

## APPENDIX A

Title: A literature review of the effect of handedness on isometric grip strength differences of the left and right hands.

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### Abstract

When estimating pre-injury grip strength for compensation and rehabilitation purposes, two methods have been identified in the literature: (a) comparison with the unaffected hand, and (b) reference to grip strength normative data. The literature is divided about whether a significant difference exists between the grip strengths of an individual's two healthy hands. Some researchers argue that handedness affects the grip strength ratio. According to these authors, there is considerable variation in the definition of handedness, its effect on grip strength ratios, and the methods of assessing handedness as it relates to grip strength. The complexity of defining and accurately evaluating handedness is discussed in this literature review. Inappropriateness of the current use of self-report questionnaires for determining handedness for grip strength purposes is highlighted. The impact of the effect of handedness on grip strength ratios cannot be clarified until a consistent definition and evaluation method for assessing handedness is developed. This handedness definition then needs to be applied to appropriately designed hand grip strength studies.

In a sample of U.S. hospital emergency departments between 1992 and 1995, 23.9% of all injuries with the principle diagnoses of fracture, sprain, strain or open wound were located in the hands and wrists (Burt & Fingerhut, 1998). Over this period, these types of hand and wrist injuries accounted for 11.5% of the total emergency visits. In a sample of accident and emergency departments in southeast Queensland, Australia, in 1997, 24% of all the injuries were to the hands and wrists (E. Miles, personal communication, June 25, 1998). Many of these injured persons were referred to occupational therapists for hand rehabilitation programs. A need exists to evaluate objectively the effectiveness of the chosen treatment methods in these programs in order to deliver optimal care, discontinue services only when appropriate, provide useful medico-legal evaluations, and justify the cost of services to third party payers. Objective evaluation requires accurate evaluation of handedness and grip strength. The purpose of this literature review is to examine the extent of the effect a person's handedness has on the grip strength ratio, between their left and right hands.

### Methods for determining grip strength

Grip strength has been measured in a number of ways. Isotonically, it has been measured with vigorimeters or rolled sphygmomanometer cuffs (American Medical Association [AMA], 1993; Bohannon, 1991). The use of isometric strain gauges has been the preferred method, because of their superior reliability (Bohannon, 1991; Fairfax, Balnave & Adams, 1995).

Over the last 4 decades, various designs for isometric strain gauges have been developed (Bassey, Dudley & Harries, 1986; Hunsicker & Donnelly, 1955; Pearn & Bullock, 1979). The Jamar or Jamar-like dynamometers (JLD) are readily available and have become the most commonly used in both clinical and research settings (Bohannon, 1991; Smith & Bengel, 1985). The American Society of Hand Therapists (ASHT, 1992) and AMA (1993) have recommended the use of JLD to assess grip strength. For ease of comparison of studies and the previously described reasons, the discussion in this literature review is limited to an examination of grip strength research that has used JLD, to determine whether hand dominance has an effect on the grip strength performance of the left and right hands.

JLD consist of two parallel handles adjustable to five static handle positions, with a sealed hydraulic system that measures the amount of force applied to the handles. Analog, digital and computer-linked versions are currently available. From 1954 to 1999, more than twenty studies were published that advanced normative data using these dynamometers. These studies are critiqued within this review.

For loss of grip strength estimations, ASHT (1992) recommended comparison of grip strength scores with the contralateral hand or longitudinal comparison with earlier values for each patient. The ASHT does not recommend comparison with existing normative databases that have used JLD, because of weaknesses in the research designs of the normative studies.

The AMA agrees with ASHT and its *Guides to the Evaluation of Permanent Impairment* (4<sup>th</sup> edition; AMA, 1993) recommend comparison with the uninjured contralateral hand when only one hand has been injured. The *Guides* state that one hand's expected grip strength can be determined by the grip strength of the unaffected hand because pre-morbidly "little evidence exists that there is significant difference in grip strength between the dominant and non-dominant hand" (p.65). The *Guides* further recommend comparing a person's loss of hand strength to the *Guides*' normative database when bilateral hand injuries are present, which is in contrast to ASHT's discouragement of the use of the current normative databases. The *Guides* database was adapted from Swanson, Matev and DeGroot's (1970) research. These *Guides* are currently used by many legal and insurance

companies in Australia and the United States as a means of assessing upper -limb impairment (AMA, 1993; Le Leu & Shanahan, 1994; Streeton, 1994).

The concept that no significant difference exists between the grip strengths of the left and right hands for all persons is negated by many studies, such as Crosby and Wehbe (1994), who found that left-handed research participants had a grip strength ratio (expressed as a percentage difference) of up to 40% between their two healthy hands. The grip strength ratio can be calculated by dividing the grip strength value (measured in kilograms force, pounds force, or newtons) of one hand by that of the other hand. Some researchers found that among dextralists (right-hand dominant people) and sinistralists (left-hand dominant people), a wide range of grip strength differences exist between the dominant and the non-dominant hand (Balogun & Onigbinde, 1992; Bechtol, 1954).

To examine the effect of handedness on the grip strength ratio of the two hands, the dominant hand must first be identified. Thus hand dominance, or handedness, needs to be defined and assessed.

### **Defining handedness**

Handedness can be viewed from three different aspects: (a) the relative *preference* for one hand in the execution of various unimanual tasks (Annett, 1970; Peters, 1998); (b) the greater *skillfulness* of one hand in the performance of these tasks (Annett, 1970; Peters, 1998); or (c) the greater *strength* of one hand (Bowman & Katz, 1984; Chau et al., 1997). Thus, depending on the specific definition, the dominant hand may not always be the preferred hand for performing certain tasks such as writing; the most skillful or dexterous hand (Mathiowetz, Wiemer & Federman, 1986); or the strongest hand (Crosby & Wehbe, 1994; Hanten et al., 1999). The dominant hand is also not necessarily the steadiest (Simon, 1964).

When handedness is viewed as a collective of all these aspects, it is multidimensional. It could be argued [by the authors] that if handedness is considered in this manner, aspects of handedness need to be studied separately because, for example, as a weak left -hander in one aspect could be a strong right hander in a different aspect. One single-aspect approach is to classify persons into degrees of hand preference for specific tasks.

Hand preference distribution in humans is J shaped; the majority of people can be classified as preferring to use their right hand for various common tasks, and the minority as preferring to use their left hand. This differentiation is established in right-handed children between 5 and 7 years of age and in left-handed children by 9 years of age (Mandell, Nelson & Cormack, 1984).

Handedness, meaning the hand preferred for performing certain unimanual tasks, is a popular way of defining hand dominance. However, the number and nature of the items in a handedness inventory needed to determine handedness validly and reliably is central to operationalising this definition.

Handedness preferences lie along a continuum from people who are consistently left handed for all one-handed tasks, to people who are consistently right handed for these same tasks (Annett, 1970; Hardyck & Petrinovich, 1977). Thus the terms “degrees of laterality” or “degrees of handedness” have been coined. Within this continuum, mixed handedness is defined as a preference to perform some unimanual tasks with one hand and to perform other unimanual tasks with the other hand. Mixed-handed persons are not particularly uncommon (Annett, 1970). Annett (1970) considered that ambidexterity, in the sense of equal preference for both hands when performing skilled actions such as writing, is rare.

### **Handedness & Grip Strength Research**

Some researchers of grip strength have classified their research participants as either dextralists or sinistralists (Balogun & Onigbinde, 1992; Bassegy & Harries, 1993; Bowman & Katz, 1984; Chatterjee & Chowdhuri, 1991; Crosby & Wehbe, 1994; Desrosiers, Bravo, Hebert & Dutil, 1995; Fullwood, 1986; Hanten et al., 1999; Newman et al., 1984; Pearn & Bullock, 1979; Petersen, Petrick, Connor & Conklin, 1989), with no attempt to sort them into smaller groups, according to the handedness continuum, from extremely left-handed to extremely right-handed for nominated tasks. Thus an examination of these studies does not help to clarify how degrees of laterality affect a person’s grip strength ratio. Other researchers have ignored the possibility that the grip strength ratio of sinistralists could be different from that of dextralists as indicated by their pooling of grip strengths of the dominant hand of the sinistralists with the dominant hand of the dextralists (Backman, Johansson, Hager, Sjoblom & Henriksson, 1989; Burke, Tuttle, Thompson, Jannay & Weber, 1953; Chau et al., 1997; Harkonen, Piirtomaa & Alaranta, 1993; Jarit, 1991; Lunde, Brewer & Garcia, 1972; Mathiowetz et al., 1986; Reikeras, 1983; Sperling, 1980; Su, Cheng, Chien & Lin 1994; Toews, 1964).

Depending on the definition of handedness, consistent right-handers may constitute only 47% of an average patient population (Coren & Previc, 1996). Possible different grip strength ratios for consistent and non-consistent left-handers, as compared with consistent right-handers needs to be carefully investigated so that occupational therapists can estimate an injured person’s unilateral loss of grip strength more accurately. A grip strength ratio profile can be built that takes into account a person’s degree of hand dominance, occupational preferences and pre-injury requirements for hand strength. It would appear that none of the researchers of grip strength have considered how the grip strength difference of the left and right hands may be influenced when one hand is preferred for precision, non-resistive tasks (eg., dealing cards or applying make-up) and the other hand is preferred for gross grip, resistive tasks (eg., hammering, opening vacuum sealed jars). For example, a person may prefer the right hand for precision tasks, such as writing, and the left hand for resistive tasks, such as opening jars, thus the left (less skilled) hand may be stronger than the right hand.

### Methods of assessing handedness in grip strength studies

To date, the issue of whether and how to determine handedness in the context of grip strength studies has been dealt with in a variety of ways. Five different approaches are evident from the literature:

- 1) Using forearm and arm girth measurements for determining the dominant hand;
- 2) Not stating how hand dominance was assessed;
- 3) Choosing to ignore hand dominance;
- 4) Using multiple item hand preference questionnaires
- 5) Using one or two item questionnaires.

The first approach, which was proposed only by Kirkpatrick (1957), did not supply supporting data showing that the dominant side is indeed larger than its non-dominant counterpart. Additionally, no data were supplied about the relationship (linear or otherwise) between simple circumferential measurements and the grip strength differences of the two hands. At a more sophisticated level, Davies (1990) demonstrated a linear relationship between lean forearm volume (which incorporates the use of skin fold calipers) and grip strength.

The second approach, which was used by many authors does not state how handedness was determined ( Backman et al., 1989; Burke et al., 1953; Chatterjee & Chowdhuri, 1991; Chau et al., 197; Crosby & Wehbe, 1994; Harkonen et al., 1993; Kellor, Frost, Silbergger, Iversen, Cummings, 1971; Lunde et al., 1972; Mathiowetz et al., 1985; Mathiowetz et al., 1986; Pearn & Bullock, 1979; Reikeras, 1983; Sperling, 1980; Su et al., 1994; Swanson et al., 1970). This omission prevents replication of the research, and the methods of assessing handedness cannot be evaluated.

The rationale for the third approach, choosing to ignore hand dominance, used in two articles (Fike & Rousseau, 1982; National Isometric Muscle Strength Data Consortium, 1996), has been based on the premise that determining handedness is too complex a task to accurately assess (Fike & Rousseau, 1982), or that the number of sinistralist participants was not large enough to warrant, or enable, separate statistical analyses. This approach was sometimes done after an initial handedness classification to determine numbers of sinistralists and dextralists (Desrosiers et al., 1995; Hamilton, Balnave & Adams, 1994; Harkonen et al., 1993; Kellor et al., 1971; Mathiowetz et al., 1985). Other researchers did not explicitly state (after classifying participants into sinistralists and dextralists) why they then ignored these dominance groupings when presenting their data and simply pooled their grip strength data into two groups: all left hands and all right hands (Agnew & Maas, 1982; Bassey & Harries, 1993; Fullwood, 1986; Newman et al., 1984). Hanten et al., (1999) presented their data as left versus right hands and dominant versus non-dominant hands. The norms they presented were based on left versus right hand rather than according to handedness because they found that more participants were stronger in their right hand, regardless of hand dominance.

The fourth approach involved the use of questionnaires or inventories for handedness classifications (Balogun & Onigbinde, 1992; Desrosiers et al., 1995; Schmidt & Toews, 1970). The historical backdrop to the development of the existing handedness inventories was the desire to develop questionnaires was the desire to develop inventories that reflected cognitive asymmetries. Early researchers aimed to create questionnaires that were as universally applicable as possible, with items that were familiar, non-gender specific, relevant across large age spans and common to many cultures (Annett, 1970; Oldfield, 1971). Recognizing the enormity of this task, Peters (1998) recommended a method for developing self-reporting questionnaires. He highlighted the validity of within-culture questionnaires, rather than one penultimate questionnaire. None of these authors considered the amount of strength required to perform the tasks as part of their criteria for item selection. That is, no inventories have been developed to distinguish persons who perform resistive tasks with one hand and non-resistive tasks with the other. Thus, according to our view of the literature, an inventory does not yet exist that reflects the magnitude and the direction of the left and right grip strength difference on the basis of preferred hand for tasks requiring at least moderate grip strength.

Of those studies that used handedness inventories (Balogun & Onigbinde, 1992; Desrosiers et al., 1995; Schmidt & Toews, 1970), none used the inventories in a way that would assist in understanding the relationship between degrees of handedness and grip strength. They did not present their grip strength data categorised according to degrees of handedness, rather they categorized research participants as left or right handed. Desrosiers et al. (1995) and Schmidt and Toews (1970) also used this classification to enable them to test the dominant hand first. Their only reason for doing this was to standardize their methodology.

Two methods were identified for using the fifth approach (using a single or dual item questionnaire) to assessing handedness. With the first method, participants were asked to state whether they were left or right hand dominant, but they were given no definitions about what constitutes hand dominance (Fairfax et al., 1995; Hamilton et al., 1994; Kellor et al., 1971; Mathiowetz, Weber, Volland & Kashman, 1984; Petersen et al., 1989;). With the second method, participants were asked which hand they preferred for specific tasks, such as writing, eating, or cutting (Bowman & Katz, 1984; Fullwood, 1986; Jarit, 1991; Mathiowetz et al., 1985).

Hanten et al's (1999) study used a combination of these two methods. If the participants were unsure of whether they were left or right handed, they were asked with which hand they ate and wrote. Similarly, if Schmidt and Toews' (1970) participants were unsure of their hand dominance, they were given a multi-item handedness questionnaire. Details of this questionnaire were not published in the article.

Questionnaire items of hand preferred for eating or hand preferred for writing are the least valid for determining handedness (Annett, 1985; Harris, 1990). For example, the hand used for eating is often dictated by the culture (Subirana, 1969). Writing can be a particularly misleading index of general hand preference (Hardyck, Goldman & Petrinovich, 1975), and using it to determine handedness could lead to artificially high numbers of dextralists in grip strength studies. Until recently, the literate world has

vigorously encouraged all students to learn to write with their right hands (Harris, 1990; Teng, Lee, Yang & Chang, 1976). The first author of this article still receives anecdotal stories of people trying to persuade left-handers to write with their right hands. Because a wide variety of familiar unilateral tasks that could be used to create handedness inventories exists, avoidance of using writing as the sole item for handedness classifications seems prudent.

### **Effect of handedness on grip strength**

Given the inconsistencies in definition and the variety of assessments used to measure handedness, determining the effect of handedness from grip strength studies is difficult. Bearing this in mind, the major findings of this literature review will now be reported.

Petersen et al. (1989) referred to the “10% rule” that therapists allegedly use as a general guideline for setting rehabilitation goals. This rule states that the dominant hand is approximately 10% stronger than the non-dominant hand. Schmidt and Toews (1970) stated that the 10% rule was derived from a survey of World War 1 soldiers and cited personal correspondence with the Chief of the Permanent Disability Rating Bureau in California in 1964. No other information was found to support the upholding of this rule.

The difference in strength between the two hands can be as high as 40% (Crosby & Wehbe, 1994). In Schmidt and Toews (1970) study, 15% of their female participants ( $n = 80$ ) and 23% of their male participants ( $n = 1,128$ ), were stronger in their non-dominant hand. Thus the 10% rule could not be applied to either gender, and the difference in strength between the hands can be very large.

The grip strength of ambidexterous persons does not appear to have been studied at all. Some studies excluded such persons (Petersen et al., 1989; Schmidt & Toews, 1970), others re-classified them (Chau et al., 1997; Desrosiers et al., 1995).

Some studies divided their participants into sinistralists and dextralists and analysed the data for the two groups separately. A considerable number of both sinistralists and dextralists have a stronger non-dominant hand (Balogun & Onigbinde, 1992; Crosby & Wehbe, 1994; Pearn & Bullock, 1979; Petersen et al., 1989; Swanson et al., 1970). Up to 29% of sinistralists and 20% of dextralists had grip strength differences between 15% and 30% for their two hands (Crosby & Wehbe, 1994). Petersen et al. (1989) found that female dextralists had an individual mean percentage difference of 15.8% in grip strength between their hands. Thus there is a considerable magnitude of difference in strength between the hands in many sinistralists and dextralists exists.

From the above four paragraphs it is apparent that the current published studies are limited in their ability to assist in the estimation of pre-injury grip strength for persons who have sustained hand injuries. Other factors, relating to participant details, such as anthropometric dimensions and types of occupations and sports played have often been overlooked when creating these databases.

### **Conclusion**

Some of the hand grip research convincingly demonstrates that there is an isometric grip strength difference between the two healthy hands. The impact of handedness is not clear. As a general guideline, it would appear that the grip strength difference for up to 29% of sinistralists is more than 15%, with the right hand being the stronger hand in just over 50% of sinistralists (Crosby & Wehbe, 1994). With regard to dextralists, up to 20% are expected to have a grip strength difference between the hands of more than 15%, with the right hand usually being the stronger. The wide individual variation in grip strength differences, from zero to 40%, indicates that we would be doing many of our clients a great disservice if we assumed that a person's hand was fully recovered when it's strength equaled that of the uninjured contralateral hand.

Thus if the pre-injury grip strength of one hand is to be estimated, making a comparison with the contralateral healthy hand will not always be accurate. As occupational therapists we need to obtain detailed information about pre-injury hand preferences for each of our patients with hand-injuries. This information would assist in our estimations of which hand would have been expected to be pre-morbidly stronger, and by what magnitude. People who prefer one hand for moderately to strongly resistive tasks and the other hand for precision tasks, cannot be identified using with the current handedness evaluation methods.

Further research is needed to develop handedness assessments that highlight the dominant hand for moderately to strongly resistive tasks and allow persons to be sorted into groups along the continuum from consistently left-handed to consistently right-handed for resistive tasks. The assessment needs to accommodate persons who are mixed-handed and persons who are ambidexterous. The hand dominance and grip strength relationship needs to be explored in large well-designed, standardized studies. We are presently conducting such a study, which will contribute toward the clarification of these important concepts. The stability of the grip strength ratio also needs to be examined. If it is not stable, pre-injury strength of one hand based on self-reporting questionnaires, prediction equations, and the grip strength performance of the contralateral healthy hand at any one point in time will be hard to estimate. We are also currently researching this issue.

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#### Footnote

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