AMERICAN SOCIETY OF HAND THERAPISTS™

Grip Strength

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Key Recommendations for Outcome Evaluation of Grip Strength

1. **Maximum grip strength is a core measure in upper extremity rehabilitation; it is used to assess dysfunction and recovery (once it has been determined to be safe and meaningful).**
2. **The tool:**
   a. **Grip strength should be measured using a calibrated dynamometer.**
   b. **The second rung of the classic dynamometer is the recommended handle position. If a different rung is used (e.g., for large hands) it should be noted and justified.**
   c. **The dynamometer's dial should be turned away from the client as no visual or auditory feedback should be provided regarding the score.**
   d. **The examiner should gently support the base of the dynamometer.**
3. **Standard position:**
   a. **The patient should be seated with the arm adducted at the side.**
   b. **The elbow should be flexed to 90°, the forearm should be in midprone (neutral), and the wrist should be positioned at 15-30° of extension (dorsiflexion) and 0-15° of ulnar deviation.**
4. **Procedure:**
   a. **The average of three repeated trials should be used as the test score. An exception is a painful grip, when a single trial may be reliable in some cases.**
   b. **Grip duration should be at least 3 seconds and until the dynamometer's dial drops.**
   c. **A rest period of at least 15 seconds should be provided between grip repetitions, which may be achieved by alternating hands.**
   d. **A practice trial should be given and standard instructions should be used, such as: *"This test will tell me your maximum grip strength. When I say go, grip as hard as you can until I say stop".***
5. **Interpretation:**
   a. **The ideal comparison for grip strength deficit is the uninjured side. Correction for the effect of dominance may be considered, but it is not always appropriate due to variations in dominance across individuals.**
   b. **Norms may also be used for comparison, but they must be based on comparable tools and large samples. Norms should also be stratified for key mediators such as age and gender and when possible for hand size, body size (height and/or weight), and occupational subgroups.**

6. **Variations of grip testing:**
   a. **Variations of standard grip testing can be considered for certain conditions, but the rationale and methods should be clearly documented. For example, pain-free grip strength is not a measure of maximal grip strength but it may be a useful outcome measure for certain conditions.**
   b. **Using grip strength tests to determine sincerity of effort: none of the existing sincerity of effort assessments are reliable or valid. Thus, using grip strength test variants to determine submaximal versus maximal effort is not recommended. When sincerity of effort decisions are necessary, no single test should be used in isolation but rather the tests in the literature should be used in combination with other data and observations about effort. A disclaimer regarding the decision's validity must be made, such as: "Sincerity of effort testing is imprecise and subject to error because reasons for submaximal results are not always intentional. Unintentional submaximal effort may be exerted due to pain, fear of pain, fear of re-injury, and other psychosocial and cognitive factors.**

OVERVIEW OF TESTING

Conceptual Basis for Testing: Grip strength testing measures the force applied by the hand when gripping, which represents the combined strength of the intrinsic and extrinsic muscles of the hand and the interaction between them (1). Grip strength is also a measure of hand function at its most fundamental level (1) as it encompasses all four domains of the International Classification of Functioning, Disability and Health (ICF). While in its most basic definition, i.e., the force applied by hand musculature, grip strength fits into the ICF domain of body function and structure (2). Grip strength scores, however, are heavily influenced by the other three domains of the ICF, namely, activity and participation (e.g., daily and occupational tasks), environmental factors (e.g., body position and time of day), and personal factors (e.g., age and gender) (2).

Tests and Subtypes/variations of Measurement: The maximal grip strength test (MGST) is used to measure grip strength, while some variations of it are aimed at determining sincerity of effort, i.e., whether or not a maximal effort was exerted.

Equipment Required: The Jamar dynamometer, which is manufactured by Sammons Preston, is the most commonly used instrument. Other dynamometers that have good validity and reliability are listed in Table 1.

Thumbnail Summary for Key Standardized Tests

1. **Test Name:** Maximal grip strength test (MGST)
   Purpose: To measure the force applied by the hand during grasping
   Recommended Testing Procedures: When testing for grip strength, a standardized body position should be employed (see "Description of Test Procedures"), the second dynamometer handle position should be used, and the mean of three trials should be recorded in either kilograms or pounds. In addition, the grip duration should be at least 3 seconds and the rest period between repeated grips should be at least 15 seconds.

FULL SUMMARY OF TESTS

Developers

Over the years, grip strength has been assessed by health-care professionals using many different instruments including various types of strain gages, sphygmomanometers, and dynamometers (bulb, spring, hydraulic and digital) (3). The Jamar dynamometer is currently the most commonly used instrument for measuring grip strength in rehabilitation. It was introduced by Bechtol in 1954 (4) and recommended by the California Medical association in 1956 as the most appropriate and accurate instrument for measuring grip strength (5). The Jamar dynamometer is a hydraulic tool with five handle positions, which measures static grip strength in pounds and kilograms of force (6). It is the recommended instrument for testing grip strength by both the American Society for Surgery of the Hand (ASSH) and the American Society of Hand Therapists (ASHT) (3).

Many studies show that the Jamar dynamometer has high instrument reliability and test-retest reliability (7-12). Other commercially available dynamometers have been evaluated for validity and reliability. These include portable hydraulic dynamometers such as Baseline (13) and Rolyan (14), and portable digital dynamometers such as the DynEx dynamometer (11) and different versions of the Jamar digital dynamometer (8, 15). Also, stationary instruments such as the Baltimore Therapeutic Equipment (BTE) grip tool (10, 16) and the Dexter (7) have been studied. Alternative hand-strength measurement tools, which decrease stress on joints and skin, such as sphygmomanometers (9) and vigorimeters

(8) have been evaluated as well (See Table 1).

Construct Being Measured

Grip strength assesses the ability of the hand to exert force while gripping (17) and is a measure of active muscular contraction of both intrinsic and extrinsic hand muscles (1). Although grip strength is used clinically to indicate hand function (1, 3) it is not a true measure of hand function (18-20). One reason is that grip strength is commonly measured isometrically, while most daily activities require dynamic gripping (20). Nevertheless, grip strength is an important parameter of hand function, which often aids in gauging impairment (18-21) and is thus a subjective measure of the integrity of overall upper extremity function (17). Grip strength is used to predict upper extremity function of various patient populations because it is significantly correlated with upper extremity function in people with certain impairments (21-24). Therapists use grip strength scores to determine the need for grip strengthening, establish rehabilitation goals, and monitor therapy interventions (25).

Purpose

Grip strength has been used in the general rehabilitation field as a gross outcome measure (26-28) and to determine disease process (23). Because grip strength is usually proportional to the loss of strength of an injured arm (29), it is used to predict upper extremity function (3, 20-24). Grip strength is commonly assessed during upper extremity rehabilitation, especially in hand therapy and return-to-work clinics. In hand therapy, grip strength scores are used to indicate the extent of injury to the upper extremity (5), to quantify chronic upper extremity disability (30-32) and to determine the progress of the rehabilitation process (33) and the degree of recovery from injury (30). In the return-to-work area, grip strength scores are used to estimate physical work capacity, to assess a person's ability to return to work after injury (31, 34, 35), and to determine the degree of disability, the change in work capacity post-injury, and the amount of worker's compensation award (5, 30-32, 36-38). When a sincere, maximal voluntary effort is exerted, grip strength is a valid indicator of musculoskeletal pathology as well as of the recovery from this pathology (12, 39-43). Thus, some grip strength based tests are commonly used to assess sincerity of effort (43-53).

Grip strength has been significantly correlated with upper extremity function in the elderly and in people with certain impairments (21-24) but not in young, healthy subjects (22, 54). For example, grip strength was found to be a good indicator of hand function in individuals with carpal tunnel syndrome as suggested by the significant correlations between grip strength and both symptom severity and functional status of the hand (21). Thus, grip strength is used to predict upper extremity function in various patient populations. Grip strength is also well correlated with, and is therefore used to assess overall body strength (55). In addition, grip strength is significantly correlated with many health-related variables and as a result, grip strength scores have been used to predict a variety of other health-related measures such as mortality (56), nutritional status (57), post-operative complications (57-59), and anthropometric variables (60-63). Grip strength has significant relationships with mortality and morbidity in patients with serious illnesses (62) and with complications following surgery (24, 57-59). Decreases in grip strength during a disease process may be due to various factors including pain, circulatory alterations, changes in electrolyte and metabolite concentrations, administration of drugs, and decreased motivation (62) as well as malnutrition and protein depletion (59). Since proteins are stored predominantly in skeletal muscle and are mobilized during starvation and stress, muscle protein breakdown may lead to muscle weakness which is expressed as decreased grip strength (59).

Conceptual / Theoretical Basis for the Construct

Grip strength is quick, inexpensive, and easy to measure, and it is also an objective, reliable and valid measurement of hand strength when maximum voluntary effort is exerted (12). Hand function at its most fundamental level may be measured in terms of grip strength (1). Muscle strength evaluation is a central component of any physical assessment and has been used to measure impairment, functional limitation and residual capacity. Further, it has been used to monitor therapy interventions and to establish rehabilitation goals and treatment planning (25).

Grip strength measures the ability of the hand to exert force while grasping (17), using active muscular contraction of both intrinsic and extrinsic hand muscles (1). The major gripping force is exerted by the extrinsic finger flexors, e.g., flexor digitorum superficialis, flexor digitorum profundus, and flexor pollicis longus (64, 65). Forearm extensor muscles are also activated to prevent flexion at the wrist joint (66). The forearm extensors perform a static contraction, holding the wrist in a slight extension, a position which enhances gripping biomechanics by placing the finger flexors in the optimal gripping position. The intrinsic hand muscles contributing to the gripping force include the palmar and dorsal interossei (65), lumbricals (65, 67, 68), thenar muscles (64, 65, 69) and hypothenar muscles (1). Gripping force is reduced at the wider dynamometer handle-settings due to decreased contribution of the intrinsic hand muscles (70).

Grip strength is proportional to height and weight in healthy subjects (6) and is affected by gender and age. Grip strength has a curvilinear relationship with age (71, 72), as it improves from childhood to adolescence, reaches a peak at 20-40 years of age, and declines with advancing age (1, 4, 22, 71-80). Grip strength decline with age is attributed to anthropomorphic factors including decreases in height, weight, lean body mass (54, 60, 63), forearm circumference area (62, 72), hand size (81), and bone density (61) as well as other factors such as decreased physical activity (82, 83), reduced use of handgrip muscles (74), declines in muscle efficiency (72, 76), and diminished capacity of other systems of the body (84). Grip strength is decreased in patients with certain injuries and disorders including fractures, arthritis, ligamentous instabilities, nerve and tendon injuries (such as carpal tunnel syndrome and lateral epicondylitis), congenital abnormalities, neurological disorders, stroke, depression, and dementia (21, 24, 56, 85-89).

Link to ICF

The most basic concept of grip strength testing, i.e., measuring the force of hand musculature while gripping (17), fits into the "body function and structure" domain of the International Classification of Functioning, Disability and Health (ICF). In other words, grip strength is an indicator of the physiological functioning and the integrity of the anatomical structures of the forearm and hand, (both musculoskeletal and nervous systems) (2). A grip strength score, however, is influenced by factors represented by the other three domains of the ICF, namely: activity and participation, environmental factors, and personal factors (2). The ICF defines activity as "execution of a task in a uniform environment" and participation as "involvement in a life situation in the current environment of the individual" (2). Muscle force produced by a hand when gripping is essential for performing everyday and occupational tasks, such as feeding and grooming, exploration of the environment, and earning a living (54). Thus, reduced grip strength would limit a person's ability to perform many work-related and daily activities. In addition, grip scores are influenced by environmental factors which, according to the ICF, constitute the physical, social and attitudinal environment of an individual. In other words, environmental factors such as positioning, time of day, location, and the gender of the evaluator, could affect grip strength scores. Attitudinally, a person may not exert their maximal effort either intentionally (for financial gain) or unintentionally (due to fear of pain). Finally, personal factors such as gender and age affect grip strength; according to the ICF, personal factors determine the background of an individual (2).

Description of Test Procedures

A standardized test-administration procedure is necessary for ensuring the validity and reliability of grip strength testing (90, 91). In 1978, the American Society for Surgery of the Hand (ASSH) recommended standardization of testing procedures with the Jamar dynamometer, which included using the second handle position and measuring three successive trials (92). In 1981, the American Society of Hand Therapists (ASHT) adopted these recommendations but added recommendations for the body posture and dynamometer positioning (93). An excellent historical overview of the attempts to standardized grip strength testing is provided by Fess in the previous ASHT Clinical Assessment Recommendations book (3). Other recommendations that were not previously addressed by the ASHT (3) are suggested in this current edition. Included are recommendations about the duration of the grip contraction, allowing a rest interval, familiarizing the client with the test before administering it, correcting the client's position as needed, avoiding muscle substitution, and not providing feedback to the client about the test scores.

Application/administration Procedures

Tools: The most commonly used tool for measuring grip strength is the Jamar dynamometer. Other reliable and valid tools are presented in Table 1.

Positioning: this section is divided into two: the positioning of the person being tested and the positioning of the dynamometer, both of which are featured in Figure 1.

Positioning of the person being tested:

- As previously recommended by ASHT, the client should be in a seated position (not a standing position) (3, 93).
- The client should be comfortably seated in a chair without arm rests, with feet fully resting on the floor, hips as far back in the chair as possible, and the hips and knees positioned at approximately 90° (10, 11).
- The gripping arm should be in the following position: the shoulder adducted, the elbow flexed at 90°, and the forearm and wrist in a neutral position (3, 93).
- The wrist should be positioned between 0° and 30° of extension (dorsiflexion) and between 0° and 15° of ulnar deviation (3, 93). The varied ranges are recommended due to a controversy in related literature regarding wrist posture (12, 93-96).
- To avoid muscle substitution patterns and ensure shoulder adduction, it is recommended that clients hold a small block between the upper arm of the gripping hand and the lateral thorax (47, 48).

- During testing, clients should be reminded to maintain their position and should be corrected as needed (42, 43).

Positioning of the dynamometer:

- The second dynamometer handle position should be used (3, 92, 93).
- The dynamometer should be placed in the client's hand by the examiner, who should gently support the base of the instrument to prevent accidental dropping (3).
- Grip force should be applied smoothly, without rapid wrenching or jerking motion (3).
- No visual or auditory feedback should be provided; thus, the dynamometer's dial should be turned away from the client so that they cannot see the display (11).

Instructions: As instructions influence performance on evaluation tests(97), standardized instructions have been used in research studies examining reliability and validity of grip strength testing (10-12). The ASHT had recommended the use of standardized testing instructions but has not previously provided specific instructions, with the exception of instructing the client to maximally grip the handle of the dynamometer (3). To ensure consistency, clients should not be coached or encouraged during grip testing and only standardized verbal directions should be given (11). Thus, the examiner should provide appropriate verbal instruction (12). Standardized instructions that are suggested are: "This test will tell me your maximum grip strength. When I say go, grip as hard as you can until I say stop. Before each trial, I will ask you 'Are you ready?' and then tell you 'Go'. Stop immediately if you experience any unusual pain or discomfort at any point during testing. Do you have any questions? Are you ready? Go!" (11). Then, as the client begins to squeeze, the examiner should say: "Harder... harder… harder…Relax" (12). The examiner should tell the client to relax when the dial of the dynamometer levels off and starts to drop, after approximately 3-5 seconds of gripping (42).

Test Procedures: The ASHT and ASSH recommend that the mean of three trials be recorded in either kilograms or pounds, and that a standardized body position be employed (3, 92, 93). In addition, it is recommended that the client be familiarized with the test procedure by viewing a demonstration by the examiner and then given at least one practice trial (11). Prior to the practice trial, the examiner should instruct the client regarding proper breathing techniques, i.e., exhalation during grip exertion. Standardized instructions need to be followed. Finally, it is recommended that grip duration should be at least 3 seconds and that a rest period of at least 15 seconds is allowed between grip repetitions (98, 99).

Scoring: The grip strength score is recorded directly from the dynamometer's dial in either kilograms or pounds; it is recommended that the average of three repeated trials be used as the actual grip test score (3, 92, 93).

Interpretation: Grip strength scores of an injured extremity are interpreted by comparing them either to pre-treatment scores or to normative data. Studies providing normative data on grip strength are summarized in Tables 2-4. Injured hands have also been compared to uninjured using the 10% rule (3), which states that grip strength is 10% greater for the dominant hand than the non-dominant hand (4, 78, 100). Multiple studies, however, have challenged the 10% rule (18, 77, 101). It appears that the 10% rule applies to most right-handed people but not to left-handed people; the majority of left-handed people were found to have equal strength in both hands (18). Thus, it is recommended that when setting treatment goals for left-handed patients, clinicians should consider both hands to be equivalent in strength or use normative data (33).

GROUPS WHO CAN BE TESTED

Grip strength testing is one of the pillars of hand therapy assessments and almost all upper extremity patient groups can be tested. Grip strength scores of patients are usually compared to norms. Normative data are developed to describe a characteristic of a particular population and to provide objective data for comparing an individual to a representative population (6). Normative values are needed for therapists to interpret evaluation data and are used for predicting future performance (102), setting treatment goals in rehabilitation (103), as well as monitoring progress and determining treatment outcomes (104). For a research study to establish norms, it must have a large representative sample of the population of interest (102). The individual client who is compared to these normative values should closely match the population from which the norms have been developed (6). Grip strength norms have been developed for specific age groups and specific patient populations.

Summary of Normative/ comparative Data Available

Age specific grip strength norms have been developed for children (105, 106), college-age men and women (100, 107), adults (24, 75, 77, 78, 80, 84, 105, 108-137), and older adults (80, 84, 103, 138) and are summarized in Tables 2-4. The norms developed for various patient populations include people with arthritis (85, 87), lateral epicondylitis (131), dementia

(56), stroke (24) and children with myelomeningocele (139). Other normative data exists for specific groups such as residents of various countries (24, 75, 77, 78, 80, 84, 105, 108-137), workers in various occupations (140-142), and athletes (83).

Measurement Properties

Reliability and Validity: The Jamar dynamometer has face validity because its hydraulic nature permits the direct measurement of force rather than pressure (3). It also shows high test-retest reliability for measurement of actual grip strength (7-12) and of known weights (5, 11, 13, 14, 143). Correlation coefficients for calibration of the Jamar dynamometer with known weights have been reported to be above 0.9994 (5, 11, 13, 14, 143). Thus, the Jamar dynamometer is currently regarded as the "gold standard" for grip strength measurement (10) and has been used by many researchers as a criterion for validating other instruments (Table 1).

Responsiveness: To be validly used as an outcome measure, grip strength must be responsive, i.e., be able to detect clinically meaningful changes over time (144), so that therapists can examine the effect of their treatment. When a measure such as grip strength is recorded both before and after an intervention session, responsiveness is calculated as the change in grip strength from pre- to post-therapy, or "change scores." Two statistical methods commonly used to calculate responsiveness are standardized response mean (SRM) and effect size (ES) (145, 146). Larger coefficients indicate greater responsiveness, i.e., greater differences between pre- and post-therapy grip strength scores. Responsiveness has been examined for detecting changes in grip strength with surgical, rehabilitative, and pharmacological interventions for various musculoskeletal conditions such as rheumatoid arthritis (147-154), carpal tunnel syndrome (155-162), and upper extremity fractures (163, 164). Responsiveness of grip strength has been compared to other measures of impairment (165) or to different measures of functional performance, such as the Disabilities of Arm, Shoulder and Hand (DASH) (157, 160, 162), the Michigan Hand Outcomes Questionnaire (MHQ) (150, 164), and the Patient Evaluation Measure (PEM) (156, 163). Table 5 summarizes the responsiveness estimates of grip strength for various health conditions.

FACTORS THAT MAY COMPROMISE TEST RESULTS

Many factors affect grip strength scores including the handle position of the dynamometer, body position, time of day, examiner experience, lack of understanding of instructions (due to cognitive impairments or language differences), and whether or not a person is exerting maximal effort. The major factors that compromise test results include: not calibrating the dynamometer (3, 143), not following a standardized test-administration protocol (3, 90, 166), and a client not exerting maximal effort (43-47, 49, 167). Grip strength test scores are some of the most reliable and valid data available to clinicians when the testing equipment (e.g., dynamometer) is calibrated and maintained (90) and when a standardized test-administration protocol is adhered to carefully (3, 90, 166).

A grip strength measurement is objective, reliable and valid only when a patient exerts a maximal voluntary effort (12, 39, 41-43, 50). Thus, sincerity of effort is a basic premise of grip strength. People with hand and upper extremity injuries may exert less than a maximal voluntary contraction (MVC) during evaluation and treatment for a variety of reasons, either intentional or unintentional. Unintentional submaximal effort may be exerted due to pain, fear of pain, or fear of re-injury (168-170) while intentional submaximal effort may be exerted for a secondary gain of money, benefits, or even attention (171-174). Exerting submaximal efforts intentionally, for secondary gain, is termed malingering or disability exaggeration, and is reported to occur in at least 1 out of 4 cases of worker's compensation, disability claims, or personal injury litigation (172). In addition, a patient cannot be effectively rehabilitated without putting forth full effort. Thus, there is a need for a valid and reliable method to determine sincerity of effort of grip strength testing.

Several methods have been developed by researchers attempting to determine if an individual exerted a maximal effort during grip strength testing. Currently, however, there are no reliable, valid and widely accepted sincerity of effort assessments. The physiological basis for many sincerity of effort assessments is the motor unit recruitment model. This model proposes that repeated maximal muscular contractions necessitate a simple motor control strategy, which consists of recruiting all motor units to fire at a maximal frequency. On the other hand, repeated submaximal contractions require grading of muscular contractions with a greater degree of motor control, constant corrections of motor signals, and constant and precise proprioceptive feedback, thus demanding greater cortical attention (42, 48, 175).

The methods devised for detecting sincerity of effort may be grouped under one of two strategies. The first is to examine certain aspects of the maximal static grip test (MSGT) and the other is to modify it. Methods used to examine aspects of the MSGT include the force-time curve (50, 175-177) electromyographic (EMG) properties (178, 179) and measures of variation (36, 37, 177) such as the coefficient of variation

(46-48, 180, 181). Methods that modify the MSGT include the five-rung test (44, 49, 55, 182-186), the rapid exchange grip test (19, 39, 42, 43, 52, 168, 187-190), and a combination of multiple grip tests (29, 39). Various combinations of the these two strategies have also been examined (37, 191).

Another way of categorizing sincerity of effort tests is according to their suitability for use in the clinic (192). Sincerity of effort assessments may be unsuitable for clinical use due to their complexity, specialized or expensive equipment, and complicated calculations (192). These include inspecting the electromyographic (EMG) nature of maximal versus submaximal grip (178, 179), examining various characteristics of the force-time curve (50, 175-177), and investigating the linearity of the torque-velocity curve, which showed greater linearity for maximal than submaximal efforts (192). None of these methods, however, is widely used or accepted due to reasons ranging from lack of availability to inadequate empirical evidence and methodological concerns.

Sincerity of effort tests are appropriate for the clinical use when they are simple, brief, affordable, and easy to administer and interpret (192). The three sincerity of effort tests most commonly used in the clinic are the five rung grip test (5R) (44, 49, 55, 182-186), the rapid exchange grip test (REG) (19, 39, 42, 43, 52, 168, 187-190) and the coefficient of variation (CV) (36, 45-48, 180, 181, 191, 193-195). Controversy exists in the literature concerning the ability of these clinically used tests to detect sincerity of effort. These three tests lack standardized administration and interpretation protocols (52, 190), reliability, validity, and adequate sensitivity and specificity values (43, 44, 47). All three tests are reported to have low sensitivity, as they misclassify 30-45% of people exerting submaximal effort as exerting maximal effort and low specificity, as they misclassify 28-36% of people exerting maximal effort as exerting submaximal effort (43, 44, 47). These high error rates deem the three clinical sincerity of effort tests inadequate for detecting submaximal or feigned effort in patients with upper extremity injury.

The clinical implications of ineffective tests, which possess insufficient sensitivity and specificity values, are serious. Low sensitivity may result in misclassifying a submaximal effort as maximal and consequently mistakenly labeling feigning individuals as sincere. This error can lead to seemingly ineffective treatment, increased unnecessary procedures, and elevated disability and health care costs (15). Low specificity may result in misclassifying a maximal effort as submaximal and consequently erroneously labeling sincere individuals as insincere. This mistake can lead to inappropriate diagnosis and treatment, reduced workers' compensation settlement, withheld payments and even job loss (16,17). Unfairly misclassifying a sincere subject as feigning can be damaging to the individual and may promote clinically unfair decisions (11).

Clearly, there is a need to find a test that would effectively identify full versus low efforts. Such a tool may assist in reducing the costs of misdiagnosis, rehabilitation, medical procedures, lost work-time, and lost productivity, and thus may be of great value to society. Such a tool will be of benefit to rehabilitation specialists (occupational and physical therapists), insurance companies, worker compensation authorities, employers, and the workers themselves. Unfortunately, such a tool does not yet exist.

List of Tools for Sincerity of Effort Testing

Existing sincerity of effort tests, which are commonly used in the clinic, namely the five rung grip test, the rapid exchange grip test and the coefficient of variation, lack standardized testing protocols, reliability and validity values, and empirical support. Their administration procedures and interpretation protocols, however, appear in the literature and are therefore described below.

The five-rung test: In 1983, Stokes proposed a test for detecting sincerity of effort of grip strength using the five-handle position Jamar dynamometer (14). The five-handle position grip strength test (the five-rung test) involves gripping the Jamar dynamometer at the five available handle positions, starting at the narrowest (position 1) and ending at the widest (position 5). Then, a graph is plotted with the handle position on the X-axis and the gripping force on the Y-axis. The author stated (without providing empirical evidence) that a plot generated by a sincere effort would produce a skewed, bell-shaped curve while a plot generated by a feigned effort would produce a straight line (14). Other researchers have proposed more sophisticated methods for analyzing the shape of the curve (44, 49, 55, 182-186) than the above visual analysis (14). Yet, the ability of this test to actually detect sincerity of effort remains questionable, regardless of the method utilized to analyze the shape of the curve.

The rapid exchange grip test (REG): This test was first introduced in 1984 in a book by Lister (188). The REG test involves gripping the dynamometer while alternating hands rapidly and then comparing grip scores of the rapid gripping to the scores of a slow grip (SG) test. The REG is considered "positive" when rapid grip scores are greater than static grip scores (REG>SG), indicating a submaximal effort. Conversely, the REG is considered "negative" when rapid grip scores are less than static grip scores (SG>REG), indicating a maximal effort. The physiological premise of the REG is that the rapid exchange of hands decreases the amount of time available for the cortex to compare between grip contractions and as a result the strong hand becomes weaker while the weak (faking) hand becomes stronger. Thus, when feigning weakness, REG scores are greater than slow grip scores (19, 42, 168, 187). Empirical testing of the effectiveness of the REG in detecting sincerity of effort yielded conflicting findings due to methodological differences among research studies. It is difficult to compare and contrast these findings because the various studies utilize different administration and interpretation protocols (19, 39, 42, 43, 52, 168, 187-190). The most common differences in testing protocols include subject positioning, dynamometer handling, the number of grips performed, and most importantly, the switch rate of the rapidly alternating hands (42). It is not surprising that currently there is no standardized administration and interpretation protocol for the REG test among therapists, as the wide variety of administration and interpretation protocols used in the literature is reflected in clinical practice (52, 190).

The coefficient of variation (CV): The CV is a measure of the variability of three or more grip strength repetitions expressed as a percent (it is calculated by dividing the standard deviation by the mean of those grip trials and multiplying this value by 100) (45, 46, 91, 181). The premise of the CV is based on the motor unit recruitment model (42, 48, 175), in which a fake, submaximal effort shows more variability and less consistency in repeated trials than a maximal effort. Thus, a greater CV value indicates greater variability (smaller consistency) of repeated grip strength trials. When using the CV to identify sincerity of effort, a cutoff value is established, above which efforts are considered inconsistent enough to be submaximal (45-48, 180, 181). The cutoff value ranges widely in the literature, from 7.5%-20% (45-48, 180, 181, 193, 194, 196). Thus, it is not surprising that there is a controversy regarding the validity and effectiveness of the CV as a measure of sincerity of effort (36, 45-48, 180, 181, 191, 193-196). A study performing a meta-analysis on the CV, showed that the CV of grip strength possesses both low stability (r = 0.024 - 0.25) rendering it unreliable and low sensitivity (misclassifying 22% to 69% of submaximal effort as maximal depending on the cutoff value) rendering it ineffective (181).

Combination of tests: Despite the lack of evidence to support the use of these three tests for detecting sincerity of effort, therapists report combining them in an attempt to identify submaximal effort (52, 190). The practice of combining sincerity of effort tests to predict submaximal effort, however, is not well researched. Two studies that used different combinations of tests to predict sincerity of effort demonstrated that combining the tests improved the ability to detect submaximal effort (37, 39). The statistical methods used in these studies, however, have their limitations; thus, more research is needed to show if combining sincerity of effort tests is acceptable.

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Table 1: Validity and reliability values of various grip strength instruments

Instrument	Author, Year	Participants	Concurrent Validity with the Jamar	Test-retest Reliability
Baseline dynamometer	Mathiowetz et al., 2000 (13)	Healthy subjects, n=80	r>0.94	r>0.9994
BTE Work-Simulator grip tool	Beaton et al., 1995(16)	Healthy subjects, n=14	r=0.87	--
BTE-Primus grip tool	Shechtman et al.(10)	Healthy subjects, n=180	r> 0.95	r> 0.97
Dexter dynamometer	Bellace et al., 2000(7)	Healthy subjects, n=70	r>0.98	-
	Brown et al., 2000(197)	Patients with hand injury, n=30	--	r>0.86
DynEx dynamometer	Shechtman et al., 2005(11)	Healthy subjects, n=100	r>0.98	r=0.986
Rolyan dynamometer	Mathiowetz et al., 2002(14)	Healthy subjects, n=30	r> 0.90	--
Sphygmomanometer	Agnew & Maas, 1991 (87)	Patients with rheumatoid arthritis, n=88	r>0.83	--
	Hamilton et al., 1992(9)	Healthy college-aged females; n=29	r=0.75	r=0.85
Vigorimeter	Fike and Rousseau, 1982(8)	Healthy subjects, n=486	r=0.60	--

Table 2. Summary of normative grip strength data for pediatric populations

Author and Year	Population	Age (years)	Sample size (*n*)	Country	Instrument
Ager et. al. (1984)(105)	Healthy	5-12	474	USA	Jamar dynamometer
Backman & Daniels (1996) (108)	Healthy	6-11	134	Canada	Martin Vigorimeter
Bowman et. al. (1984)(198)	Healthy	6-9	153	USA	Jamar dynamometer
Dunn et. al. (1993)(199)	Healthy vs. rheumatic disorders	3-7	273	USA	Sphygmomanometer
Fullwood et. al. (1986)(109)	Healthy	5-12	214	Australia	Jamar dynamometer
Hager-Ross et. al. (2002)(110)	Healthy	4-16	530	Sweden	Grippit
Holm et. al. (2008)(111)	Healthy	7-12	376	Norway	Jamar dynamometer
Link et. al. (1995)(200)	Healthy	3-6	231	USA	Martin Vigorimeter
Marrodan et. al. (2009)(112)	Healthy	6-18	2125	Spain	Digital dynamometer
Mathiowetz et. al. (1986)(106)	Healthy	6-19	471	USA	Jamar dynamometer
Molenaar et. al. (2010)(113)	Healthy	4-12	225	Netherlands	Lode dynamometer
Montpetit et. al. (2003)(201)	Osteogenesis imperfecta	7.3-15.9	42	Canada	Jamar dynamometer
Newman et. al. (1984)(114)	Healthy	5-18	1417	Australia	Strain gauge dynamometer
Robertson et. al. (1988)(202)	Healthy	3-5.5	380	USA	Martin Vigorimeter
Yim et. al. (2003)(115)	Healthy	7-12	712	Korea	Jamar dynamometer

Table 3. Summary of normative grip strength data of healthy and patient adult populations

Author and Year	Population	*n*	Age (years)	Country	Instrument
Agnew & Mass (1982)(116)	Healthy	383	16-90	Australia	Jamar dynamometer
Agnew & Mass (1991)(87)	Rheumatoid arthritis	88	25-65	Australia	Jamar dynamometer and sphygmomanometer
Amosun et. al. (1995)(117)	Healthy	204	18-56	Zimbabwe	Jamar dynamometer
Angst et. al. (2010)(118)	Healthy	978	18-85	Switzerland	Jamar dynamometer
Balogun et. al. (1991)(119)	Healthy	960	7-84	Nigeria	Harpenden dynamometer
Chen et. al. (2007)(203)	Multiple Sclerosis	44	34-68	USA	Jamar dynamometer
Crosby et. al. (1994)(18)	Healthy	214	16-63	USA	Jamar dynamometer
Fike & Rousseau (1982)(8)	Healthy	486	16-79	USA	Jamar dynamometer and Vigorimeter
Fraser et. al. (1983)(121)	Healthy	120	20-79	England	Vigorimeter
Frederiksen et. al. (2006)(120)	Healthy	8342	46-102	Denmark	Smedley dynamometer
Gilbertson et. al. (1994)(122)	Healthy	260	15-92	England	Jamar dynamometer
Gunther et. al. (2008)(123)	Healthy	769	20-100	Germany	Baseline digital dynamometer
Harkonen et. al. (1993)(124)	Healthy	204	19-62	Finland	Jamar dynamometer
Kunelius et. al. (2007)(125)	Automotive workers	161	18-63	Australia	Jamar dynamometer
Massy-Westropp et. al. (2004)(126)	Healthy	476	18-97	Australia	Jamar and Grippit dynamometers
Mathiowetz et. al. (1985)(77)	Healthy	638	20-75 plus	USA	Jamar dynamometer
Meldrum et. al. (2007)(127)	Healthy	494	20-76	Ireland	Digital Jamar dynamometer
	Post-polio	44			
Merlini et. al. (2004)(128)	Spinal muscular atrophy	120	5-60	Italy	Type CT 3001
Mroszczyk-McDonald et. al. (2007)(204)	Coronary heart disease	1960	27-92	USA	Jamar dynamometer
Myers et. al. (1980)(85)	Healthy	20	32-74	USA	Electronic dynamometer
	Rheumatoid arthritis	30			
O'Connell et. al. (2006)(205)	Special Olympians	104	20-59	USA	Jamar dynamometer
Puh (2010)(129)	Healthy	199	20-79	Slovenia	Baseline dynamometer
Reed et. al. (1991)(206)	Healthy	344	59-70	USA	Adapted dynamometer
Sandler et. al. (1991)(207)	Healthy women	620	25-73	USA	TEC Grip dynamometer
Soer et. al. (2009)(130)	Healthy workers	701	20-60	Netherlands	Jamar dynamometer
Stratford et. al. (1989)(131)	Lateral epicondylitis	35	44.5	Canada	Smedley dynamometer
Sunderland et. al. (1989)(24)	Stroke patients	38	31-82	England	Digital Pinch/Grip Analyzer
Thorngren & Werner (1979)(208)	Healthy	450	21-65	Sweden	Martin Vigorimeter
Vianna et. al.(2007)(132)	Healthy	2648	18-90	Brazil	Digital Grip dynamometer
Werle et. al. (2009)(133)	Healthy	1023	18-96	Switzerland	Jamar dynamometer
Wu et. al. (2009)(134)	Healthy	482	20-80	Taiwan	Jamar dynamometer

Table 4. Summary of normative grip strength data of older adults

Author and Year	Population	n	Age (years)	Country	Instrument
Brennan et. al. (2004)(209)	Well elders	113	60-90	USA	Jamar dynamometer
Desrosiers et al. (1995)(84)	Well elders	360	60-80 plus	Canada	Jamar dynamometer
Fiebert et al. (1995)(135)	Well elders	48	61-85	USA	Jamar dynamometer
Horowitz et al. (1997)(103)	Well elders	178	64 and older	USA	Jamar dynamometer
Jansen et. al. (2008)(136)	Well elders	224	65-85 plus	USA	Jamar dynamometer
Shechtman et. al. (2004)(80)	Frail elders	654	60-80 plus	USA	Jamar dynamometer
Slatkowsky-Christensen et. al. (2007)(137)	Healthy	144	50-70	Norway	Jamar dynamometer
	Rheumatoid arthritis	194			
	Hand osteoarthritis	190			

Table 5. Summary of Grip Strength Responsiveness Estimates

Population	Author	Intervention	Responsiveness Statistics SRM	ES
Rheumatoid Arthritis	Adams et. al. (2010)(147)	Disease modifying antirheumatic drugs	0.40-0.45	0.27-0.32
	Buchbinder et. al. (1995)(148)	Cyclosporine vs. placebo	--	0.52
	Escalante et. al. (2004)(149)	Not described	--	0.55
	van der Giesen et. al. (2008)(150)	Conservative and/or surgical treatment	0.46	0.32
	Lefevre-Colau et. al.(2001)(151)	Surgery of the wrist and/or fingers	0.32-0.53	0.36-0.37
	Lefevre-Colau et. al.(2003)(152)	Surgery of the wrist and/or fingers	0.36	0.43
	Sandqvist et. al. (2009)(153)	Hand surgery and post-surgical occupational therapy	0.2-0.80	--
	Verhoef et. al. (2008)(154)	Multidisciplinary treatment consisting of disease modifying antirheumatic drugs, anti-inflammatory drugs, and rehabilitation	0.55-0.57	0.31
Median / Ulnar nerve injury	Rosen et. al. (2000)(165)	Nerve repair	--	0.44-2.80
Carpal Tunnel Syndrome	Dias et. al. (2004) (155)	Carpal Tunnel release surgery	--	0.06 - 0.22
	Hobby et. al. (2010)(156)	Carpal Tunnel release surgery	0.32	0.30
	Imaeda et. al. (2006)(157)	Carpal Tunnel release surgery	0.17	0.08
	Itsubo et. al. (2009)(162)	Carpal Tunnel release surgery	0.076	0.044
	Katz et. al. (1994)(158)	Non-operative therapy consisting of wrist splints and corticosteroid injection	0.25	0.20
	Nakamichi et. al. (1997) (159)	Carpal Tunnel release surgery	--	0.43 - 1.69
	Rosales et. al. (2009)(160)	Carpal Tunnel release surgery	0.25	0.15
	Uchiyama et. al. (2007)(161)	Carpal Tunnel release surgery	0.26	0.17
Upper extremity fractures	Dias et. al. (2001)(163)	Receiving treatment for acute scaphoid fractures	1.30 - 1.32	1.16 - 1.63
	Kotsis et. al. (2007)(164)	Volar locking plating system for distal radial fractures	0.80 - 1.00	--
Guillain-Barré Syndrome	Merkies et. al. (2000)(210)	Immunoglobulins and prednisone	0.8 - 1.3	
	Merkies et. al. (2003)(211)	Immunoglobulins and prednisone	0.90 - 1.05	1.05 to 1.13
Stroke	Beebe and Lang, (2009)(212)	Standard stroke rehabilitation	--	0.50 to0.65

Figure 1. Position for grip strength testing.

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