occupational therapists to obtain accurate and reliable information regarding patients' hand function are essential for setting realistic goals and measuring patients' progression during the rehabilitation of upper limb injuries (Carrasco-Lopez et al., 2016). Amongst the several resources available, standardised manual tests are extensively used during the evaluations of hand function to assess the upper limb coordination and skill through a series of tasks involving the manipulation of objects in established patterns (Ekstrand, Lexell, & Brogardh, 2016; Srikesavan, Shay, & Szturm, 2015; van de Ven-Stevens et al., 2016).

Despite focusing on the measurements of body functions and structures, standardised dexterity tests provide valid and reliable data that aids therapists in understanding the impact of hand injuries on patients' activities of daily life. Commonly used standardised tests have high inter-rater and test-retest reliability, usually with an intraclass correlation coefficient (ICC) greater than 0.85 (Aaron & Jansen, 2003; Desrosiers, Bravo, Hebert, Dutil, & Mercier, 1994; Earhart, Cavanaugh, Ellis, Ford, Foreman, & Dibble, 2011).

However, given the existence of multiple standardised dexterity tests and an even greater variety of structured tasks involved in each assessment, there is no consensus on which test is more suitable for evaluating the entire function of upper extremities (van de Ven-Stevens et al., 2016). Moreover, there is an increasing concern regarding the way by which the scores assigned to hand dexterity can accurately measure hand function required for daily activities (Rallon & Chen, 2008; Rand & Eng, 2010; van de Ven-Stevens et al., 2016).

The study of muscle activation through surface electromyography (sEMG) allows a real-time, noninvasive assessment of the activation pattern of muscles during the activity performance (Gurney et al., 2016). Although sEMG has been used to evaluate the muscle activation patterns in several self-care (Meijer et al., 2014), productivity (Almeida, Cruz, Magna, & Ferrigno, 2013; Ferrigno, Cliquet, Magna, & Zoppi Filho, 2009), and leisure activities (Donoso Brown, McCoy, Fechko, Price, Gilbertson, & Moritz, 2014), few studies have analysed the different recruitment of muscle fibres during the performances of different hand function tests (Brorsson, Nilsdotter, Thorstensson, & Bremander, 2014; Calder, Galea, Wessel, MacDermid, & MacIntyre, 2011).

Considering the lack of studies describing the muscle activities of the upper extremities in standardised hand assessments, this study aimed to evaluate and compare the differences in muscle activation patterns during the performance of the box and blocks test (BBT), nine-hole peg test (9HPT), and functional dexterity test (FDT)—the three hand dexterity tests used by occupational therapists during hand function evaluation.

Methods

Participants

A convenience sample of 20 university students, aged 18—30 years, participated in this nonexperimental, descriptive, and cross-sectional study. These students were invited to participate through institutional e-mail or phone call. Participants were undergraduates in mechanical engineering, civil engineering, and occupational therapy, however, undergraduates in physical education and music were excluded because they could have specific upper limb-related skills, like dexterity, that could confound the results. Participants included were exclusively right handed, had no history of pain, discomfort, trauma, or sequelae relating to the upper extremities, and had no familiarity with hand dexterity tests.

Participants who had a body mass index (BMI) of 30 kg/m^2 or more, used medications, or who performed excessive exercise 72 hours before the evaluation were excluded from the study as these factors potentially interfere with the collection of sEMG signals (Cram & Kasman, 2011).

The study was approved by the ethics committee of the proposing institutions, and all participants were informed about the experimental procedures and asked to provide a written consent prior to the experiment.

Instrumentation

Hand Dexterity Tests

Three hand dexterity tests were selected for this study, BBT (Desrosiers et al., 1994), 9HPT (Mathiowetz, Volland, Kashman, & Weber, 1985), and FDT (Aaron & Jansen, 2003).

BBT consists of repeatedly moving 2.5-cm wooden cubes from one box to another when the boxes are placed side by side (Yancosek & Howell, 2009). Scores are based on the number of blocks successfully moved between the two boxes in 60 seconds. Since its development, the test has been used on various populations, has presented established reference values, and is considered to have a high construct validity and reliability (ICC = 0.83–0.99) (Desrosiers et al., 1994; Ekstrand et al., 2016; Mathiowetz, Volland, et al., 1985).

FDT involves the grasping and manipulation of 16 wooden pegs, measuring 2.2 cm in diameter and 4 cm in length, that are placed in a 21 cm^2 shardwood board (Aaron & Jansen, 2003). The test requires the use of a tripod grasp and rotational movements performed by a single hand; it is scored according to the time used to turn all of the pegs. FDT has a high inter-rater (ICC = 0.82–0.93) and intra-rater reliabilities (ICC = 0.91) (Aaron & Jansen, 2003).

Similar to FDT, 9HPT measures hand dexterity by placing wooden pegs in a pegboard as fast as possible. The test uses thin, 7-mm diameter pegs, and also considers the removal of pegs as a part of the evaluation (Oxford Grice, Vogel, Le, Mitchell, Muniz, & Vollmer, 2003). 9HPT has a moderate retest reliability (Pearson $r = 0.43–0.69$) and a high inter-rater reliability (Pearson $r = 0.97 - 0.99$) when compared to the Purdue Pegboard Test (Mathiowetz, Weber, Kashman, & Volland, 1985).

The selection of the three tests was based on the type of motor tasks required by each instrument to measure hand dexterity, in accordance with the categorisation proposed by van de Ven-Stevens et al. (2016). Scores of the selected tests were timed, and all the tests consisted of a single task.

We selected BBT based on its use in studies investigating hand and upper extremity function in acute and chronic conditions (Desrosiers et al., 1994; Ekstrand et al., 2016; Mathiowetz, Volland, et al., 1985; van de Ven-Stevens et al., 2016; Yancosek & Howell, 2009).

Despite being classified as pegboard tests, FDT and 9HPT require different movement patterns during test performance (Yancosek & Howell, 2009); therefore, we selected both the tests to investigate the differences in muscle activation during similar movement activities.

Electromyography Equipment

The New MioTool Wireless® (Miotec Biometric Equipment — Porto Alegre, Rio Grande do Sul, Brazil), an 8-channel system with a common mode rejection of 126 db and amplification to a gain of 1000, was used to collect the sEMG data. Signals were conditioned with a digital band-pass filter between 10–500 Hz and a 60-Hz notch, with a 14-bit analog to digital conversion at a sampling frequency of 1000 Hz, and sensors with entry impedance of 1010 Ω.

Disposable, bipolar Ag/AgCl surface electrodes with a 15 mm diameter and 20 mm inter-electrode distance (3M Healthcare, Sumaré, SP, Brazil) were used. Electrodes were fixed to the skin of participants with Micropore (3M Healthcare, Sumaré, SP, Brazil) and custom-made, low-compression elastic tape, to reduce the signal interference caused by the movement of sensors.

Anthropometric data was obtained through a digital scale with 150 kg capacity and a 100-g interval (Filizola —Sao Paulo, SP, Brazil). A vertical stadiometer was fixed to the scale to measure participants' height in centimetres. Additionally, the JAMAR Hydraulic Hand Dynamometer (Patterson Medical Holdings, Inc., — Warrenville, IL - USA) was used to measure the flexor digitorum superficialis' (FDS) maximum voluntary contraction.

Electronic placement

Muscles selected for this study were located by palpation during voluntary contraction. Portions of each participant's skin directly over the muscle bellies of the muscles were shaved and carefully cleaned to reduce the contact impedance (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). Electrodes, positioned on the cleaned skin over the muscle belly, were placed parallel to the direction of the muscle fibres (Basmajian & Blumenstein, 1989; Cram, Kasman, & Holtz, 2011), in accordance with sEMG for noninvasive assessment of muscles recommendations (Hermens, Freriks, Merletti, Stegeman, Blok, & Rau, 1999).

Muscle selections were based on the actions of proximal and distal muscles during upper extremity movement (Table 1). The upper portion of the Trapezius (Tp) muscle, the anterior (AD) and posterior (PD) portions of the Deltoid, the Pectoralis Major (PM) muscle, the Biceps Brachii (Bbr), and Triceps brachii (Tbr) were selected for their major roles in the stabilisation and movement of the shoulder and elbow joints during activities involving fine hand movements (Ferrigno et al., 2009; Naider-Steinhart & Katz-Leurer, 2007; Ricci, Santiago, Zampar, Pinola, & Fonseca, 2015; Yoo, Jung, Jeon, & Lee, 2010).

Distal muscles, the Extensor Carpi Radialis Brevis (ECRB) and the Flexor Digitorum Superficialis (FDS), were selected

Table 1 Selected Muscles and Electrode Positioning.

Muscle	Corresponding movement	Electrode placement*
Trapezius (upper fibres)	Scapular adduction, elevation and upward rotation	Half the distance between the C7 spinous process and the acromion, parallel to the shoulder ridge
Deltoid (anterior fibres)	Shoulder flexion, medial rotation and abduction	4 cm below the clavicle lateral portion, over the anterior portion of the shoulder
Deltoid (posterior fibres)	Shoulder extension, lateral rotation and abduction	2 cm below the lateral border of the spine of scapula, in an oblique angle in relation to the arm
Pectoralis major	Shoulder adduction and medial rotation	2 cm below the clavicle, medial to the axillary fold, over the chest and oblique to the clavicle.
Biceps brachii	Elbow flexion and forearm supination	Centre of the muscle belly
Triceps brachii	Elbow extension	2 cm from the midline of arm, at half the distance between the acromion and the olecranon of the elbow.
Extensor carpi Radialis brevis	Wrist extension	Muscle mass 5 cm distal from the lateral epicondyle of the elbow, dorsal side of the forearm.
Flexor digitorum superficialis	Flexion of the proximal interphalangeal joints through II to V digits	Muscle mass at $^{3}/_{4}$ the distance between the elbow and the wrist, palmar side of the forearm

* Based on Cram et al., 2011.

according to their functions in wrist and finger movements and due to their functions in wrist positioning (Oikawa, Tsubota, Chikenji, Chin, & Aoki, 2011) and finger movements (Almeida et al., 2013; Brorsson et al., 2014). A reference electrode was positioned over the C7 spinous process.

Procedures

We selected a convenience sample of 10 male and 10 female students from undergraduate and graduate courses at a public university in Brazil. They were invited to participate through an institutional e-mail address or phone call. Participants were contacted before data collection to explain the research requirements (no exercise and use of medications 72 hours before the experimental procedure). All the procedures necessary for data acquisition were conducted on the same day, in an acclimatised environment, with sessions scheduled to allow the use of natural light to reduce the interference of electrical equipment with the sEMG signal.

First, 1 hour prior to the data acquisition, the electrodes were placed and the maximum voluntary contraction (MVC) of each muscle was obtained. For each muscle, participants were asked to perform three repetitions of maximum isometric contraction under manual resistance for 10 seconds, with a 2-minute interval between each attempt. To obtain the MVC of the FDS, we used the JAMAR hydraulic hand dynamometer (Patterson Medical — Warrenville, Illinois, United States of America), in accordance with the American Society of Hand Therapists guidelines (ASHT, 2015).

The arithmetic mean of the three attempts, expressed in microvolts, was calculated and used as a reference representing 100% of the muscle sEGM activity (Burden, 2010). The MVC was used for the normalisation of the raw sEMG signal, allowing comparisons between the relative percentages of muscle activation used by different participants during the performance of a specific activity (Burden, 2010).

After obtaining the MCV, participants were instructed to perform the hand dexterity tests. The order of the tests was randomised by drawing pieces of paper with the test names from an opaque paper bag. The hand dexterity tests were placed on a wooden desk (120 cm × 60 cm) at a height of 100 cm (Figure 1). For the performance of all hand dexterity tests, participants were seated in a height-

Figure 1 Experimental setting. (A) Box and blocks test; (B) Nine-hole peg test; (C) functional dexterity test.

adjustable chair without arm supports and instructed to sit with their feet resting on the floor and hips and knees at 90° flexion (Leonard et al., 2010; Naider-Steinhart & Katz-Leurer, 2007; Ricci et al., 2015). Before the beginning of trial, participants were instructed to place both arms on the table top and remain in this position until the maximal relaxation point with simultaneous visualisation of the sEMG signal was registered. At this point, the beginning of the task was requested through a clear and precise verbal command.

Each test was performed five times, with a 30-second rest between each repetition. A chronometer was used to record the 60 seconds of each BBT repetition and the time required for participants to complete the 9HPT and FDT. The arithmetic mean of the sEMG signal obtained during the five repetitions for each test was calculated, and a final value expressed in microvolts was obtained for each muscle. The values were normalised according to the MVC obtained previously, and the final data regarding the muscle activation pattern was expressed as a percentage of the MVC.

Data analysis

Descriptive statistics were used to calculate participants' mean age, BMI, and the mean percentage of the MVCs for each muscle during performances of the BBT, 9HPT, and FDT.

Data was assessed for normality through the Shapiro–Wilk test, which showed a non-normal distribution for the sEMG activity of the selected muscles between participants. The Friedman test was used to compare the normalised muscle activity patterns observed in each test and a post hoc analysis was conducted using individual Wilcoxon signed rank test with a Bonferroni-adjusted alpha value.

To investigate the existence of differences in sEMG activity between male and female participants, the Mann–Whitney test was used to compare the MVC percentage of the eight muscles during the performance of the three hand function tests between sexes. Additionally, the relationship between the activation patterns of the evaluated muscles during the hand dexterity tests were investigated using the Spearman rank order correlation. The SPSS software version 20.0 was used for all data analysis, with a significance level set at .05.

Results

Participants' demographics

Participants' mean age was 24.2 (± 3.4) years and average BMI was 23.6 (± 2.8). The mean anthropometric data for female participants was a height of 1.6 m (± 5 cm) and a weight of 60.3 kg (± 7.56 kg), with the average height of 1.75 m (± 5 cm) and 72.6 kg (± 9.6 kg) amongst male participants (Table 2).

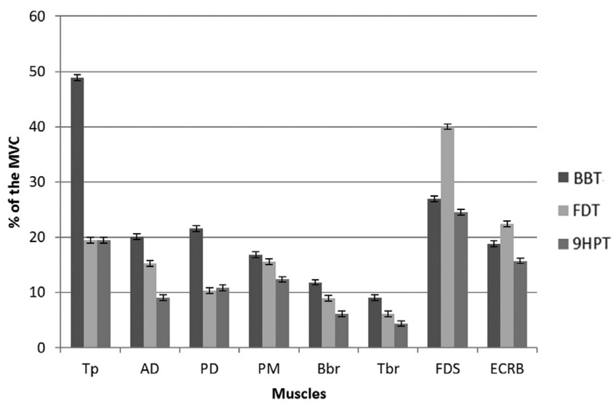
sEMG activity during hand function tests

Changes in the muscle activation were observed when comparing the mean sEMG activity of the three tests (Figure 2). The results of the Friedman test indicated statistically significant differences in the activity of all muscles ($\chi2$ [7, $n = 60$] $= 229.65$, $p < .001$), except for the FDS ($\chi2$ [2, $n = 20$] $= 0.3$, $p = 0.86$), during the performance of the BBT, 9HPT, and FDT tests, thereby suggesting a variation in the recruitment of proximal and distal muscles according to the tasks required by each type of test.

Table 2 Participants' Demographic Data.

Participant	Sex	Age (y)	Height (m)	Weight (kg)	BMI (kg/m^2)
N1	F	29.7	1.58	61	24.4
N2	F	23.7	1.60	69	27.0
N3	F	25.6	1.58	61	24.4
N4	F	19.6	1.61	67.5	25.9
N5	F	23.7	1.64	58	21.6
N6	F	26.7	1.49	49	22.1
N7	F	22.8	1.60	48	18.8
N8	F	26.4	1.56	67.5	27.7
N9	F	24.6	1.63	56	21.1
N10	F	20.1	1.71	66	22.6
N11	M	18.7	1.74	73	24.1
N12	M	23.7	1.79	81	25.3
N13	M	24.8	1.76	73	23.7
N14	M	24.4	1.79	82	25.6
N15	M	21.9	1.80	76	23.5
N16	M	28.3	1.73	65	21.7
N17	M	28.3	1.71	84	28.7
N18	M	29.9	1.62	58	22.1
N19	M	21.5	1.75	77	25.1
N20	M	19.9	1.78	57	18.0

Note. BMI = body mass index; F = female; M = male.



Note. AD = anterior fibres of the deltoid; Bbr = biceps brachii; BBT = box and blocks test; ECRB = extensor carpi radialis brevis; FDS = flexor digitorum superficialis; FDT = functional dexterity test; MVC = maximum voluntary contraction; 9HPT = nine-hole peg test; PD = posterior fibres of the deltoid; PM = pectoralis major; sEMG = surface electromyographic; Tbr = triceps brachii; Tp = upper fibres of the trapezius.

Figure 2 sEMG activity during the performance of the three hand dexterity tests.

Post hoc analyses of muscle activation patterns obtained using individual Wilcoxon signed rank test revealed a significant increase in the activation of the Tp, AD, PD, PM, and Tbr sEMG activity during the performance of BBT when compared to FDT and 9HPT ($p < .001$), indicating an increase in the activation of proximal muscles during BBT.

Despite the similarities between the two pegboard tests, no differences were observed in muscle activation when comparing FDT with 9HPT, suggesting that the muscle recruitment pattern and the motor strategies involved in the performance of both tests may be similar.

Comparisons of the sEMG activity between the sexes revealed significant differences in muscle recruitment. During the BBT performance, female participants presented an increased activity of the AD, PM, Bbr, Tbr, and ECRB muscles. Increased muscle activation was also observed in the PD, PM, Bbr, Tbr, and ECRB among female participants performing the 9HPT, with a similar activation pattern observed with the FDT results (Table 3).

Correlation between the sEMG activities of the selected muscles suggests different patterns for each test. During BBT, a significant, strong, and positive correlation ($p < .05$; $r > .5$) was observed between the recruitment of the AD, PM, and TBr. The same correlation was observed between the PM, TBr, and FDS muscles, suggesting a coordinated function of these muscles during the reaching activities required by the test (Table 4).

The correlation of the muscle activation during the 9HPT indicated a coordinate activation of the PD, Bbr, TBr, and ECRB. Although a similar pattern of strong and positive correlations between proximal muscles was observed when analysing the sEMG activity of the FDT, significant correlations were also found between FDS and the AD, PM, Bbr, and Tbr.

This muscle activation pattern could be explained by the finger motions required for the FDT performance, in addition to the reaching movements.

Discussion

The present study measured the sEMG activities of eight muscles in the upper extremities during three hand function tests. Although the three tests selected for this study aimed to measure the hand dexterity and function, important differences in the muscle activity were observed. An increased activity of proximal muscles was found during the performance of BBT, whereas a significantly higher activation of the distal muscles occurred during FDT and 9HPT, with no differences between them.

The results indicate the varying influence that different tasks have on muscle activity, which based on the objectives of clinical assessment, can impact test selections. As previously presented by Ekstrand et al. (2016), BBT may be preferred for patients with moderate upper extremity impairments. Since it requires movements of proximal and

Table 3 Comparison of Mean sEMG Activity—Female and Male Participants.

Muscle	Female mean BBT sEMG Activity (MVC %)	Male mean BBT sEMG Activity (MVC %)	Female mean 9HPT sEMG Activity (MVC %)	Male mean 9HPT sEMG Activity (MVC %)	Female mean FDT sEMG Activity (MVC %)	Male mean FDT sEMG Activity (MVC %)
Tp	50.7	47.1	23.2	15.7	21.6	17.3
AD	24.4*	15.7*	11.8	6.2	14.1	16.4
PD	23.9	19.2	14.5**	7.3**	12.9*	7.8*
PM	21.6**	12.1**	16.2**	8.5**	14.0	17.2
Bbr	15.8*	7.9*	8.7**	3.5**	9.6	8.3
Tbr	11.2*	6.8*	5.9**	2.9**	5.2*	7.0*
ECRB	22.2**	31.6**	21.4**	10.1**	20.8*	24.1*
FDS	25.1	12.6	22.6	26.4	21.4	58.6

Note. AD = anterior fibres of the deltoid; Bbr = biceps brachii; BBT = box and blocks test; ECRB = extensor carpi radialis brevis; FDS = flexor digitorum superficialis; FDT = functional dexterity test; MVC = maximum voluntary contraction; 9HPT = nine-hole peg test; PD = posterior fibres of the deltoid; PM = pectoralis major; sEMG = surface electromyographic; Tbr = triceps brachii; Tp = upper fibres of the trapezius.
*$p < .05$ (Mann–Whitney test). **$p < .01$ (Mann–Whitney test).

Table 4 Spearman Correlation Coefficient (rho) for the sEMG Activity of Selected Muscles during Hand Dexterity Tests.

	Tp	AD	PD	PM	Bbr	Tbr	ECRB	FDS
Box and blocks test								
Tp	–	.06	.28	−.22	.13	.07	−.03	−.23
AD		–	.22	.59**	.22	.51*	.08	.40
PD			–	.63	.27	.03	-.52*	−.53
PM				–	.42	.73**	.03	.75**
Bbr					–	.43	−.33	.22
Tbr						–	−.05	.61**
ECRB							–	−.36
FDS								–
Nine-hole peg test								
	Tp	AD	PD	PM	Bbr	Tbr	ECRB	FDS
Tp	–	.21	.47*	.04	.20	.07	.21	−.16
AD		–	.28	.40	.07	.23	.47*	−.01
PD			–	.49*	.65**	.57**	.50*	−.14
PM				–	.46*	.72**	.79*	.10
Bbr					–	.45*	−.40	.07
Tbr						–	−.76**	.143
ECRB							–	.15
FDS								–
Functional dexterity test								
	Tp	AD	PD	PM	Bbr	Tbr	ECRB	FDS
Tp	–	.23	.32	−.14	.32	.12	.21	.38
AD		–	.37	.49*	.19	.48*	.22	.52*
PD			–	.43	.68*	.67**	−.29	.36
PM				–	.50*	.72**	−.15	.46*
Bbr					–	.62*	.08	.52*
Tbr						–	−.06	.63**
ECRB							–	10
FDS								–

Note. AD = anterior fibres of the deltoid; Bbr = biceps brachii; ECRB = extensor carpi radialis brevis; FDS = flexor digitorum superficialis; PD = posterior fibres of the deltoid; PM = pectoralis major; Tbr = triceps brachii; Tp = upper fibres of the trapezius. *$p < .05$. **$p < .01$.

distal joints, BBT should be used to measure the hand function of patients with health conditions affecting the whole upper limb (Desrosiers et al., 1994; Mathiowetz, Volland, et al., 1985; van de Ven-Stevens et al., 2016).

In contrast to the muscle activity observed during the BBT performance, 9HPT and FDT did not show significant activation of the proximal muscles. In both the tests, the Tp, AD, PD, PM, BBr, and TBr showed an activation of less than 20% of the MCV, suggesting a stabilising action of the proximal muscles during the performance of FDT and 9HPT (Straker, Pollock, Burgess-Limerick, Skoss, & Coleman, 2008).

Similar results were observed in studies that aimed to analyse fine motor skills using sEMG. Naider-Steinhart & Katz-Leurer (2007) found decreased variability in the electromyographic activity in the Tp during handwriting activities. A similar pattern of activation, below 25% of the MVC of the Tp was also observed during computer-related (Marker, Balter, Nofsinger, Anton, Fethke, & Maluf, 2016) and assembling tasks (Yoo et al., 2010).

Differences in the sEMG activity of male and female participants were also reported by other studies. Marker et al. (2016) analysed the sEMG activity of the Tp in office workers and found increased muscle activation between female office workers when compared with their male colleagues. Another study observed an increased activation of agonist and antagonist muscles amongst women who underwent highly cognitive-demanding tasks, possibly due to different neural activation strategies used by each sex (Pereira, Spears, Schlinder-Delap, Yoon, Nielson, & Hunter, 2015).

Although not significant, an increased sEMG activity, expressed in a higher percentage of the MVC, was observed in women during a hand stabilisation test (Endo & Kawahara, 2011). The study also observed a superior hand stability of female participants compared with male participants, which could also suggest the use of different motor strategies between sexes.

A positive correlation between the activation of individual muscles was observed in the three hand function tests. A similar pattern of activation of the Tp, AD, and TBr was observed by Ricci et al. (2015) in a study evaluating biomechanical differences in reaching tasks. Despite the coordinating activity of the proximal muscles, some differences were found regarding the activation of distal muscles, with increased sEMG activity of the ECRB and FDS during 9HPT and FDT, respectively.

In addition, significant correlations in the range of motion of the upper extremity joints were also found during reaching and grasping tasks by using kinematic analysis (Alt

Murphy, Willen, & Sunnerhagen, 2011; Postacchini et al., 2015), further suggesting the use of different motor strategy according to the task demands.

This study had several limitations. A small sample size can influence the generalisation of the results. Although there were only 20 participants, this number of participants conforms to the studies using electromyography as an evaluation method. In this study, we did not evaluate the sEMG activity of the intrinsic hand muscles. Although the thenar and lumbricalis muscles have a fundamental role in fine hand movements, the authors believe that the presence of electrodes and the materials necessary for its proper fixation at the palm of the hand would influence the movements used to complete the hand function assessment. The sEMG activity of intrinsic hand muscles and its relation with proximal muscles should be investigated in future studies.

Conclusion

The results of the sEMG of the eight muscle groups, measured during three standardised functional tests, indicated that the proximal muscles were more active during BBT, whereas FDT and NHPT activated more distal muscles and had no significant statistical differences between them.

Women showed a higher percentage of muscle activation than men; this result may be justified by different neural activation strategies used by each sex. The research may contribute to the evaluation processes used in occupational therapy and strengthens the recommendation to use such tests to evaluate the functions of the upper limbs.

The results suggest the existence of differences in the muscle activation pattern during the performance of hand function evaluations. Occupational therapists should be aware of unique muscle requirements and its impact on the results of dexterity tests during evaluation.

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