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Relationship between hand function and grip force control in women with hand osteoarthritis

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Abstract—Hand osteoarthritis (OA) usually results in decreased strength and function of the hand and deficits in motor control. However, no data exists on the relationship among these symptomatological features of hand OA. Ten females with hand OA and ten matched, nondisabled control subjects participated in this study. The outcomes of the Moberg Pickup Test (MPUT) and other functional hand tests were correlated with the measures of grip force control obtained during the performance of a functional task of lifting and transporting a handheld object. Strong correlations existed between the MPUT and parameters of grip force control, such as latency ($r = 0.85$) and force at the moment of liftoff ($r = 0.72$), seen in these patients. The established strong correlation between the MPUT and parameters of grip force control might help researchers and clinicians better understand how deficits in controlling grip forces affect hand function in patients with hand OA.

Key words: clinical assessment, control, disability, function, functional test, grip force, hand, joint, osteoarthritis, outcomes, rehabilitation.

INTRODUCTION

Hand osteoarthritis (OA) is the most common joint disorder, affecting about 70 percent of people aged 65 and above. This disease is characterized by pain, stiffness, and swelling of the finger joints, along with damage of the articular cartilage mostly in the four distal and proximal interphalangeal joints and the first carpometacarpal joint [1]. These factors contribute considerably to decreased grip strength and hand function in individuals with hand OA, leading to significant limitations in the performance of everyday manual activities including but not limited to writing, handling small objects, and opening jars or bottles [2–4].

The decrease in maximum isometric grip force (MIGF) has been extensively investigated in people with hand OA. For example, Zhang et al. [5] compared the MIGF between individuals with symptomatic hand OA and nondisabled control subjects. A substantial reduction in MIGF was reported in both males and females with OA when compared with control subjects. It was also described in the literature that OA-related impairment in grip force production leads to a decline in hand function while performing tasks that require using a power or precision grip [6]. In addition, it was reported that decreased

Abbreviations: ADL = activity of daily living; AUSCAN = Australian/Canadian Osteoarthritis Hand Index; DASH = Disabilities of the Arm, Shoulder and Hand (questionnaire); GFP = grip force peak; FMLO = grip force at moment of liftoff; MIGF = maximum isometric grip force; MPUT = Moberg Pickup Test; MPUT-EC = MPUT with eyes closed; MPUT-EO = MPUT with eyes open; OA = osteoarthritis; PE = percentage error rate; PVEL = peak velocity of instrumented object; SWMT = Semmes-Weinstein Monofilament Test; VAS = visual analog scale.

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pinch and grip forces are positively and highly correlated with the performance of activities of daily living (ADLs) in individuals with hand OA [5,7].

Functional limitations in individuals with hand OA can be assessed using various clinical tests and questionnaires such as the Jebsen-Taylor Test of Hand Function [8]; the Australian/Canadian Osteoarthritis Hand Index (AUSCAN) [9]; Dreiser's Functional Index Score [4]; and the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire [10]. For example, significant limitations of hand function in individuals with hand OA were confirmed using the Dreiser's Functional Index Score [4] and Jebsen-Taylor Test of Hand Function [7]. Moreover, the Moberg Pickup Test (MPUT) has been used to demonstrate limitations of hand function and the effectiveness of specific treatments in patients with hand OA. The MPUT has been shown to be a test of high reliability and easy implementation [8]. There are no studies, however, correlating the MPUT with the parameters of grip force control generated during lifting objects. A lack of such specific information limits the ability of clinicians to make a prognosis of the recovery of hand function.

It was demonstrated recently that patients with hand OA apply excessive grip forces and have longer latencies (the time difference between the contact of the object and lifting it off) during manipulation of objects compared with nondisabled control subjects [11]. It was suggested that insufficient control of grip force observed in individuals with hand OA might limit their hand function and, over time, exacerbate pain. However, the relationship between clinical signs of hand OA and the elements/parameters of grip force control remains unknown. As such, information on the relationship between decreased strength and function of the hand and deficits in motor control in individuals with hand OA might help in the development of new assessment strategies of grip force control. Moreover, this information will be important for improving clinical and functional diagnostic tests for individuals with hand OA and providing new data for the development of more focused physical therapy interventions.

The aim of this study was to investigate whether relationships exist between parameters of grip force control and outcomes of clinical tests commonly used in the assessment of hand function in individuals with hand OA. We hypothesized that the MPUT, which assesses the functional status of the hand, would be correlated with the applied force and temporal parameters of grip force control obtained during the performance of functional tasks. To test this hypothesis, we had individuals with hand OA and nondisabled control subjects perform tasks involving lifting an instrumented object and conducted clinical and functional tests assessing their hand impairments and disabilities.

METHODS

Subjects

Ten females with hand OA and ten age-matched, nondisabled females without any history of upper-limb disorder or any other condition that could prevent them from performing the experimental tasks participated in the study. The selection of women for this study is justified by the demographic data suggesting that the highest prevalence of hand OA is in women as compared with men [5,12]. All the individuals with hand OA were referred by a hand specialist physician who used the inclusion criteria for the classification and reporting of hand OA developed by the American College of Rheumatology. Hand radiographs were used to confirm diagnosis. The exclusion criteria were upper-limb fractures in the past 6 months, neurological disorders, or any other upper-limb problems that could prevent performance of the experimental tasks. All of the participants were right-hand dominant.

Clinical Examination

We administered the DASH questionnaire with the purpose of measuring the symptoms and disabilities in the upper-limb function of individuals with hand OA. DASH scores range from 0 (no disability) to 100 (highest disability) [13–14]. The Semmes-Weinstein Monofilament Test (SWMT) (Touch-Test Sensory Evaluators, North Coast Medical, Inc; Gilroy, California) was used to evaluate the sensory perception thresholds of the hand and fingers. It is well established that a decrease or loss of ability to use sensory information from the fingertips adversely affects grip force control [15–16]. To perform the SWMT, we applied the monofilaments to the skin of the distal and proximal interphalangeal joint regions and the pulp of all fingers as well as the metacarpophalangeal joint of the thumb, three times at each site. Correct detection of touch provided by a filament in two out of three trials was considered to be that subject's sensory threshold. The scores for all sites were averaged and used in the analysis [17]. A visual analog scale (VAS) was used to assess the presence

of pain in the dominant hand at the moment of the test. The VAS score ranges from 0 to 10, where 0 is the absence of pain and 10 reflects a very strong feeling of pain [13].

The MPUT was used to evaluate hand function [10,18–19]. The test involves measuring the time needed to pick up small objects: it includes a stop watch, 12 small objects, a container (15 cm diameter), and a wooden surface (29.21 × 44.45 cm) [18–20]. The MPUT was performed under two conditions: with eyes open (MPUT-EO), to evaluate precision grip; and with eyes closed (MPUT-EC), to assess functional performance of the hand based on the proprioception of the upper limb and the tactile inputs of the fingertips, which are prerequisites for regulation of grip force and grip speed [21]. Patients were seated in front of a table and required to pick up the 12 small objects (randomly arranged on a wooden surface) and place them into a container positioned on the opposite side of the tested hand (dominant). The time between the instruction, "May start," and the instant in which the last object was placed in the container was recorded. Each condition of the test was repeated three times. The mean of three trials was used to obtain the final score. The outcomes of clinical examination tests for each subject are shown in **Table 1**.

Instrumentation

The MIGF of the individuals was measured using a hydraulic dynamometer (JAMAR Hydraulic Hand Dynamometer, model PC-030J1, Fred Sammons, Inc; Burr Ridge, Illinois) following the American Society of Hand Therapists guidelines [22].

A cylindrical, plastic, instrumented object (6 cm diameter, 16 cm height, and 431 g weight) was used in the experiments. The instrumented object, designed in the form of a cup, included a piezoelectric force sensor (model 208CO3, PCB Piezotronics Inc; Depew, New York) installed in the center of the cup. Two aluminum pads (2.5 cm wide and 9.0 cm long) connected to the force sensor with two metallic projections were used as grasping surfaces. A triaxial piezoelectric accelerometer (model 333B32, PCB Piezotronics Inc) was fixed to the cup to register the acceleration in the *x*-, *y*-, and *z*-planes (**Figure 1(a)**) [23]. The accelerometer and force sensor data were powered with two signal conditioners (ICP R Sensor Signal Conditioner, model Y482A22, and Line-Powered ICP R Signal Conditioner, model 484B06, respectively, PCB Piezotronics Inc). The force and accelerometer signals were sampled at 100 Hz with a 16-bit analog-digital converter (National Instruments; Austin, Texas) and stored for further analysis. Data collection was performed using a customized LabView Signal Express program (version 2.5.1 for Windows, National Instruments).

Experimental Procedure

The subjects were seated in an adjustable chair with back support, feet on the floor, and elbows flexed at 90°. The chair was positioned in front of a table. Prior to performance of the lifting task, the subjects' fingertips

Table 1.
Clinical details of female patients with hand OA.

Individual with Hand OA	Age (yr)	MPUT-EO (s)	MPUT-EC (s)	MIGF (N)	SWMT (threshold)	DASH (score)	VAS (score)
1	68	12.92	21.04	285.07	4.31	17.50	0
2	61	38.74	51.39	209.67	3.61	38.33	4.5
3	69	16.23	30.30	173.59	3.61	41.66	0
4	68	26.57	63.67	111.37	4.56	55.00	4.5
5	59	17.79	29.23	19.66	2.83	15.00	0
6	61	11.84	27.35	196.60	3.61	20.83	2.5
7	62	17.77	29.01	255.58	3.61	75.00	5
8	48	12.16	23.91	235.92	3.61	27.50	4
9	57	14.33	23.17	206.43	3.96	20.00	1
10	53	17.47	25.64	111.37	3.61	28.33	4
Mean ± SD	60.60 ± 6.78	18.58 ± 8.26	32.47 ± 13.83	180.05 ± 79.23	3.73 ± 0.46	33.91 ± 19.08	2.55 ± 2.10

DASH = Disabilities of the Arm, Shoulder and Hand (questionnaire); MIGF = maximum isometric grip force; MPUT-EO/MPUT-EC = Moberg Pickup Test with eyes open and eyes closed, respectively; OA = osteoarthritis; SD = standard deviation; SWMT = Semmes-Weinstein Monofilament Test; VAS = visual analog scale.

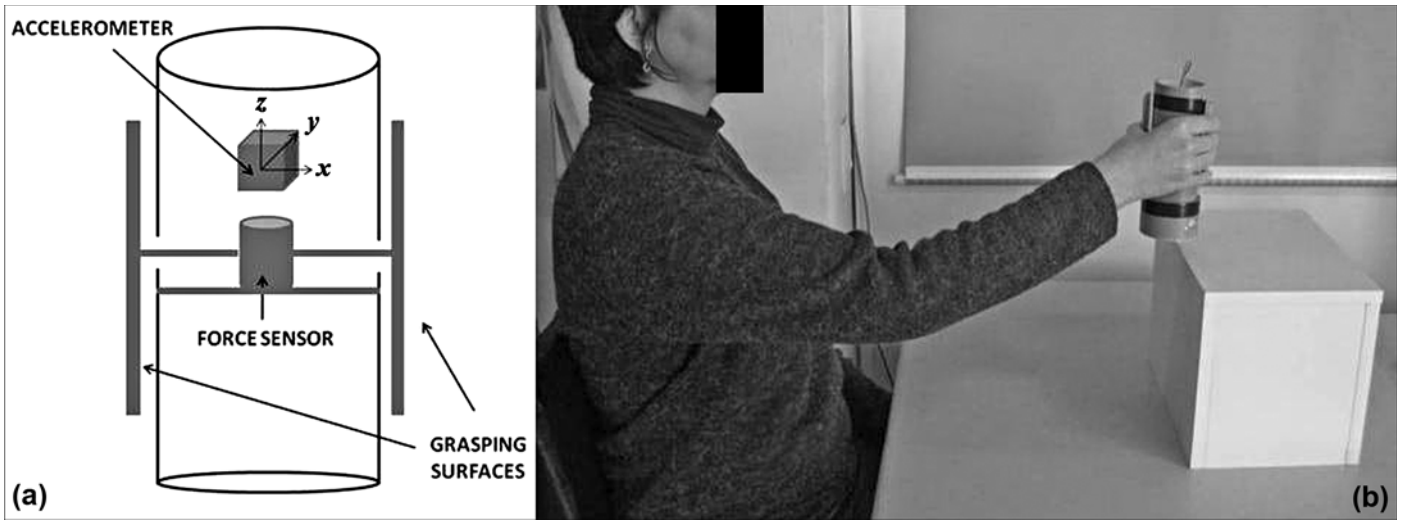

Figure 1.
(a) Schematic representation of instrumented object and **(b)** subject performing experimental task.

and the objects' grasping surfaces were cleaned with alcohol swabs to remove any grease. The subjects were instructed to hold the cup with the opposition of the thumb and the other four fingers positioned on the grasping surfaces and to lift the cup and place it on a 20 cm-high wooden box, located 20 cm away horizontally from the instrumented object's initial position (**Figure 1(b)**). The subjects were required to perform the task "as natural[ly] as possible" without tilting the instrumented object. Each subject performed five lifting trials with their dominant hand: each trial lasted 5 s, with 10 s intervals between trials.

Data Processing

The outcomes of the DASH, VAS, SWMT, MPUT, and MIGF tests were tabulated in Excel (Microsoft Office Excel, version 2007, Microsoft; Redmond, Washington) and stored for statistical analysis. DASH final scores were calculated by dividing the sum of the 30 first questions by 1.2, as proposed by Orfale et al. [14].

The force sensor and the accelerometer signals were processed using a customized MATLAB program (version 7.12.0.635, The MathWorks Inc; Natick, Massachusetts). The following variables were automatically identified and calculated: (1) peak velocity of the instrumented object (PVEL; centimeters/second) determined by integrating the vectorial sum of the three axis-acceleration signals; (2) grip force at the moment of liftoff (FMLO; Newtons); (3) grip force peak (GFP; Newtons), the maximum grip force during the lifting of the instrumented object; (4) load force (Newtons), calculated by multiplying the mass of the object by the vector sum of the horizontal (*y*-axis), lateral (*z*-axis), and vertical (*x*-axis) accelerations, taking into account gravity (*g*) (this variable was calculated during the entire task); and (5) latency (milliseconds), calculated as the time difference between the instant of grip force application and the time of object liftoff from the contact surface.

Statistical Analysis

We performed the Shapiro-Wilks test to confirm that the data were normally distributed. The Student *t*-test was performed to compare the outcomes of the clinical tests (MPUT-EO, MPUT-EC, MIGF, DASH, VAS, and SWMT) and the lifting task variables (FMLO, GFP, latency, and PVEL) between the experimental and control groups. The multiple comparisons were performed to determine variables that were different between the two groups. This was helpful to better understand the results in the subsequent correlation analysis. The effect size (Cohen's *d*) for these *t*-tests was also calculated. According to Cohen [24], the effect sizes are defined as small $d = 0.2$, median $d = 0.5$, and large $d = 0.8$ or above.

Spearman correlations were used to investigate the relationship among the clinical tests MPUT, MIGF, DASH, and VAS and between the clinical tests (DASH and VAS) and the grip force control variables (FMLO, GFP, and latency). Pearson correlations were used to investigate the relationship between the clinical tests (MIGF, MPUT-EO,

and MPUT-EC) and the grip force control variables (FMLO, GFP, and latency). Statistical analysis was performed using SPSS software (version 13.0, IBM SPSS; Somers, New York). Significance was set at $p < 0.05$. The percentage error rate (PE) was calculated for the multiple comparisons (Student *t*-tests) and for the correlations using the following approximation: $PE = 100c\alpha/m$, where c is the number of statistical comparisons, α is the level for a set of comparisons, and m is the number of tests equal to or less than the designed level. The PE reflects the fraction of results labeled as statistically significant different that are likely to be type I errors [25].

RESULTS

Individuals with hand OA performed the MPUT test slower than control subjects; however, the difference between groups was statistically significant only in conditions with eyes open. Moreover, individuals with hand OA had significantly higher scores on the DASH questionnaire than control subjects. The MIGF was significantly lower in individuals with hand OA than the control group. The grip force control variables FMLO, GFP, and latency were significantly higher in individuals with hand OA than nondisabled control subjects. The effect size for all statistically significant *t*-tests was above 1.0, which means a large difference effect (**Table 2**). The PE for these multiple tests was 7 percent.

Spearman correlation coefficients between the outcomes of the MPUT, MIGF, DASH, and VAS tests for the individuals with hand OA are presented in **Table 3**. Spearman coefficients among these clinical tests showed the DASH questionnaire had a moderate positive correlation with the MPUT-EC and strong correlation with the VAS. The PE for the Spearman correlations was 17 percent.

Analysis of the relationship between the clinical tests and the grip force control parameters performed using Spearman and Pearson correlation coefficients showed that the MPUT (both the MPUT-EO and MPUT-EC) had a strong positive correlation with latency. The FMLO outcome showed a strong positive correlation with the DASH questionnaire and MPUT-EO and moderate correlation with the MPUT-EC. The DASH questionnaire showed strong positive correlation with latency (**Table 4**). The PE for these relationships was 14 percent.

DISCUSSION

Individuals with hand OA commonly demonstrate decline in the ability to perform functional tasks as confirmed by the outcomes of the DASH and clinical tests, such as the MPUT [20]. Moreover, it is known that individuals with hand OA apply excessive grip force as compared with nondisabled control subjects while manipulating objects (**Table 2**). Development of new rehabilitation approaches focused on restoration of hand function in individuals with hand OA could be enhanced by considering

Table 2.
MPUT-EO/EC, DASH, MIGF, SWMT, and grip force control parameters in individuals with hand OA and control subjects.

Variable	Hand OA (± SD)	Control (± SD)	*t*-test *p*-Value	Effect Size Cohen *d*
MPUT-EO (s)	18.58 ± 8.26	12.58 ± 1.45	0. 03	1.0
MPUT-EC (s)	32.47 ± 13.83	24.86 ± 1.89	0.10	0.8
MIGF (N)	180.05 ± 79.23	260.85 ± 62.07	0.02	1.1
DASH (score)	33.91 ± 19.08	1.81 ± 1.48	<0.001	2.4
FMLO (N)	9.83 ± 3.84	5.70 ± 1.60	0.005	1.4
Grip Force Peak (N)	15.47 ± 3.05	11.78 ± 2.84	0.01	1.3
Latency (ms)	195.60 ± 121.16	87.53 ± 35.80	0.01	1.2
Peak Velocity (cm/s)	58.79 ± 16.29	65.70 ± 9.20	0.30	0.5
VAS (score)	2.55 ± 2.10	0	0.001	1.7
SWMT (threshold)	3.73 ± 0.46	3.71 ± 0.23	0.91	0.05

DASH = Disabilities of the Arm, Shoulder and Hand (questionnaire); FMLO = grip force at moment of liftoff; MIGF = maximum isometric grip force; MPUT-EO/MPUT-EC = Moberg Pickup Test with eyes open and eyes closed, respectively; OA = osteoarthritis; SD = standard deviation; SWMT = Semmes-Weinstein Monofilament Test; VAS = visual analog scale.

Table 3.
Spearman correlation coefficient matrix between MPUT-EO/EC, MIGF, DASH, and VAS in patients with hand osteoarthritis.

Variable	MPUT-EO (s)	MPUT-EC (s)	MIGF (N)	DASH (score)	VAS (score)
MPUT-EO (s)	1.00	0.75†	–0.35	0.42	0.42
MPUT-EC (s)		1.00	–0.49	0.59*	0.36
MIGF (N)			1.00	0.06	0.19
DASH (score)				1.00	0.73†
VAS (score)					1.00

*$p < 0.05$.
†$p < 0.01$.
DASH = Disabilities of the Arm, Shoulder and Hand (questionnaire); MIGF = maximum isometric grip force; MPUT-EO/MPUT-EC = Moberg Pickup Test with eyes open and eyes closed, respectively; VAS = visual analog scale.

Table 4.
Spearman and Pearson correlation coefficients between grip force control parameters, hand function, MIGF, and perceived pain in patients with hand osteoarthritis.

Variable	MPUT-EO (s)	MPUT-EC (s)	MIGF (N)	DASH (score)	VAS (score)
FMLO (N)	0.72*	0.71*	–0.45	0.71*	0.61*
GFP (N)	0.31	–0.03	0.30	0.19	0.33
Latency (ms)	0.71*	0.85†	–0.51	0.71*	0.46
Peak Velocity (cm/s)	–0.33	–0.43	0.44	–0.49	–0.24

*$p < 0.05$.
†$p < 0.01$.
DASH = Disabilities of the Arm, Shoulder and Hand (questionnaire); FMLO = force at moment of liftoff; GFP = grip force peak; MIGF = maximum isometric grip force; MPUT-EO/MPUT-EC = Moberg Pickup Test with eyes open and eyes closed, respectively; VAS = visual analog scale.

data connecting the outcomes of the functional (DASH and MPUT) and clinical (MIGF, VAS, and SWMT) tests to the force and temporal parameters of grip force control used by individuals with hand OA while performing functional tasks. However, no data exists on the relationship among these outcomes. Thus, this study aimed to fill this gap by investigating the relationship between these functional, clinical, and grip force control variables.

The results of this study confirm our hypothesis that there are relationships between the outcomes of commonly used functional and clinical tests and parameters of grip force control in individuals with hand OA.

Relationship Between Hand Function Tests and Parameters of Grip Force Control

This study demonstrated a strong positive correlation between clinical test outcomes and grip force control. Thus, the force applied to the instrumented object at the time of liftoff (FMLO) showed strong correlation with the DASH and MPUT-EO and moderate correlation with the MPUT-EC. The outcome of the current study revealed that the FMLO was increased in individuals with hand OA compared with nondisabled control subjects (**Table 2**). Unnecessarily high grip forces during object manipulation have been reported in individuals with hand OA [11], as well as in the elderly [26] and in patients with neurological diseases [23,27–28]. It is also known that individuals with neurological disorders as well as those with hand OA demonstrate difficulties in performing manual tasks [29]. **Figure 2(a)** shows the relationship between MPUT (EO and EC) and FMLO in patients with hand OA; patients who applied high grip forces took more time to complete the MPUT. There is an exception: subject number 10 for the MPUT-EC condition (25.65 s for the MPUT-EC vs 14.23 N for the FMLO). The observed correlation between the MPUT-EC and FMLO may indicate that applying excessive grip force when manipulating an object adversely affects the time required to accomplish the task. Therefore, rehabilitation programs that aim to reduce excessive grip forces during object manipulation, such as application of adequate grip forces to objects through use of force tracking devices (biofeedback) [30–31], may help to improve hand function in patients with hand OA. This possibility should be tested in future studies.

Moreover, the latency, which is the time difference between the moment of grip force application and the moment of the object liftoff, showed strong correlation with the MPUT. The relationship between these variables is shown in **Figure 2(b)**: the higher the latency, the longer the time to accomplish the MPUT. Latency is considered a measurement of temporal coordination between the distal muscles that hold the object and proximal ones that are responsible for the object lifting [27,32]. The strong positive correlation between the MPUT and latency in individuals with hand OA suggests that the speed and dexterity in manipulating objects is affected in these individuals. Why do individuals with hand OA show longer latency and extended time to complete the MPUT? The increased latency during object manipulation has been shown in individuals with hemiparesis [27] and cerebellar diseases [32]. So, one possible explanation could be impaired motor control in individuals with hand OA. However, individuals

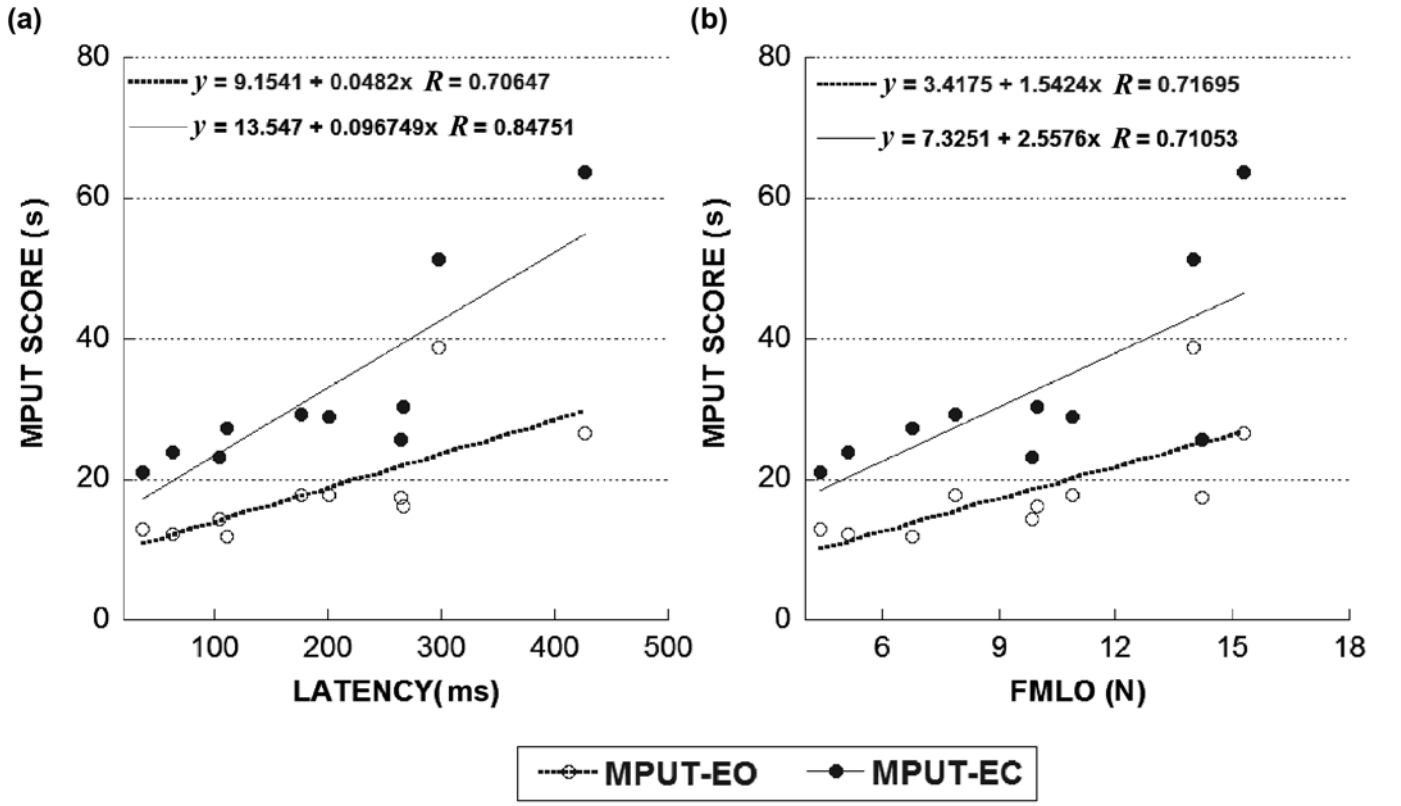

Figure 2.
(a) Relationship between Moberg Pickup Test-Eyes Open/Eyes Closed (MPUT-EO/EC) and latency. Regression lines and regression equations are shown. **(b)** Relationship between MPUT-EO/EC and grip force at moment of liftoff (FMLO) in individuals with hand osteoarthritis.

with hand OA involved in this study did not report any apparent neurological deficit that could be transformed into impairment of the motor control system and, as such, result in problems with muscular coordination. Another possible explanation for the observed longer latency and time to complete the MPUT relates to the deformity and decreased movements of the finger joints as well as joint stiffness that is characteristic of individuals with hand OA [1,4,33]. The associated mechanical disadvantage in such individuals could make the tasks of grasping and handling objects more difficult. This deficiency could generate a delay between applying grip force and lifting the object to be manipulated. This, in turn, would prevent individuals with hand OA from performing manipulative tasks with the same dexterity as nondisabled individuals [34]. This possibility highlights the importance of passive and active exercises to maintain or improve the range of motion of the finger joints in patients with hand OA.

An additional explanation for this finding (longer latency and time to complete the MPUT) and their high correlation is a possible deficit in joint proprioception caused by the degenerative process associated with hand OA. Indeed, decreased joint proprioception was described in patients with OA and rheumatoid arthritis [35–36]. It has been suggested that such proprioception deficits are due to changes resulting from joint capsular effusion and/or inflammatory nature of the synovial fluid [37]. Therefore, it is possible that individuals with hand OA also experience loss of joint proprioception with consequent changes in parameters of grip force control (**Table 2**). Decreased proprioception at the finger joints may prevent the individuals with hand OA from properly coordinating multijoint movements [38], which might explain the observed longer latency and time to complete the MPUT. However, we can only speculate about the possible effect of diminished proprioception because no assessments of

proprioceptive deficit other than SWMT were performed in the current study.

It is known that patients with hand OA frequently show high scores on the DASH questionnaire [39]. In the present study, the DASH outcomes were positively correlated with latency. This provides some evidence that latency (the time between grabbing an object and moving it) may predict how individuals with hand OA will be able to perform everyday manual tasks such as turning a key, writing, or using a knife to prepare food; this possibility might be verified in further studies using different tasks.

Relationship Between Functional and Clinical Tests

The study revealed that relationships exist between the outcomes of clinical and functional tests in individuals with hand OA. The present study found that in individuals with hand OA, the DASH questionnaire had a moderate correlation with MPUT (**Table 3**). Similar correlations between the clinical tests have been reported previously in patients with finger joint arthroplasty [10]. For instance, it was demonstrated that in patients with rheumatoid arthritis, who had arthroplasty of the finger joints, the MPUT had a high correlation with the DASH questionnaire [10]. Although, the DASH questionnaire has a couple of questions about fine hand dexterity, the majority of the questions are concerned with general tasks and regular activities such as gardening, making a bed, carrying a suitcase, washing and drying hair, and recreational activities (volleyball, hammering, fishing, etc.). Therefore, the results of the previous study taken together with the outcomes of the current study suggest that patients who experience difficulty in handling small objects, such as picking up a clip, coins, or nails (the tasks that are evaluated by the MPUT), may also have problems in performing routine manual tasks, such as preparing a meal or gardening (the items assessed by the DASH questionnaire).

Role of OA-Related Pain in Functional Tasks Involving Application of Grip Force

A strong correlation between the DASH and VAS scores (which assess pain levels) and a weak to moderate correlation between the MPUT (which assesses hand function) and the VAS were observed in the individuals with hand OA. Five patients in this study reported moderate pain during the evaluation (**Table 1**: patient 2, 4, 7, 8, and 10); they also demonstrated high scores on the DASH questionnaire (for example, patient 7 showed the highest pain score as well as the highest DASH score) (**Table 1**). An exception was patient number 3 (**Table 1**), who exhibited no pain (VAS = 0) and a relatively high score on the DASH questionnaire (41.66). Nevertheless, the correlation between the DASH and VAS suggests that pain might play an important role in outcomes of upper-limb functional disability assessments; however, this conclusion should be considered with caution, since other factors such as joint stiffness may also affect hand function of the study participants. Indeed, this might be the case for patient number 3. On the other hand, a previous study involving individuals with hand OA demonstrated that pain relief had a strong correlation with improved stiffness ($r = 0.66$), illness perception ($r = 0.76$), and hand function ($r = 0.75$) as assessed by the AUSCAN [9]. In addition, significant improvement in pain, assessed by the VAS, and hand function, evaluated by the DASH questionnaire, were demonstrated in patients with OA of the thumb carpometacarpal joint after a single corticosteroid injection [39]. Both the DASH and AUSCAN tools are used for subjective evaluation of functional activities of the hand. Thus, the outcome of the current study taken together with the previous literature suggests that pain is an important factor that substantially limits the performance of ADLs in individuals with hand OA, and as such, the level of pain should be considered when assessing functional performance in this population.

At the same time, no correlation was observed between pain and the parameters of grip force control (**Table 4**). Why did pain not affect lifting the instrumented object? It is quite possible that the performance of a relatively simple task of lifting an instrumented object was not associated with additional pain compared with the VAS pain level reported by the study participants before starting data collection. As such, one might expect to see no correlation between the pain level before the test and grip force measures obtained during the test performance. Thus, pain was apparently a subjective and nonlimiting factor in performing the experimental task (lifting a 431 g object) or participating in the MPUT.

No correlation between MIGF and grip force control parameters and other functional and clinical test outcomes was observed in the current study. In contrast, Adams et al. [40] found a strong correlation between the MIGF and the DASH questionnaire in individuals with early rheumatoid arthritis. The difference in the outcomes of the current study and the previous study might be explained

by the differences in the stage of the disease. Indeed, in the Adams et al. study, the participants were in the acute stage of illness (postsurgical and early rheumatoid arthritis), while in the current study the individuals were in the chronic stage of the disease.

A need for a relatively small force to manipulate the instrumented cup or pick up small and light objects (MPUT) could be another reason for the lack of correlations between the MIGF and the other variables. Actually, only 14 percent of the maximal grip force is required to perform the majority of the manipulative ADL tasks [41]. For example, in the present study, the minimum force needed to lift the instrumented object was about 7 N (that does not take into consideration the friction), while individuals with hand OA were able to produce much higher grip forces on the MIGF test (mean of 180.05 N) (**Table 2**). Therefore, decreased MIGF observed in individuals with hand OA might not be a factor in disruption of grip force control variables or performance of manual functional tasks in activities that do not require using large grip forces. Clinicians might be aware that increasing grip strength in patients with hand OA does not necessarily improve the patients' hand function, dexterity, and grip force control [42].

Admittedly, our study has limitations, largely related to the generalizability of the results, given the fact that this study was conducted at a single center with 10 subjects with hand OA. On the other hand, the strength of the correlations between the MPUT and both the latency and FMLO were quite sizeable, r = 0.85 and 0.72, respectively. It is likely, therefore, that correlations would be identified in similar populations of patients with hand OA.

CONCLUSIONS

The principal result of this study was the observed strong positive correlations between the variables of grip force control and some parameters of hand function and dexterity in patients with hand OA. This finding provides additional information about the functional diagnosis of hand OA. For instance, the cause of the deficits in hand function in patients with OA might be partially related to impaired control of grip forces. Hence, rehabilitation programs that include grip force control training might be useful for improving hand function and dexterity in individuals with hand OA. These possibilities may prompt the launch of new, larger investigations with a focus on studying the effects of grip force control on the functionality of the hand.

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