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Original Research

Upper Limb Strength: Study Providing Normative Data for a Clinical Handheld Dynamometer

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Abstract

Objective: To establish normative clinical data for upper extremity strength of men and women, ages 20-64 years, using a portable clinical device, the Nicholas Manual Muscle Tester (NMMT).
Design: The study collected objective upper extremity strength data for 180 healthy men and women using the NMMT.
Setting: The study was conducted in outpatient and community settings.
Subjects: One hundred eighty normal volunteers (90 men and 90 women).
Methods: Eleven upper extremity muscle groups were tested using standardized methodology.
Main Outcome Measurements: Data were recorded for each muscle group in each subject.
Results: This study presents data from 180 healthy, normal subjects, equally divided by gender and age. Means $\pm$ standard deviations were determined for each group and further categorized by age, gender, and hand dominance. These data confirm some expected patterns: In all the muscle groups men have significantly higher strength than women, and the dominant side is stronger than the nondominant side in men and women. Relative values for various muscle groups are analyzed and presented.
Conclusions: This study provides an initial normative database across a wide age range in men and women for upper extremity strength for monitoring clinical care and research for injured and impaired patients. These data are an essential and initial step toward comprehensive normative databases for upper extremity objective ordinal strength measurements with the NMMT.

Introduction

Muscle strength is the most important predictor of function, mobility, independence, and activities of daily living. Assessment of muscle strength in clinical settings is usually quantified by manual muscle testing [1]. Different systems and scales have been developed over the decades, but currently, modified Kendall systems (variously called the Medical Research Council Scale or Oxford Scale) are ubiquitous [2-4]. These grading scales classify strength into 6 cardinal levels (0-5). Grade 0 represents no muscle activity. In grade 1, tension is palpated in the muscle or tendon, but no motion occurs at the joint. In grade 2 the part moves through a full range of motion with gravity eliminated with no added resistance. In grade 3 the part moves through full range of motion against gravity. In grade 4 the part moves through full range of motion against moderate resistance. In grade 5 the part moves through full range of motion against maximum resistance and gravity. Modifiers of "+" and "−" may be added for grades 1, 2, 3, and 4. This system facilitates quick clinical assessments and description of muscle strength in upper and lower extremities.

Although these manual muscle testing scales provide valuable clinical insight in diagnosis and in following improvement or decline, they have significant limitations in rehabilitation assessment and planning. First, the scales are cardinal, not ordinal—that is, they are descriptive evaluations, putting each muscle group into a "grade" that best fits a description. The only objective aspect of such clinical systems is the use of gravity to distinguish between grade 2 and grade 3. Even this aspect is quite variable, however, because it is dependent upon the weight of the limb distal to the joint being tested, and considerable inter-rater and intra-rater variation exists, especially for muscle grades 3+ to 5. The assessments can be affected by the evaluator's own strength and experience [5,6]. Rehabilitation progress assessment could benefit from objective ordinal data, especially for these antigravity muscle grades (3+ to 5).

During the past 3 decades, many research-based and commercial analog, digital, and mechanical

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quantitative instruments have been developed to provide such objective, ordinal data, such as Cybex Isokinetic Dynamometer (Cybex International, Medway, MA); Biodex (Biodex Medical Systems, Shirley, NY); and Isostation (Isotechnologies, Hillsborough, NC) [7-9]. These instruments can record forces produced by concentric, eccentric, isokinetic, and isometric muscle contractions. They are highly sensitive, reproducible, and contribute valuable data. However, they are typically limited to research settings and large institutions. They are cumbersome, time consuming, expensive, and lack portability. They can measure only a few limited muscle groups. Few have proved to be practical in busy clinical practices.

More recently, handheld, portable, quantitative instruments have been introduced. These instruments include the Nicholas Manual Muscle Tester (NMMT; Lafayette Instrument, Lafayette, IN) and the MicroFet 2 (Hoggan Health Instruments, West Jordan, UT) [10,11]. They are relatively inexpensive, simple to use, and practical for busy clinical settings. They still have drawbacks, however, particularly an absence of large-sample normative isometric data with age and gender subsets and available normative data for only limited numbers of upper extremity muscle groups.

This study was designed to provide an initial database of dominant and nondominant values for 11 upper extremity muscle groups in men and women aged 20-64 years for one such device, the NMMT. We selected the NMMT for this study because of the authors' and evaluators' familiarity and experience with its use and the availability of published studies of inter-rater and intrarater reliability [4,5,10-15].

Methods

This study includes 11 major muscle groups in each upper extremity (see Tables 1 and 2), Kendall and Kendall MMT testing parameters (isometric strength, proximal resistance, and break test), 180 healthy subjects (90 men and 90 women), and ages of subjects ranging from 20-64 years (10 men and 10 women in each equal 5-year age group).

Subjects

The study included 180 healthy adult volunteers, 90 men and 90 women, aged 20-64 years old. Subjects were recruited from among hospital employees, hospital volunteers, the surrounding community, and local

Table 1
Male strength on the dominant and nondominant side (kilograms)

	Age (y)								
Side	20-24, mean ± SD	25-29, mean ± SD	30-34, mean ± SD	35-39, mean ± SD	40-44, mean ± SD	45-49, mean ± SD	50-54, mean ± SD	55-59, mean ± SD	60-64, mean ± SD
Dominant									
Shoulder flexion	19.6 ± 4.6	22.4 ± 4.7	22.8 ± 5.9	20.0 ± 4.9	23.9 ± 3.9	18.3 ± 4.4	18.6 ± 6.28	20.3 ± 4.6	18.4 ± 3.7
Shoulder extension	14.9 ± 5.0	17.9 ± 3.3	17.9 ± 4.1	19.1 ± 3.6	18.7 ± 4.2	14.1 ± 5.4	14.7 ± 5.3	15.6 ± 3.1	15.6 ± 4.3
Shoulder abduction	15.2 ± 4.5	19.3 ± 3.7	18.3 ± 6.4	14.8 ± 3.7	19.0 ± 4.1	14.7 ± 4.7	16.4 ± 6.4	18.5 ± 5.0	15.1 ± 2.8
Shoulder horizontal abduction	11.2 ± 4.1	12.4 ± 3.9	12.3 ± 4.0	11.2 ± 2.4	13.7 ± 3.0	8.7 ± 3.2	11.4 ± 5.4	11.2 ± 2.1	9.4 ± 2.3
Shoulder horizontal adduction	17.3 ± 6.5	22.8 ± 5.6	22.0 ± 6.6	18.4 ± 6.3	23.6 ± 3.0	16.5 ± 8.2	17.1 ± 5.2	19.2 ± 6.7	19.5 ± 4.5
Shoulder internal rotation	10.117 ± 4.3	11.7 ± 3.7	14.2 ± 5.9	10.5 ± 6.6	15.1 ± 4.3	11.3± 4.9	8.3 ± 3.0	10.7 ± 3.2	11.3 ± 3.7
Shoulder external rotation	10.0 ± 3.1	12.7 ± 2.1	12.4 ± 4.0	10.1± 2.9	12.0 ± 2.6	10.2 ± 3.6	9.0 ± 4.1	11.2 ± 3.3	8.4 ± 2.4
Elbow flexion	26.73 ± 8.2	29.2 ± 6.7	29.7 ± 10.2	29.7 ± 8.9	32.4 ± 7.0	27.5 ± 10.6	29.0 ± 7.6	30.3 ± 9.1	31.5 ± 7.2
Elbow extension	15.55 ± 5.3	19.1 ± 2.6	20.7 ± 6.2	17.7 ± 3.1	20.6 ± 4.2	17.4 ± 6.2	17.6 ± 5.0	21.6 ± 5.5	19.8 ± 3.6
Wrist flexion	14.6 ± 45.0	14.7 ± 4.0	18.8 ± 7.1	15.4 ± 4.5	16.6 ± 5.1	14.7 ± 6.4	13.8 ± 4.0	16.1 ± 2.3	15.3 ± 4.8
Wrist extension	16.7 ± 5.1	18.7 ± 3.11	21.1 ± 4.1	18.2 ± 4.6	20.5 ± 4.7	18.1 ± 7.7	18.8 ± 5.7	19.7 ± 4.8	22.2 ±4.5
Nondominant									
Shoulder flexion	16.7 ± 6.1	19.6 ± 3.4	19.3 ± 5.1	18.2 ± 4.9	20.9 ± 3.2	16.2 ± 4.3	16.7 ± 6.3	17.3 ± 4.9	15.2 ± 4.1
Shoulder extension	12.3 ± 3.7	15.3 ± 3.3	16.0 ± 3.5	15.3 ± 2.6	14.3 ± 2.6	12.3 ± 4.7	13.9 ± 6.4	12.8 ± 3.0	13.3 ± 3.4
Shoulder abduction	13.8 ± 5.2	16.25 ± 2.9	16.8 ± 5.4	13.7 ± 4.3	16.2 ± 4.0	13.1 ± 3.7	14.9 ± 5.6	16.4 ± 5.8	11.5 ± 2.9
Shoulder horizontal abduction	9.8 ± 3.2	10.6 ± 3.1	10.9 ± 3.7	10.7 ± 4.0	11.4 ± 1.9	8.1 ± 4.0	10.7 ± 5.5	9.7 ± 3.1	7.8 ± 3.0
Shoulder horizontal adduction	15.2 ± 6.4	20.7 ± 5.6	20.8 ± 6.0	15.7 ± 5.5	22.4 ± 4.8	15.1 ± 8.9	16.3 ± 5.1	17.3 ± 6.6	15.3 ± 4.3
Shoulder internal rotation	8.0 ± 3.4	9.3 ± 1.8	10.7 ± 4.0	8.6 ± 5.7	11.2 ± 4.6	9.6 ± 4.1	7.8 ± 3.6	8.5 ± 3.8	8.7 ± 3.9
Shoulder external rotation	8.0 ± 3.0	10.8 ± 2.5	11.1 ± 3.7	8.6 ± 3.9	9.8 ± 2.2	8.8 ± 3.4	7.2 ± 7.0	9.2 ± 3.2	6.6 ± 2.7
Elbow flexion	24.3 ± 8.2	27.5 ± 5.9	25.6 ± 9.8	27.5 ± 5.6	28.6 ± 8.1	24.7 ±10.9	26.4 ± 8.6	26.7 ± 10.3	26.8 ± 7.4
Elbow extension	14.3 ± 3.7	15.7 ± 2.8	17.0 ± 5.7	14.1 ± 3.6	18.4 ± 3.4	14.7 ± 5.4	15.0 ± 4.2	17.9 ± 4.0	17.4 ± 3.2
Wrist flexion	13.1 ± 4.7	13.84 ± 4.2	16.2 ± 4.3	15.0 ± 2.5	15.2 ± 7.8	14.1 ± 5.1	13.5 ± 2.9	14.3 ± 3.4	13.6 ± 3.6
Wrist extension	14.6 ± 5.7	17.0 ± 4.2	17.8 ± 3.4	17.0 ± 4.5	17.3 ± 4.6	16.9 ± 5.8	16.3 ± 4.9	16.4 ± 3.4	18.3 ± 3.4

Table 2
Female strength on the dominant and nondominant side (kilograms)

Side	Age (y) 20-24, mean ± SD	25-29, mean ± SD	30-34, mean ± SD	35-39, mean ± SD	40-44, mean ± SD	45-49, mean ± SD	50-54, mean ± SD	55-59, mean ± SD	60-64, mean ± SD
Dominant									
Shoulder flexion	10.3 ± 3.2	9.8 ± 3.5	9.5 ± 2.6	10.4 ± 4.7	11.2 ± 3.6	12.1 ± 3.9	11.0 ± 4.0	9.4 ± 3.5	9.2 ± 2.5
Shoulder extension	9.9 ± 4.2	7.0 ± 2.8	8.5 ± 2.7	8.4 ± 3.7	7.5 ± 3.5	10.6 ± 2.8	7.2 ± 2.6	6.9 ± 3.2	7.2 ± 1.7
Shoulder abduction	9.0 ± 2.1	8.6 ± 3.4	7.5 ± 3.0	8.8 ± 3.5	8.8 ± 3.4	10.3 ± 4.2	7.9 ± 3.7	8.0 ± 2.6	7.8 ± 2.9
Shoulder horizontal abduction	5.8 ± 3.3	4.9 ± 2.8	4.7 ± 2.4	5.4 ± 2.7	4.9 ± 3.2	6.1 ± 2.9	4.8 ± 1.9	5.0 ± 2.	4.4 ± 1.2
Shoulder horizontal adduction	9.7 ± 4.4	8.2 ± 3.4	8.8 ± 4.0	9.1 ± 4.0	9.3 ± 4.1	11.56 ± 4.3	9.21 ± 2.3	9.78 ± 3.6	10.1 ± 3.7
Shoulder internal rotation	5.7 ± 2.4	4.8 ± 2.1	4.5 ± 2.4	4.7 ± 2.4	6.3 ± 2.9	7.0 ± 2.00	5.0 ± 1.6	4.7 ± 2.2	5.9 ± 3.8
Shoulder external rotation	6.3 ± 2.0	6.0 ± 2.3	5.3 ± 2.4	5.7 ± 2.4	5.9 ± 2.7	7.7 ± 2.8	6.1 ± 2.2	5.3 ± 1.8	5.6 ± 2.4
Elbow flexion	16.7 ± 3.6	16.2 ± 5.1	15.4 ± 6.3	16.0 ± 4.0	18.9 ± 6.1	18.9 ± 4.8	15.6 ± 4.0	15.5 ± 6.9	18.4 ± 6.3
Elbow extension	12.6 ± 3.2	10.9 ± 3.2	11.8 ± 4.6	9.7 ± 3.7	12.3 ± 4.1	15.7 ± 3.4	12.2 ± 2.4	12.7 ± 3.4	12.9 ± 2.3
Wrist flexion	10.2 ± 3.4	8.1 ± 2.7	8.9 ± 2.9	9.3 ± 4.1	10.2 ± 2.6	15.4 ± 9.2	9.5 ± 2.4	9.8 ± 3.6	10.4 ± 2.0
Wrist extension	12.8 ± 4.5	9.1 ± 4.0	9.4 ± 4.2	10.4 ± 4.6	11.7 ± 4.1	13.6 ± 4.8	9.9 ± 3.6	11.1 ± 3.8	13.2 ± 2.3
Nondominant									
Shoulder flexion	9.5 ± 2.2	7.8 ± 2.3	7.4 ± 2.8	8.4 ± 4.2	9.4 ± 34.0	9.2 ± 3.2	8.1 ± 3.1	7.33 ± 3.5	6.44 ± 1.8
Shoulder extension	9.2 ± 4.0	5.7 ± 2.6	6.5 ± 2.3	6.9 ± 3.3	6.3 ± 3.3	8.1 ± 3.8	5.7 ± 2.9	5.7 ± 23.0	5.7 ± 1.7
Shoulder abduction	8.8 ± 2.7	7.3 ± 3.3	6.1 ± 2.6	7.4 ± 2.5	7.2 ± 3.4	7.8 ± 3.3	6.9 ± 3.0	6.1 ± 3.0	6.1 ± 2.8
Shoulder horizontal abduction	5.6 ± 2.6	4.0 ± 2.5	3.5 ± 2.1	4.2 ± 1.9	4.2 ± 2.8	5.2 ± 3.1	3.8 ± 1.9	3.6 ± 2.1	3.1 ± 0.9
Shoulder horizontal adduction	8.4 ± 3.4	7.5 ± 3.4	6.7 ± 4.2	8.2 ± 4.1	8.0 ± 4.5	9.1 ± 4.1	7.6 ± 2.4	8.0 ± 3.3	8.7 ± 3.0
Shoulder internal rotation	4.7 ± 2.1	3.4 ± 1.6	4.0 ± 2.6	3.9 ± 1.9	4.4 ± 2.6	5.1 ± 1.9	3.8 ± 1.2	3.8 ± 2.3	4.6 ± 3.3
Shoulder external rotation	5.9 ± 1.5	4.7 ± 1.4	4.0 ± 2.0	4.4 ± 1.8	3.9 ± 2.5	5.7 ± 2.3	3.8 ± 1.5	3.5 ± 1.0	4.4 ± 1.9
Elbow flexion	16.0 ± 3.8	14.7 ± 5.4	14.8 ± 6.4	13.7 ± 3.1	17.6 ± 6.3	18.4 ± 6.5	14.0 ± 4.1	13.0± 5.0	14.7 ± 5.0
Elbow extension	11.8 ± 3.6	9.3 ± 3.1	9.7 ± 4.6	8.6 ± 2.3	9.7 ± 3.5	13.0 ± 3.6	9.1 ± 1.9	10.2 ± 2.9	9.9 ± 1.9
Wrist flexion	8.9 ± 2.5	8.3 ± 3.1	8.1 ± 2.9	8.7 ± 3.6	9.8 ± 3.6	10.9 ± 2.4	8.9 ± 2.6	8.4 ± 3.6	9.1 ± 1.5
Wrist extension	10.8 ± 4.5	7.4 ± 3.8	8.3 ± 3.4	8.9 ± 4.1	9.6 ± 5.4	12.1 ± 5.3	8.7 ± 3.6	9.7 ± 3.6	10.1 ± 2.7

health fairs. Recruitment was via word of mouth, posted bulletins, and study booths at health fairs. No hospital patients were included. Health history questionnaires and direct interviews were conducted to address the subject's occupation and avocational activities and hand dominance. All subjects who provided consent were free of cardiovascular, neurologic, and musculoskeletal disease and free of any upper extremity impairments. Each subject completed the health history questionnaire, informed consent form, and biometric data including age, gender, height, weight, hand dominance, ethnicity, and occupation. Ambidextrous subjects were excluded. For both men and women, selection was into 9 equal age groups (20-24, 25-29, 30-34, 35-39, 40-44, 45-49, 50-54, 55-59, and 60-64 years), with 10 men and 10 women in each age group.

Procedure

Eleven major upper extremity muscle groups were tested bilaterally with the NMMT. All measurements were made in a sitting position. During testing the subjects were seated with proper body alignment on a standard height chair without arm support, and with both feet placed flat on the floor (Figure 1). The evaluation chair was located in front of a wall to stabilize the chair during elbow extension. Published methodology known as the "break test" was used for the testing procedures [12-15]. The subject applies a maximal force that is resisted by the examiner. The "breaking force" is the amount of force required to overcome a maximal effort muscle contraction in order to move the limb from the initial starting position. Two nonresistive training trials were provided for each muscle group to demonstrate to the subjects the positions and specific muscle group contraction that would have the resistance applied. Three measurements of each muscle group were recorded using this technique [12-15]. To ensure maximal isometric strength and to minimize muscle fatigue, the evaluator performed each test by alternating right and left sides. The elbow extensors were evaluated at minus 30° of extension. The evaluator stopped any measurement if there was evidence of fatigue, the subject was attempting to compensate with another muscle groups, the subject changed body posture, or the subject was no longer able to maintain the isometric contraction.

The testing sequence follows the standard muscle testing sequence performed by occupational therapists, proceeding proximal to distal and starting with the dominant side. The order is shoulder flexion, extension, internal rotation, external rotation, abduction, horizontal adduction, and horizontal abduction; elbow flexion and extension; and wrist flexion and extension. Thus 22 muscle groups were recorded for each subject. All testing was performed by one of two experienced registered occupational therapists (authors WVH and LB) who had extensive training and experience using the NMMT.

Results

For this study, 1188 measurements were recorded. This number represents 30 recordings for each of the 11 muscle groups, in each age group, for either gender, and for each side (dominant versus nondominant). A wide range of occupations were represented: nurse, secretary, clerk, hospital aide, occupational therapist, physical therapist, technician, cytologist, student, housekeeper, physician, administrator, engineer, psychologist, biologist, welder, pharmacist, painter, waiter, upholsterer, tutor, handyman, social worker, rehabilitation councilor, vocational rehabilitation specialist, and computer technician. Analysis of avocational activities for the oldest age group (60-64 years) confirmed that 9 of the 10 women and 9 of 10 men regularly participated in exercise activities, which was typical of all age groups. These exercise activities included walking, running, gardening, farming, yard work, aerobics, bicycling, swimming, sailing, dancing, weight lifting, tennis, golf, and basketball. Of the 180 subjects studied, only 4 men and 4 women were left-hand dominant. In these subjects the left-sided data were recorded as the dominant side.

Statistics

A mean and standard deviation were calculated for each of the 396 such sets. These data are presented in Table 1 for men and in Table 2 for women. In addition to providing the raw data for clinical and research reference, analysis of the data was performed to search for strength patterns for each muscle group, per age, per gender, and per side. Statistical analysis revealed that several patterns in the data are of significance. A paired-samples *t*-test was used to compare each set of muscle groups, comparing dominant to nondominant sides, for all age groups and both genders. The dominant side is stronger without exception in both men and women in all age groups ($P = .0001$).

Using results of the one-way analysis of variance between men and women, the strength values are higher in men than in women in all muscle groups and in all age groups ($P = .0001$). Analysis of correlation was undertaken to determine relationships between strength and age. Although variances exist between age groups, there is not a significant pattern of decline in strength with age in men and women, with one exception: such an age-related decline is found in shoulder external rotators in men with age. Age correlates with external rotator strength ($P < .05$). This relationship is negative ($r = -0.23$), demonstrating lower scores in external rotation with age in men. No other relationship with age was significant ($P < .05$).

Figure 2 illustrates the relative strength of each muscle group for men and women. The values illustrated here are presented as a sum value calculated for each muscle group. This sum value was determined by adding the strength measurements of each muscle group, including dominant and nondominant sides, and including all age groups for that muscle group. The pattern of relative muscle group strength is similar for men and women. In both men and women elbow flexors are the strongest, followed by shoulder flexors, then elbow extensors and horizontal shoulder adductors. The weakest groups are the internal rotators and external rotators, namely, the rotator cuff muscles.

Figure 1. Shoulder extension testing.

Discussion

Objective strength measurements of upper extremity muscle groups can be performed using handheld dynamometers such as the NMMT. Without availability of a normative database for such a device, serial measurements of a muscle group over time still has value.

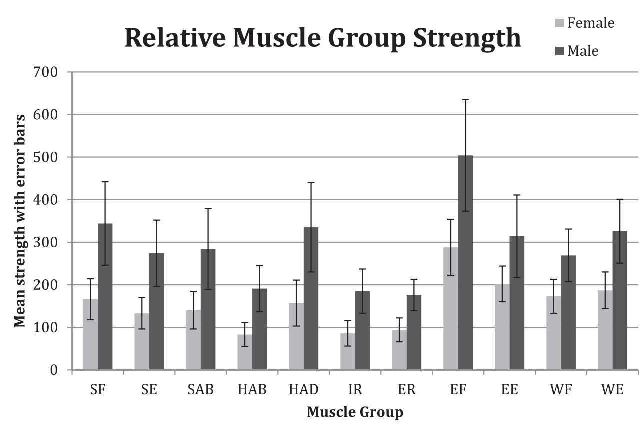

Figure 2. Relative muscle group strength.

However, having normative values specific to that muscle group, gender, age, and hand dominance can provide a more objective view of individual upper extremity muscle group strength at a specific time. This research has provided an initial database for upper extremity strength using the NMMT dynamometer in 11 important functional muscle groups in a wide age range of men and women, including dominant and nondominant sides. Availability of this database could enhance rehabilitation clinicians' assessments with a normative reference tool when objective ordinal data are needed. These data may assist in setting rehabilitation goals and better monitoring progress in patients with upper extremity injuries, disease, or impairments.

Analysis of this data confirms what has generally been previously published: men are stronger than women, and the dominant side is stronger than the nondominant side in men and women. This was the case in all muscle groups and in all age groups. Evaluation of relative strength between the 11 muscle groups revealed that the shoulder horizontal abductors, the internal rotators, and the external rotators were the weakest muscle groups for all genders, age groups, and hand dominance. An unexpected finding was that in these healthy subjects, there was no significant strength decline with age in men or women, with one exception: Strength in the shoulder external rotators declined with age in men.

This study may reflect a selection bias because most subjects who volunteered to participate reported regular participation in exercise (walking, running, gardening, aerobics, swimming, weight lifting, and physically demanding employment). In addition, the study did not include subjects older than 64 years. There were too few left-handed dominant subjects to compare any left-side to right-side dominance patterns.

These data provide the first normative references for the 11 major upper extremity muscle groups tested, but they do not include all upper extremity groups. Pronation and supination measurements are not feasible with this device. Hand-grip strength measurements are already available using the Jamar handheld dynamometer, and normative data have already been published for this device, so those data are not reported here.

Conclusion

The value of this study is the addition of a normative database for upper extremity ordinal strength measurements for one handheld dynometer, the NMMT. These data should add a first step toward a comprehensive normative database for upper extremity objective ordinal strength measurements with the NMMT. This study presents data from 180 healthy, normal subjects, equally divided by gender and age. However, a larger subject sample is recommended to explore other possible findings and relationships in understanding upper extremity strength. Although considerable time and effort was spent in recruiting 180 subjects who fit into 9 age groups, additional studies with larger sample sizes are warranted. However, this study represents a start. The inclusion of subjects younger than 20 years and older than age 64 years should be considered in future studies. Additional studies should include recruitment of a wider range of subjects who are less physically active to reflect the population at large. Normative and comparative data need to be established for other similar clinical devices, and all these data need to be made available for clinical care personnel and researchers. Finally, the need remains for such normative ordinal data for lower extremity and trunk muscle groups. This study of 11 upper extremity muscle groups is perhaps a first step in this process.

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Disclosure

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