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This is to certify that the thesis prepared by Michael S. Reith entitled: "The Relationship of Isometric Grip Strength, Optimal Dynamometer Settings, and Certain Anthropometric Factors" has been approved by his committee as satisfactory completion of the thesis requirement for the degree of Master of Science.

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The Relationship of Isometric Grip Strength, Optimal Dynamometer Settings, and Certain Anthropometric Factors

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science at
Virginia Commonwealth University

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This thesis is dedicated to my parents Richard and Wanda, for their unfailing support and belief.

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Abstract

THE RELATIONSHIP OF ISOMETRIC GRIP STRENGTH, OPTIMAL DYNAMOMETER SETTINGS, AND CERTAIN ANTHROPOMETRIC FACTORS

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A study was conducted to determine (a) the relationships between isometric grip strength and eight anthropometric dimensions of the upper extremity, (b) the relationship between isometric grip strength and handle position of the Jamar dynamometer, and (c) a means of predicting optimal positioning of the Jamar dynamometer handle. Measurements were taken from 30 females between the ages of 21 and 25. Data were analyzed by means of the Pearson product-moment correlation, ANOVA and multiple ANOVA, predictive discrimination, and multiple regression.

Significant correlations ($p<.05$) existed between all dimensions of the hand and grip strength in all handle positions except the smallest, ranging from .36 to .61. Analysis of variance demonstrated significant differences between strength at the different handle positions.

Greatest strength was obtained in position two or three. Multiple comparison revealed no significant difference between strength at position two or three, but did demonstrate differences between all others (alpha = .05). Predictive discriminant analysis of optimal handle position correctly assigned 70% to 80% of subjects to their actual optimal position compared to the 40% to 60% that would occur by chance alone. Multiple regression revealed low values of $\underline{r}^2$ for all dimensions, being highest for hand breadth ($\underline{r}^2$ = .27 - .38).

The results support the use of position two or three of the Jamar dynamometer handle for testing of maximum grip strength. Specific adjustment of the dynamomater handle seems unnecessary, but if desired it should be based upon hand length or length of the long digit. No anthropometric dimension appears to be strong enough to predict grip strength.

CHAPTER ONE

INTRODUCTION

Background

Since the late 19th Century, assessment of isometric grip strength has been an interest of numerous fields, involving physical educators, anthropologists, and physicians (Montpetit, Montoye, & Laeding, 1967), as well as occupational therapists. Many of these have sought overt data, such as loss or gain of grip strength, or have wished to compare different populations. Interest in relationships of various human factors and human performance to grip strength has characterized past research (Malina, 1975). Typical of this trend is literature which has reported the use of grip strength data for its predictive and diagnostic value, such as for partial prediction of mortality (Phillips, 1986), determining recovery from anesthesia (Russell & Serle, 1987), or for differential diagnosis in schizophrenia (Merrin, 1984).

Although numerous dynamometers have been developed, researchers have turned toward the use of models with adjustable handle settings, allowing for adjustment of the instrument to the size of the human hand or for assessing strength at various spans of grip (e.g., Bowers, 1961; Heyward, McKeown, & Geeseman, 1975). Within the field of occupational therapy, the most popular device remains the Jamar adjustable dynamometer, described by C. G. Bechtol (1954). In a survey of 195 occupational therapy settings, Smith and Benge (1985) reported that 79% of all respondents indicated that the Jamar was the most commonly used dynamometer in their settings.

There has been much interest in developing normative data for the Jamar dynamometer. Numerous studies have been made of adult and child populations (Ager, Olivett, & Johnson, 1984; Fike & Rousseau, 1982; Fullwood, 1986; Hinson & Gench, 1989; Kellor, Frost, Silberberg, Iversen, & Cummings, 1971; Matheson, Carlton, & Niemeyer, 1988; Mathiowetz et al., 1985; Mathiowetz, Wiemer, & Federman, 1986; Pierson & O'Connell, 1962; Schmidt & Toews, 1970). Grip strength, as assessed by the Jamar dynamometer, has been found to be associated with gender, age, and dominance, confirming similar conclusions drawn with other instruments (Agnew & Maas, 1982; Fisher & Birren, 1947; Lunde, Brewer, & Garcia, 1972; Montoye & Lamphiear, 1977; Newman et al., 1984; Parizkova & Adamec, 1980; Petersen, Petrick, Connor & Conklin, 1989; Robertson & Deitz, 1988).

Unfortunately, normative data collected by such studies demonstrates marked variance within age groupings, diminishing the predictive value of such data to the clinician. Furthermore, the value of acquired data is often compromised by the lack of standardized instrumentation and methods of assessment (Fess, 1986; Fess, 1987; Kellor et al., 1971).

Some studies have demonstrated relationships of grip strength to anthropometric factors such as weight and height (Tinkle & Montoye, 1961; Wessel & Nelson, 1961), measurements of the upper extremity (Bowers, 1961; Everett & Sills, 1952; Montoye & Faulkner, 1964), and appropriate handle adjustment of an adjustable dynamometer (Bowers, 1961). Such studies have disagreed as to the exact association of strength to human dimensions and are less than conclusive (Malina, 1975). What potential value they might have in further clarifying norms is limited by several factors. The majority of such studies have used dynamometers other than the Jamar. Many mention various anthropometric measurements such as hand breadth, hand length, or circumferences of the wrist and forearm, but few have described the measurements specifically. Procedures for assessing strength have varied, and details as to anthropometric instruments, anatomical landmarks, or accepted procedures of anthropometry have been lacking.

There has been a continuing call to determine the objectivity and reliability of occupational therapy assessment instruments and procedures (Fess, 1986; Fess, 1989a), with several authors having specified this need in the assessment of grip strength (Fike & Rousseau, 1982; Kellor et al., 1971; Smith & Benge, 1985). Efforts have been made to demonstrate reliability of the Jamar dynamometer (Flood-Joy & Mathiowetz, 1987; Matheson et al., 1988; Mathiowetz et al., 1984). Some attempts have been made to determine validity through the comparison of the Jamar dynamometer to other instruments (King & Berryhill, 1988; Mathiowetz et al., 1984).

There have been recent attempts to establish standard assessment procedures for the Jamar dynamometer. Within the past decade, the American Society for Surgery of the Hand (1978), and the American Society of Hand Therapists (Fess & Moran, 1981) have made similar recommendations, addressing standardized arm positioning and the placement of the dynamometer handle in the second position or notch. Several research studies have validated specific positioning of the elbow (Mathiowetz, Rennells, & Donahue, 1985) and the wrist (Pryce, 1980). However, the literature reflects a paucity of research addressing appropriate handle positioning, other than those which have suggested that greatest strengths can be obtained at either position 2 or 3 (Bechtol, 1954; Niebuhr & Marion, 1987). Unfortunately, these studies did not use standardized assessment procedures.

1987). Unfortunately, these studies did not use standardized assessment procedures.

Purpose of the Study

At the 1989 Symposium for Surgery and Rehabilitation of the Hand, E. E. Fess stressed the need for research to determine appropriate positioning of the Jamar dynamometer handle (Fess, 1989b). This study examines the relationship of several anthropometric variables to isometric grip strength and the position of the Jamar dynamometer handle at which greatest strength is achieved. Findings which demonstrate that greatest strength values are obtained at a specific handle position and that that position is significantly different than the other four handle positions could support or contradict the recommended use of the second handle position. If the second handle position is not the position at which all individuals obtain their maximum strength values, meaningful relationships between specific anthropometric variables and the handle position at which greatest strength values are achieved could provide a means of clinically determining optimum positioning of the Jamar dynamometer handle for each individual.

Further potential benefit lies in the predictive value of a demonstrated relationship between grip strength and anthropometric measures of the upper extremity. Such a relationship has been demonstrated for lateral pinch surgery (Burmeister & Flatt, 1975). In considering the implications of demonstrated, positive relationships, the anthropometric variables which will be studied are based upon recognized standards of anthropometry, anatomical landmarks familiar to the clinician, and instruments available to the clinician.

Finally, this study offers the opportunity to enhance, update, and clarify the understanding of the relationships between isometric grip strength and anthropometric dimensions. The value of earlier studies has been limited by the lack of standardized anthropometric technique, the lack of grip strength assessment protocols which are consistent with current practice, and the use of a wide variety of dynamometers, many of which are not in common use in occupational therapy clinics. Such information is certainly useful to the occupational therapist as part of grip strength evaluation, but also offers an increased understanding of the dynamics of human grasp as it relates to body dimensions and the size of the object grasped.

CHAPTER TWO

REVIEW OF THE LITERATURE

Introduction

The body of literature which addresses the assessment of grip strength is quite large. Research has been directed at instrumentation, assessment methodology, reliability and validity issues, normative studies, studies of the association of grip strength to human factors or human performance, and studies of the application of such knowledge in assessment or prediction. Comparatively, literature pertaining to the anthropometry of the upper extremity, or its relation to grip strength, is limited. This review discusses that literature which directly or indirectly addresses the three variables of interest: positioning of the Jamar dynamometer handle, isometric grip strength, and anthropometric factors. These are reviewed within the context of the relationships of interest.

The first section reviews the relationship of grip strength to anthropometric variables. The anthropometric factors of height and weight are briefly reviewed, and linear and circumferential factors are discussed in detail. The second section discusses the relationship of grip strength to handle settings of the adjustable dynamometer. Related topics, such as current methods of adjustment and characteristics of the Jamar dynamometer, are reviewed. The final section reviews anthropometry as it pertains to the upper extremity. Topics covered include the science of anthropometry, instrumentation, accepted procedures of measurement, and the reliability of upper extremity anthropometric measurements.

Grip Strength and Anthropometric Variables

Weight, Height, and Grip Strength

In research of the relationship of weight, height, and grip strength, subjects have often been studied within specific age ranges, adding the additional variable of age. Using a strain-gauge dynamometer, Newman et al. (1984) measured the weight, height, and grip strength of 1,417 children and adolescents. They concluded that height and weight were as strongly associated with grip strength as was age, reporting a correlation coefficient within age group classes that was often more than .50 and was rarely less than .30. In commenting on the relationships of the variables of age, weight, and grip strength, the authors suggested that small differences in weight could result in grip strength measurements which fell within adjacent age groupings.

Using an elliptical dynamometer, Montpetit et al. (1967), in a study of over 900 children ranging in age from 8 to 17 years old, found that grip strength and height and weight were related, with correlations within age group classes ranging from $r = .22$ to $r = .65$ for height and ranging from $r = .21$ to $r = .74$ for weight. They conducted analyses with weight and height partialled out and found that height was more strongly associated with grip strength through 11 years of age, but weight was more closely related after that age.

Literature related to the adult population has shown less agreement. Using an unspecified dynamometer, Tinkle and Montoye (1961) studied the relationship of grip strength and achievement in physical education in 635 college men. They reported significant correlation coefficients between grip strength and height ($r = .33$), and between grip strength and weight ($r = .45$). With age accounted for by partial correlation, weight remained significant, but height did not. They concluded that grip strength was only indirectly related to height but was directly related to and perhaps dependent upon body weight. Wessel and Nelson (1961) conducted a concurrent study of 200 college women, arriving at similar results. Similar correlation coefficients were also found by Fisher and Birren (1947) in a study of 978 military and industrial personnel and by Lunde, Brewer, and Garcia (1972) in a study of 57 college women.

A similar relationship between weight and grip strength was reported by Pierson and O'Connell (1962) in a study of 299 policemen and college students using the Jamar dynamometer. As with the studies reported earlier, they removed the effects of height, weight, and age, respectively, and found a low but significant correlation for grip strength and weight ($r = .32$) and an insignificant correlation for height ($r = .08$). They proposed that the relationship of body build and strength might explain the different associations between grip strength and height, and grip strength and weight.

A more recent study using the Jamar dynamometer was conducted by Schmidt and Toews (1970). Testing a group of 1,128 male and 80 female steel workers, they reported a direct association of grip strength with height, up to 75 inches in males, and a direct association of grip strength with weight, up to 215 pounds in males. Similar relationships were found for females; however, in neither case did they report their correlation coefficients. It should be noted that the assessment protocol employed appeared consistent with standards later proposed by professional organizations (American Society for Surgery of the Hand, 1978; Fess & Moran, 1981); however, the Jamar dynamometer was altered by coating its handles with a sand and paint mixture.

The general relationship of grip strength to weight and height was summarized by Malina (1975), who reported that correlations for both young and adult males range between .35 and .66 for weight, and between .27 and .60 for stature. Further, he concluded that the relationships between strength and body dimensions were low to moderate and were not practical for prediction.

Measurements of the Upper Extremity and Grip Strength

Bowers (1961) explored the relationship of certain anthropometric characteristics of the hand and forearm to the grip strength of 100 college students. Grip strength was assessed using Stoelting adjustable and Naragansett hand spring dynamometers, as well as with a cable tensiometer. Anthropometric measurements were taken once from the dominant arm. Measurements of hand length, middle finger length, first phalanx of the middle finger length, and hand width were made by sliding caliper, being recorded to the nearest millimeter. Girth measurements were made with the arm extended and muscles contracted, with forearm girth being taken at the largest circumference, and wrist girth being taken at the styloid processes. In addition, height and weight measurements were also recorded. Other than the failure to take more than one recording, descriptions of measurement techniques for the caliper reflected those prescribed by authorities in anthropometry (Cameron, 1984; Comas, 1960; Hrdlicka, 1939).

Bowers reported that zero order coefficients between grip strength and forearm girth (r = .57 - .64), between grip strength and wrist girth (r = .52 - .60), between grip strength and length of the proximal phalanx of the middle finger (r = .46 - .55), between grip strength and finger length (r = .41 - .49), between grip strength and hand width (r = .40 - .44), and between grip strength and hand length (r = .31 - .42) were significant. He concluded, however, that no single factor was strong enough in its association to serve as a predictor of grip strength. The use of partial correlations to account for weight resulted in the correlation between hand length and grip strength becoming insignificant for data that had been recorded by one of the three dynamometers.

Bowers further analyzed the relationship of body weight, forearm and wrist girths, and grip strength, concluding that weight was somewhat related to lower arm and hand measurements, but that its relationship was not strong enough to change the relationship between lower arm girth and grip strength. He also advised that dynamometers should be adjusted according to the lengths of the hand and middle finger. Noting the higher scores obtained with the use of an adjustable dynamometer, Bowers theorized that the difference might be explained by anatomical leverage and that the adjustable dynamometer scores more nearly reflected true hand strength. The data were reported as comparing closely with a study by Everett and Sills (cited in Bowers, 1961), who reported a similar relationship between length of the fingers and grip strength in a study of 400 students. A similar relationship was described by Fess (1982), who studied the relationship of various hand dimensions and grip strength as tested in the five handle positions of the Jamar dynamometer. The dimensions included length of the palm, length of fingers, and length of the rays. A ray consists of the length of the finger plus the length of the corresponding metacarpal bone. She reported that the length of the long finger was the most important factor in determining the optimal position of the dynamometer handle when assessing maximal strength.

Using a Stoelting adjustable dynamometer, Montoye and Faulkner (1964) studied the relationship of hand size to grip strength in 202 adults and children in an attempt to determine optimum setting of the dynamometer handle. Anthropometric measurements consisted of an arbitrary scale of glove sizes, second finger length, hand length, and hand width. Measurements were made by a desk ruler to the nearest millimeter. Hand length was measured as the distance from the proximal end of the scaphoid to the tip of the long finger, and width of the hand was measured at the metacarpal joints. Finger length was not defined.

Montoye and Faulkner reported that grip strength was higher for larger glove sizes. Zero order correlation coefficients for males and females were moderate to strong for hand length ($\underline{r}$ = .84 and .65), hand width ($\underline{r}$ = .85 and .81), and finger length ($\underline{r}$ = .84 and .86). The authors noted only small differences in grip strength scores at different handle settings, except for those subjects with large or very small hands. They further commented that hand size appeared to have little significance at settings from 4.5 cm to 5.5 cm. Their conclusions were that a precise setting on the dynamometer for each hand size was not necessary, that large subjects had some advantage with an adjustable dynamometer, and that hand width was the best criterion for determining optimal settings of the dynamometer.

The relationship of arm strength to arm morphology was investigated by Roberts, Provins, and Morton (1959) in a study of 75 British navy personnel. Grip strength was measured by a Salter's dynamometer, with the subjects' elbows flexed. In addition to height, weight, and upper arm dimensions, measurements were made of right forearm length and girth and right hand length. Strength of elbow flexion and extension were also measured by strain gauge dynamometer. Unlike the study by Bowers (1961), anthropometric measurements were taken with muscles relaxed. Forearm length was measured from the upper margin of the head of the radius to the tip of the radial styloid process. Forearm girth was taken as maximum, with the arm hanging. Hand length was measured from the tip of the radial styloid process to the tip of the long finger. Instrumentation was not discussed.

Significant correlations were reported for grip strength and hand length (*r* = .47), grip strength and forearm length (*r* = .41), and grip strength and forearm girth (*r* = .38). Interrelationships of linear measures were analyzed and found to be strong. Following partial correlations and factor analysis, the relationship between grip strength and girth was reduced. In contrast, strength of elbow flexion and strength of elbow extension appeared more closely related to girth measures than linear measures. In their conclusions, the authors suggested that the fixed position of the dynamometer handle may explain the stronger relationship of grip strength with linear measures than with girth.

In an anthropological study of 151 nomadic Turkana pastoralists and 38 American adults, Little and Johnson (1986) compared several measurements, including forearm girth, grip strength, muscle fatigue, and estimates of muscle fiber composition. Forearm girth was taken approximately 1 cm below the inner forearm crease and grip strength was measured by a Smedley dynamometer. The instrument was adjusted to the size of the subject's hand, and several measurements of maximum grip strength were taken, with the highest value being recorded. Correlation coefficients are not given; however, the authors reported that the values were equal to those reported in the studies by Bowers (1961) and Roberts et al. (1959). They also reported that males tended towards stronger correlations than females and that the coefficients for the American population were highly significant.

A study of less-common anthropometric dimensions and grip strength was conducted by Plato and Norris (1980). In their study, 236 males between the ages of 25 and 95 underwent radiography of both hands and grip strength assessment with a Smedley dynamometer. Three trials of grip strength were made and the average of the highest two was recorded. The radiographs were used to measure various dimensions of the second metacarpal bone. Accounting for age, weight, and height, the relationships between grip strength and bone dimensions were analyzed. Grip strength was reported as positively correlated with bone width, cortical thickness, and cortical area, but as not correlated with bone length.

Though not studies of grip strength, Burmeister and Flatt (1975) and Weiss and Flatt (1971) explored the relationship of hand size and pinch strength. In both studies, measurements were made of palmar width, palmar depth, and the length of all digits. The exact instrumentation used for measuring was not described. Although the earlier study was a pilot study, the final study by Burmeister and Flatt included 1,741 elementary school children. The authors used step-wise regression to select the variables that would best predict pinch strength. Width of the palm was found to be the most predictive of pinch, as measured using any digit. The study produced a prediction equation for palmar pinch strength which the authors stressed as having predictive value in considering potential improvement from correctional surgery.

Grip Strength and Jamar Dynamometer Handle Settings

Since its development (Bechtol, 1954), the Jamar dynamometer (Asimow Engineering Company) has been described as the best instrument for measuring strength of grasp (Kirkpatrick, 1956; Mathiowetz et al., 1984) and has received acceptance from recognized professional organizations (American Society for Surgery of the Hand, 1978; Fess & Moran, 1981). Though now available in a digital model, several other models exist. The analog models come with either metal (Model 1) or plastic handles (Model 1A) that can be set at five different spacings that range from 1.35 to 3.35 inches, increasing at .5 inch intervals. Force of grip is registered in pounds, kilograms, or both, with a maximum reading of 200 pounds or 90 kilograms. Isometric force is transmitted to the gauge by a hydraulic system which is sealed under vacuum (Kirkpatrick, 1956).

Though described by its manufacturer as a "standard testing instrument" (Asimow Engineering Company), the Jamar dynamometer[1] is not a standardized instrument. It is supplied by the manufacturer with suggested standard

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[1] Jamar Dynamometer Model 1; Asimow Engineering Company, Santa Monica, California.

instructions for assessment and with scant normative data. The suggested standard instructions appear to have been taken from the recommendations of the American Society of Hand Therapists, with the exception of handle spacing, for which the manufacturer makes no specific recommendation. Although professional organizations have recently recommended specific protocols for handle spacing, the literature which reports use of the Jamar dynamometer for the collection of data reflects inconsistency. Of twelve studies published during the last 20 years, seven reported that the handle was set at the recommended standard second notch or position (Hinson & Gench, 1989; Kellor, Kondrasuk, Iversen, Frost, Silberberg, & Hoglund, 1971; King & Berryhill, 1988; Mathiowetz et al., 1984; Mathiowetz, Kashman, Volland, Weber, Dowe, & Rogers, 1985; Mathiowetz, Rennells, & Donahoe, 1985; Mathiowetz et al., 1986). Two reported adjustment of the instrument to the subject's hand size or age (Ager et al., 1984; Fullwood, 1986), one reported using the third position (Fike & Rousseau, 1982), and two gave no information as to handle setting (Agnew & Maas, 1982; Kellor, Frost, Silberberg, Iversen, & Cummings, 1971). Whereas the trend in the more recent occupational therapy research literature appears to be adherent to suggested standards, professional texts still present disagreement.

In a recent professional text on rehabilitation of the hand, two separate sections recommended assessment in all five handle settings (Aulicino & DuPuy, 1984; Baxter & McEntee, 1984), one recommended the second notch (Fess, 1984), and another recommended setting the handle at 6 cm (Baxter & Ballard, 1984). Other sources have recommended adjustment of the handle to fit the size of the patient (Brand, 1985; Smith, 1981). Although all sources have not agreed on a standard position for setting the Jamar dynamometer handle, the general relationship of grip strength to handle position appears to have been recognized.

Following the advent of adjustable dynamometers, authors have noted the variation in maximum grip strength values with adjustments in the handle spacing or variations in the size of the hand (Bechtol, 1954; Everett & Sills, 1952; Kirkpatrick, 1956). In a limited study of 22 adults, Petrofsky, Williams, Kamen, and Lind (1980) studied the effect of handgrip span on isometric strength with a strain gauge dynamometer. Strength assessments were made at six handle settings which ranged from 3.2 cm to 8.0 cm. The greatest strength for all subjects, female and male, was elicited within a 1 cm range of settings between 5 cm and 6 cm. At the smallest setting of 3.2 cm, the average strength of all subjects was 72.6% of the maximum value. At the largest setting of 8.0 cm, the average strength of all subjects was 92.4% of the maximum value. Although they found no significant correlation between hand size and strength, they concluded that there is one optimal grip span for each individual and they noted that changing the span by only 0.6 cm could produce less than maximum values.

Two previously mentioned studies also explored the relationship of grip span to maximum strength values and optimal setting of a dynamometer handle. Bowers (1961) advised adjustment of the dynamometer based upon length of the middle finger and width of the hand. Montoye and Faulkner (1964) agreed with the general relationships of hand size, handle settings, and maximum grip strength, but disagreed as to the need to adjust the instrument for the hand size of the individual. They reported that optimal strength values were obtained within a 1 cm range of handle span (4.5 cm - 5.5 cm). A similar 1 cm range of optimal values (5.0 cm - 6.0 cm) was again reported in a study by Petrofsky et al. (1980). Likewise, Kiser and Rodgers (1983) cited studies at the State University of New York at Buffalo in 1982, which found greatest grip strengths when the grip span of a Stoelting dynamometer ranged from 4.5 cm to 5.5 cm.

The reason behind the relationship of maximum grip strength, hand size, and grip span of a dynamometer has been theorized by Petrofsky et al. (1980), who suggested that variation in the length of sarcomeres occurs with changes in hand span. They suggested that the optimal span is that span in which the greatest number of actomyosin bridges occur. Bowers (1961) and Kiser and

Rodgers (1983) suggested that the reason might have to do with mechanical leverage.

Whereas the research discussed thus far has employed dynamometers other than the Jamar, there are related studies using that instrument. Fess (1982; 1984) described a biomechanical curve that is produced when measuring normal maximum grip values across the five different settings of the Jamar dynamometer, with strongest grip registering in the second or third position. Values decrease from the fourth to the fifth position, and lowest values occur in the first position. A study by Niebuhr & Marion (1987) confirmed the existence of such a curve, even in subjects who were attempting to deceive the examiner. Matheson et al. (1988) described the same curve in a disabled population.

Anthropometry of the Upper Extremity

Anthropometry has been given various definitions by the many fields that have measured the human body. An inclusive definition was given by Hrdlicka (1939), who stated that "anthropometry is the systemized art of measuring and taking observations on man, his skeleton, his brain, or other organs, by the most reliable means and methods, for scientific purposes" (p. 3). The uses of anthropometry have been as diverse as those of grip strength assessment, with applications in the fields of human engineering (Garrett, 1971), anthropology, and the medical sciences (Comas, 1960). As a science, anthropometry has developed or adapted sets of instruments, techniques, terminology, and definitions; however, there remains a problem with standardization. This section reviews instruments which have been used to measure the upper extremity, definitions and techniques of common arm and hand measurements, and the general reliability of those measurements.

Instrumentation

Perhaps the most characteristic instrument used for measuring the body dimensions is the anthropometer, or flat, sliding caliper. The anthropometer is used to measure linear dimensions such as lengths, heights, and breadths. The instrument is constructed of a rule or bar, one fixed crossarm, and one movable crossarm (Malina, Hamill, & Lemeshow, 1973). It is available in a small version, which is used for measurements up to 250 mm, and a large version, for measurements up to 700 mm, and is calibrated in centimeters and millimeters (Hrdlicka, 1939).

The anthropometric tape measure is also calibrated in centimeters, millimeters, inches, or all three, and has graduations on both sides of the tape (Cameron, 1984). A steel tape is used to avoid the possibilities of error as the result of shrinkage or stretching (Comas, 1960), though synthetic tapes are considered adequate (Cameron, 1984). The tape is used for taking circumferential or girth measurements (Sills, 1960). Other instruments have been used for the upper extremity, such as measuring boards and tables, though they are not commonly referred to.

Measurements, Definitions, and Technique

The literature reflects much disagreement concerning the standard or most appropriate definitions for various anthropometric measurements. There has been some agreement that the left side of the body should be measured, as there may be less chance that the non-dominant side will have been altered by pathology, trauma, or occupation (Comas, 1960; Hrdlicka, 1939). Others have researched the difference between left and right sides of the body and concluded that the difference is too small to consider (Martorell, Mendoza, Mueller, & Pawson, 1988). For the forearm and hand, common linear measurements have been reported as various lengths and breadths, though the field of human factor engineering has included various thicknesses and depths (Davies, Abada, Benson, Courtney, & Minto, 1980; Garrett, 1971). Circumferential or girth measures have included maximum forearm girth, middle forearm girth, wrist girth, and digit circumference.

Forearm length has been defined as the distance from the head of the radius to the gap between the carpus and radius (Cameron, 1984), and as the distance from the head of the radius to the tip of the radial styloid process (Roberts et al., 1959; Weiner & Lourie, 1969). A similar measurement is elbow to hand length, or forearm to hand length, and it has been defined as the distance from the olecranon to the tip of the middle finger (Martin, Carter, Hendy, & Malina, 1988; Snow, Reynolds, & Allgood, 1975). Elbow to wrist length has been described as the distance from the olecranon process to the distal end of the ulnar styloid process (Malina et al., 1973; Martin et al., 1988). Forearm girth or circumference has been taken at various points along the length of the forearm and has been described as being halfway between the elbow and wrist (Gavan, 1950), immediately distal to the elbow joint, 1 cm distal to the elbow crease (Little & Johnson, 1986), or at the maximum girth (Bowers, 1960; Callaway et al., 1988; Cameron, 1984; Roberts et al., 1959; Snow et al., 1975).

Wrist measurements have included girth and breadth. Girth has been taken perpendicular to the long axis of the arm and proximal to the ulnar styloid process (Cameron, 1984; Garrett, 1971; Snow et al., 1975), across the styloid processes (Bowers, 1961), or just distal to the styloid processes (Callaway et al., 1988; Weiner & Lourie, 1969). Breadth has been described as being across the styloid processes (Cameron, 1984, Snow et al., 1975), and from the most medial aspect of the ulnar styloid process to the most lateral aspect of the radial styloid process (Wilmore et al., 1988).

Measurements of the hand have been numerous, and the literature reflects much disagreement. For hand length, proximal landmarks have been defined as the wrist crease (Champney, Crist, Cushman, Lucas, & Rodgers, 1983), various points along the distal wrist crease (Garrett, 1971; Malina et al., 1973), the middle of a line drawn between the styloid processes (Bowers, 1961), the proximal edge of the scaphoid bone (Montoye & Faulkner, 1964; Snow et al., 1975), the center of a line drawn from the proximal limits of the thenar and hypothenar eminences (Hrdlicka, 1939), the radial styloid process or its tip (Martin et al., 1988; Roberts et al., 1959), or the distal end of the radius (Cameron, 1984). There seems to be agreement that the distal landmark should be the tip of the long finger. For hand breadth, some authors have described the distance across the hand at the metacarpal-phalangeal joints or heads of the metacarpals (Bowers, 1961; Champney et al., 1983; Garrett, 1971; Montoye & Faulkner, 1964; Snow et al., 1973; Weiner & Lourie, 1969), and another defined it as the perpendicular distance from the angle of the thumb and index finger to the ulnar edge of the palm (Hrdlicka, 1939). Digits have been measured from the metacarpal-phalangeal joint to their tips (Bowers, 1961), from various creases to their tips (Burmeister & Flatt, 1975; Weiss & Flatt, 1971), circumferentially, or in crease-to-crease segments (Davies et al., 1980; Garrett, 1971).

Techniques of measurement have varied, and many authors have stressed the need for a standard subject position, exact location of appropriate landmarks, and proper application of and familiarity with the instrument (Cameron, 1984; Comas, 1960; Sills, 1960). For the anthropometer, fixation of the movable blade followed by placement of the fixed blade has been recommended (Cameron, 1984). For the tape, light or gentle application has been advised. For both instruments, indentation of the skin has been advised against, unless it is used to compress the soft tissue which directly overlies a bony prominence. Standard position has been less agreed upon and has varied from an erect subject with arm suspended loosely, to flexion of the elbow, to various positions of the arm on a measuring table, and with various degrees of muscle tone.

Consistency of Anthropometry

Malina (1975) stated that "no discussion of anthropometry would be complete without a consideration of observer error" (p. 250). He described interobserver and intraobserver error as contributing to measurement error, whether randomly or systematically. Other authors have commented on the inherent problem of measurement error in anthropometry (Cameron, 1984; Gavan, 1950) which has been attributed to a lack of reliability studies and the differing terminology used in discussing reliability (Mueller & Martorell, 1988). Discussing the implications of numerous studies demonstrating the poor consistency of anthropometry, Bennett and Osborne (1986) commented that "the biological meaning of the inferences and hypotheses that arise from these investigations must be viewed with considerable reservation" (p. 752). The attention given to the reliability of anthropometric measurement has been described as scant (Mueller & Martorell, 1988). What value previous studies might have is limited by the lack of attention given to measurements of the upper extremity, lack of standard definitions and methods for the measurements, and a lack of standard terms used to define and describe reliability.

In a recent discussion of the reliability and accuracy of anthropometry, Mueller and Martorell (1988) recommended that two statistics would completely define the reliability of an anthropometric variable. The statistic "technical error of measurement" gives information concerning the units of measurement and might be compared to a standard deviation. It was earlier defined by Malina et al. (1973) as "the square root of the sum of the squared differences of replicates divided by twice the number of pairs" (p. 42). The same statistic is defined by Mueller and Martorell (1988) as the square root of within-subject variance of replicate measures. The second statistic is termed "reliability," and is described as "a correlation-like coefficient that allows comparison of measurement errors for different variables and an estimate of the degree to which the intersubject variance is compromised by error " (p. 85).

Mueller and Martorell (1988) stated that the technical error of measurement provides an estimate of measurement error that is in the units of measurement of the variable in question. They interpreted this statistic as, "two thirds of the time a measurement should come within ± the value of the technical error of measurement" (p. 85). Using this statistic as a reference value, the authors suggested that the technical error of measurement of observers could be compared to a reference value by means of an F ratio of variances. They also suggested that the technical error of measurement could be used to set permissible tolerance limits by which an investigator could determine if replicate measurements should be remeasured. Mueller and Martorell explain that these limits are set by the investigator at one or more magnitudes of the measurement error. In estimating technical error of measurement and reliability, they recommend a sample size of at least 50 subjects.

Studies which have employed the statistics described by Mueller and Martorell (1988) are limited. In their national anthropometric study of children in 1973, Malina, Hamill, and Lemeshow addressed the problem of reproducibility of measurements in a thorough discussion of quality control and estimation of residual measurement error. Of the 6,768 children in their study, 301 children underwent replicate measurements. Some children were remeasured by the same observer, whereas others were remeasured by a different observer. The authors analyzed intra- and interobserver variance, explored the magnitude of difference between and within observers by use of the median difference between replicate measures, and compared the technical error of measurement. The authors noted that those measurements which appeared most reliable in terms of median differences also showed the lowest technical error of measurement. Within observers the technical error of measurement ranged from 0.106 cm to 1.466 cm. For upper extremity measurements repeated by the same observer the technical error of measurement was reported as 0.115 cm for wrist breadth, 0.304 cm for forearm girth, and 0.347 cm for upper arm girth. Between observers the difference between the medians of repeated measurements was reported as 0.2 cm for forearm girth, and 0.1 cm for wrist breadth.

While they termed their statistic "total variance," Martorell et al. (1975) reported on technical error of measurement in a study of the relative reproducibility of 18 different dimensions. Their data were collected during an ongoing study of preschool Guatamalan children. As part of the quality control process, replicate measurements were made of 10% of the total sample. This provided approximately 100 subjects for each dimension. Martorell et al. reported a total variance of 0.11 cm for wrist breadth and a total variance of 0.24 cm for mid-arm circumference. In analyzing variance by instrument used, Malina et al. concluded that measurements made with the sliding or spreading caliper, such as wrist breadth, and girth measurements of the extremities are highly replicable.

Other studies have varied in the terminology and methods by which they have analyzed and discussed reliability. Gavan (1950) categorized 62 common measurements into classes of high, medium, or low consistency. The 62 different measurements were first divided into 100 mm classes, based upon the average of the means for each measurement. This allowed comparison of measurements of similar magnitude. The standard deviation and coefficient of variation of each measurement were then used to divide the measurements into classes of high, medium, or low consistency. Gavan concluded that measurements of high consistency tended to have easily located landmarks, such as bony prominences. The upper extremity measurements included in this category were forearm to hand length and hand breadth. Upper forearm circumference, wrist circumference, and hand length fell into the medium consistency category, which was characterized by measurements in which the landmarks were less clearly defined. He suggested that uncertainty over the exact location for placement of the tape characteri.ed low consistency measurements. Mid-forearm circumference was found to have low consistency.

In a study of intraobserver and interobserver reliability, Munro et al. (1966) found consistency to vary across different instruments and different observers. They used the variance between measurements as an estimate of intraobserver and interobserver reliability. Although no measurements of the upper extremity were included, the authors reported significant differences between observers for 6 of 21 different measurements. They noted that those differences occurred in measurements taken with the small anthropometer, tape, and spreading caliper, as compared with the skinfold caliper, large anthropometer, or sliding caliper. They suggested that observers should be given greater training with these instruments. In discussing intraobserver consistency, the authors advised the use of confidence intervals based upon variance.

In a study of interobserver reliability, Bennett and Osborne (1986) found significant differences between observers for 42 of 63 measurements made on male subjects and for 50 of 63 measurements made on females. They employed a two-way ANOVA to evaluate interobserver error levels. Inconsistent measurements of the upper extremity included hand length, hand breadth, mid-digit length, wrist diameter, and forearm circumference. They concluded that reduction of error to acceptable levels was questionable, due to the inherent difficulty in taking many of the measurements. They stressed that anthropometric surveys should be designed with internal controls and that observers should be aware of those measurements which tended to be the least replicable.

In a similar study, Jamison and Zegura (1974) explored interobserver consistency for 16 dimensions which were measured by two anthropologists on 20 male and 22 female Eskimos. Upper extremity measurements included hand breadth, wrist breadth, hand length measured from bone, and hand length measured from the wrist crease. Data were analyzed by comparison of the means for each variable, by analysis of variance, and by product-moment correlation coefficients. In both males and females, significant differences between observers were found for 5 of the 16 variables. The only female upper extremity measurement which differed significantly between the observers was hand length, as measured from a bony land mark. In males, a significant difference between observers was found for wrist breadth and hand breadth. Correlation coefficients for all measurements ranged from $\underline{r}$ = .38 to $\underline{r}$ = .98 for female subjects and from $\underline{r}$= .46 to $\underline{r}$ = .98 for male subjects. Correlation coefficients for upper extremity measurements ranged from $\underline{r}$ = .85 to $\underline{r}$ = .91 in female subjects and from $\underline{r}$ = .83 to $\underline{r}$ = .91 in male subjects. The use of both analysis of variance and correlation coefficients to study reliability of measurements has also been described by Cameron (1984), who pointed out that correlation coefficients in test-retest studies of anthropometry often exceed $r = .90$, but that correlational analysis alone offers little insight into the magnitude of actual error, which might be better understood by analyzing variance. Jamison and Zegura suggested that strong positive correlations between observers could indicate that they obtained the same results or that there was systematic covariance. By ranking the variables in their study by correlation coefficient and then by analysis of variance F-ratio values, they demonstrated that there was no apparent relationship between the magnitude of the correlation coefficient and the F-ratio values.

The recently published Anthropometric Standardization Reference Manual (Lohman, Roche, & Martorell, 1988) provides a compilation of the demonstrated reliability of several measurements for the upper extremity. Data are reported in terms of tolerance limits, correlation coefficients, variance, and technical error of measurement. Table 1 includes intraobserver reliability data cited by Lohman, Roche, and Martorell along with data from studies which have been previously discussed, while interobserver reliability data are presented in Table 2.

Several factors have been described as influencing consistency of observations. There appears to be general agreement that experience of the observer may influence consistency. Gaito and Gifford (1958) discussed the

Table 1

Intraobserver Reliability of Upper Extremity Measurements

Study	Statistic or description			
	r	TEM	Tolerance	Other
Forearm girth or circumference				
Behnke & Wilmore (1969)[a]	.99	--	.20 cm	--
Malina et al. (1973)	--	.30 cm	--	.2 cm[b]
Martorell et al. (1975)	--	.24 cm	--	--
Wrist circumference				
Behnke & Wilmore (1969)[a]	.99	--	.20 cm	--
Wrist breadth				
Behnke & Wilmore (1969)[c]	.96	--	--	--
Malina et al. (1973)	--	.115 cm	--	.10 cm[b]
Martin (1986)[c]	.994	--	--	--
Martorell et al. (1975)	--	.11 cm	--	--

Table 1 - continued

Intraobserver Reliability of Upper Extremity Measurements

	Statistic or description			
Study	*r*	TEM	Tolerance	Other
		Elbow to wrist length		
Stewart (1985)[d]	--	--	--	.29[e]
Chumlea (1983)[d]	--	.31,.32 cm	--	--

Note. TEM = technical error of measurement.

[a]Cited by Callaway et al. (1988). [b]Difference between the median values of repeated measurements. [c]Cited by Wilmore et al. (1988). [d]Cited by Martin et al. (1988). [e]Estimate for intrameasurer variance.

Table 2

Interobserver Reliability of Upper Extremity Measurements

Study	Statistic or description			
	r	TEM	Tolerance	Other
Forearm girth or circumference				
Bennett & Osborne (1986)	--	--	--	inconsistent
Gavan (1950)	--	--	--	low/medium
Malina et al. (1975)	--	.582 cm	--	--
Wrist circumference				
Gavan (1950)	--	--	--	medium
Wrist breadth				
Bennett & Osborne (1986)	--	--	--	inconsistent
Jamison & Zegura (1974)	.83 [a]	--	--	consistent
	.90 [b]	--	--	--
Malina et al. (1973)	--	.115 cm	--	--
Elbow to wrist length				
Gavan (1950)	--	--	--	high

Table 2 - continued

Interobserver Reliability of Upper Extremity Measurements

Study	Statistic or description			
	r	TEM	Tolerance	Other
	Hand length			
Bennett & Osborne (1986)	--	--	--	inconsistent
Gavan (1950)	--	--	--	medium
Jamison & Zegura (1974)	.86,.91 [c]	--	--	consistent
	.91,.85 [d]	--	--	inconsistent

Note. TEM = technical error of measurement.

[a] Male subjects. [b] Female subjects. [c] Male subjects. The first figure represents hand length as measured from the wrist crease. The second figure represents hand length as measured from bone. [d] Female subjects. First figure represents hand length as measured from the wrist crease. Second figure represents hand length as measured from bone. A significant difference between observers was found for hand length as measured from bone. There was no difference between observers for hand length as measured from the wrist crease.

influence of the subject's body build or percentage of body fat as an important factor. Others have discussed amount of soft, subcutaneous tissue under the point of instrument application (Gavan, 1950), age of the subject (Chumlea, Roche, & Rogers, 1984), and sex of the subject (Bennett & Osborne, 1986). Cameron (1984) described the body positioning of the subject as a factor that produces variance when there is a brief period between measurement sessions. He also mentioned the additional effect of biological changes, such as growth, over longer periods of time. Malina, Hamill, and Lemeshow (1973) suggested that consistency is affected by the state of the muscles underlying the area of measurement, that is, whether or not they are contracted or relaxed.

Suggestions have been made to assist the observer in controlling for error. Kemper and Pieters (1974) recommended that the observer take care in applying the tape measure during girth measurements, insuring that the same tension is applied to the tape for each subject. Several authors have suggested that the observer take each measurement twice (Cameron, 1984; Chumlea et al., 1984; Gaito & Gifford, 1958). Others have suggested marking the points of instrument application before measurement (Comas, 1960; Hrdlicka, 1939). Malina et al. (1973) suggested that error is inevitable despite efforts to control it and recommended that variation should therefore always be reported.

Conclusion

Grip strength has been the subject of many studies across diverse professional fields and has been found to be related to many human factors. Literature about the relationship of these factors to grip strength is extensive for some variables and less developed for others.

The relationships between grip strength and height or grip strength and weight appear to be consistent across many studies. In general, the correlations between grip strength and height have been moderate at best, ranging from as low as $r = .08$ to as high as $r = .65$. The association between grip strength and weight has been shown to be slightly stronger than that of the association between grip strength and height. Correlation coefficients have ranged from as low as $r = .22$ to as high as $r = .74$. Length and girth measurements of the forearm and hand have been shown to have varying relationships with grip strength. For these measurements in general, correlation coefficients have ranged between $r = .35$ and $r = .55$, although a few studies have reported coefficients which exceeded $r = .80$. Some studies have suggested that hand width is the factor most strongly related, while others have indicated that length of the hand, and particularly the middle finger, is more closely associated with grip strength. Length of the hand has also been shown to be associated with the most advantageous position of an adjustable dynamometer. There is agreement on the general relationship of grip strength to increases or decreases in the grip span of an adjustable dynamometer and regarding the existence of specific settings or ranges of settings which will produce a maximum result; however, those studies which have been most definitive have not used the Jamar dynamometer.

The anthropometric measurements reported in studies of grip strength have varied from study to study and in comparison to standards suggested by researchers in the field of anthropometry. Information concerning instrumentation and technique has been lacking and a reference manual of standard methodology only recently became available. Anthropometry literature has reported varying degrees of consistency of measurements, even for trained anthropologists. The consensus of opinion appears to reflect that consistency is poor for anthropometry in general, but that measurements of the upper extremity, particularly those with fixed landmarks and measured by caliper or tape, are relatively consistent and that reliability can be improved by proper design and safeguards.

The review of the literature suggests a need for further study of the relationship between specific anthropometric factors of the hand and grip strength, as measured by the Jamar dynamometer. The literature suggests that strength is a multivariate entity and that adjustment of a dynamometer based upon selected anthropometric measures enhances results and may give a more valid and true measurement of grip strength. Despite attempts at establishing standard assessment procedures, handle settings used in recent literature have reflected disagreement. Further study is needed to define the relationship between anthropometric measurements, grip strength, and appropriate adjustment of the Jamar dynamometer, using recently recommended standards of assessment and recognized anthropometric technique.

CHAPTER THREE

METHOD

This chapter contains a description of the methods used to conduct this study. Areas discussed include research questions, instruments, operational definitions, subjects, a pilot study, data collection methods, assumptions, and data analysis procedures.

Research Questions

1. Are there positive relationships between selected anthropometric dimensions of the hand and forearm and clinical isometric grip strength (CIGS) at each handle position of the Jamar dynamometer?

2. Are there positive relationships between selected anthropometric dimensions of the hand and forearm and maximum isometric grip strength (MIGS) at each handle position of the Jamar dynamometer?

3. Are there significant differences in CIGS values at different handle positions of the Jamar dynamometer?

4. Are there significant differences in MIGS values at different handle positions of the Jamar dynamometer?

5. Are there significant differences in specific dimensions of the hand and forearm among groups of subjects with different optimal positions for CIGS?

6. Are there significant differences in specific anthropometric dimensions of the hand and forearm among groups of subjects with different optimal handle positions for MIGS?

7 How well do the anthropometric dimensions predict optimal handle position for CIGS?

8. How well do the anthropometric dimensions predict optimal handle position for MIGS?

9. Which anthropometric dimensions or combination of dimensions predicts CIGS and the highest individual clinical isometric grip strength (HICIGS)?

10. Which anthropometric dimensions or combination of dimensions predicts MIGS and the highest individual maximum isometric grip strength (HIMIGS)?

Instruments

Anthropometric Measures

The anthropometric dimensions selected include those that have been demonstrated in the literature to have some known relationship to grip strength, such as hand length, hand breadth, and long finger length. The linear dimensions of elbow to wrist length, elbow to hand length, hand length, hand breadth, and wrist breadth were selected because of their relationship to the height or stature of the subject and the known relationship of height to grip strength. Circumferential dimensions were selected because of their known relationship to body composition and weight. These include maximum forearm circumference and wrist circumference.

Anthropometric definitions were based upon standards set forth in the Anthropometric Standardization Reference Manual (Lohman et al., 1988) and in previous studies of interest. For purposes of enhancing consistency, landmarks were palpated prior to measurement. For the same reason, all anthropometric dimensions were measured twice, with at least one day between measurements. The average of the two measurements was used in data analysis. Otherwise, measurement technique, including instrument selection and application, complied with the standards set by Lohman et al. (1988). The instruments used for each measurement are specified on the data collection sheet (Appendix A) and exhibited in Figure 1. The large and small aluminum anthropometers[1] were used for linear measurements. Measurement increments range from 0.1 cm to 30.0 cm for the small model, and range from 0.1 cm to 60.0 cm for the large model. A fiberglass anthropometric tape[2] was used for all circumferential measurements.

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[1] Large anthropometer, catalog number BK-7478-02; Small anthropometer, catalog number BK-7478-01; Fred Sammons, Incorporated, Brookfield, Il.

[2] Gulick anthropometric tape, catalog number BK-0193; Fred Sammons, Incorporated, Brookfield, Il.

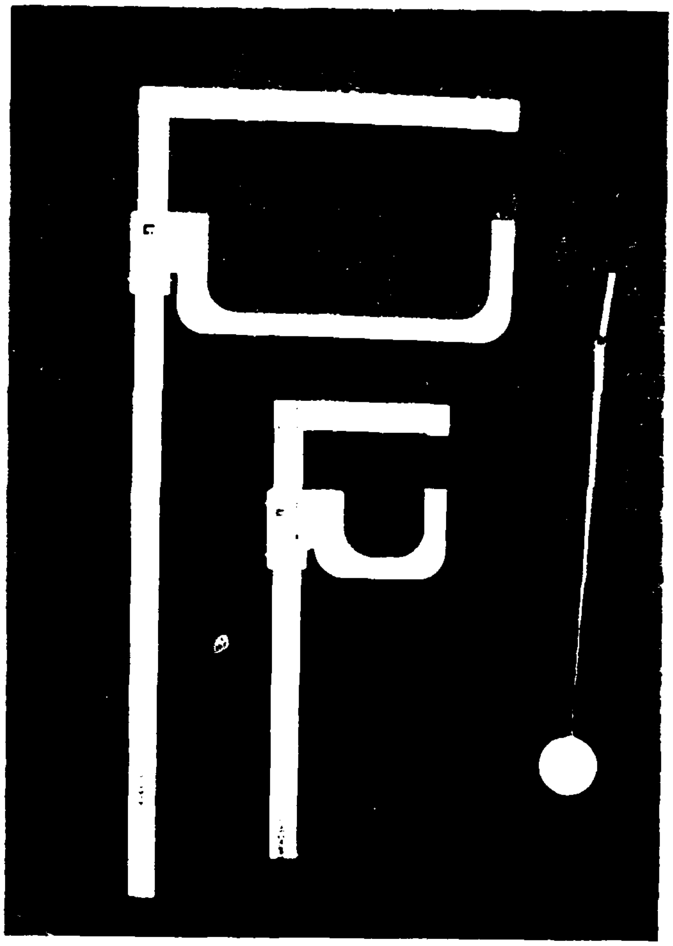

Figure 1. Large anthropometer, small anthropometer, and anthropometric tape measure.

Grip Strength as Measured by the Jamar Dynamometer

Grip strength was measured by Jamar Model 1 dynamometer[1] (Figure 2) and was assessed by the protocol recommended by the American Society of Hand Therapists (Fess & Moran, 1981). As this protocol is not inclusive of verbal instructions, verbal protocol followed Mathiowetz et al. (1984). Additional instructions were added to advise the subject that the dynamometer handle would not perceptibly move when it was squeezed and that the handle should be squeezed as rapidly as possible (Matheson et al., 1988). Positioning of the subject followed Mathiowetz, Kashman, Volland, Weber, Dowe, and Rogers (1985). Only the right hand was assessed. The Jamar dynamometer was calibrated in accordance with the method recommended by Fess (1987), prior to and following data collection. While the American Society of Hand Therapists recommends taking the average of three trials (Fess & Moran, 1981), as is reflected in many recent studies (Heyward et al., 1975; King & Berryhill, 1988; Matheson et al., 1988; Mathiowetz et al., 1984; Mathiowetz, Rennells, & Donahoe, 1985), others have administered only one trial (Fike & Rousseau, 1982), or have taken the highest value obtained over two trials (Petrofsky et al., 1980; Pierson & O'Connell, 1962;

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[1] Jamar Dynamometer Model 1; Asimow Engineering Company, Santa Monica, California.

Figure 2. Assessment of grip strength with the Jamar dynamometer.

fatigue in repeated trials of strength testing were mentioned in studies by Kroll (1962, 1963). Some authors have attempted to control for fatigue by allowing a prescribed period of rest between trials (Bohannon, 1986; Heyward et al., 1975; Petrofsky et al., 1980). This has generally varied from 30 seconds to one minute. However, the studies by Kroll demonstrated that even with a one minute rest period between trials there was a gradual decline from the first to fifth trials. He attributed that to fatigue. Although adjacent trials were not significantly different, the first trial differed significantly from the third, fourth, and fifth trials. Similar findings were reported by Weiss-Lambrou and Dutil (1986). Others have cautioned that this effect is especially marked in children (Newman et al., 1984).

In light of the demonstrated effect of endurance on repeated trials of strength, the use of a mean or average of three trials in each handle position may be questioned, particularly if the resulting mean value is defined as maximum. However, the current protocol of the American Society of Hand Therapists recommends the averaging of three trials. As a primary value of this study rested in comfirming or placing in question those recommendations, the protocol necessarily included the averaging of three trials to obtain CIGS. In light of the possible effect of repeated trials on endurance, the highest value of the first two trials was recorded as MIGS. This enabled analysis of the relationships in question both with and without the effect of repeated trials, thereby serving as a control for fatigue and also enhancing the analyses which could be performed. Fatique was further controlled for by testing only one handle position on any given day and by allowing between-trial rest periods.

Operational Definitions

1. CIGS is defined as the mean of three measurements taken at the same handle position of the Jamar dynamometer.

2. MIGS is defined as the greater measurement of the first two measurements taken at the same handle position of the Jamar dynamometer.

3. Highest individual clinical isometric grip strength (HICIGS) is defined as the greatest CIGS value of all values for each subject.

4. Highest individual maximum isometric grip strength (HIMIGS) is defined as the greatest MIGS value of all values for each subject.

5. Handle position number one is that handle position of the Jamar dynamometer which is obtained by placing the adjustable handle into the notch which is nearest the dial of the instrument. Handle positions are numbered consecutively from number one through number five, with handle position number five being the greatest distance from the dial of the instrument.

6. Optimal handle position for CIGS is defined as the handle position of the Jamar dynamometer at which HICIGS is achieved for each subject.

7. Optimal handle position for MIGS is defined as the handle position of the Jamar dynamometer handle at which the HIMIGS is achieved for each subject.

8. Elbow to wrist length is defined as the average of two measurements of the distance, in centimeters, from the most posterior aspect of the olecranon process to the most distal palpable point of the ulna, as taken by large anthropometer and with the elbow flexed to 90 degrees.

9. Forearm to hand length is defined as the average of two measurements of the distance, in centimeters, from the most posterior surface overlying the olecranon to the tip of the middle finger of the extended hand, as taken by large anthropometer and with elbow flexed at 90 degrees.

10. Forearm circumference is defined as the average of two measurements of the circumferential distance, in centimeters, around the forearm, as taken with tape measure placed at the point of greatest girth and perpendicular to the long axis of the arm.

11. Wrist circumference is defined as the average of two measurements of the circumferential distance, in centimeters, around the wrist, as taken with tape measure placed immediately proximal to the ulnar styloid.

12. Wrist breadth is defined as the average of two measurements of the distance, in centimeters, from the

most medial aspect of the ulnar styloid to the most lateral aspect of the radial styloid, as taken with small anthropometer.

13. Hand length is defined as the average of two measurements of the distance, in centimeters, from the distal end of the styloid process of the radius to the tip of the middle finger, as taken with small anthropometer.

14. Hand breadth is defined as the average of two measurements of the distance, in centimeters, from the most radial aspect of the second metacarpal-phalangeal joint to the most ulnar aspect of the fifth metacarpal-phalangeal joint, as taken with small anthropometer.

15. Middle digit length is defined as the average of two measurements of the distance, in centimeters, from the mid-point of the most proximal middle digit crease to the tip of the middle finger, as measured by the small anthropometer.

Description of Subjects

A convenience sample of 30 female occupational therapy students was used in this study. Subjects selected were right handed and were between the ages of 21 and 25 years old. Dominance of hand was determined by statement of the subject. Subjects were verbally and visually screened to rule out any medical history of past or current injury to the right hand or medical condition which might diminish normal grip strength. All subjects were given an explanation of the purpose of the study and then asked to read and sign a release form (Appendix B).

Testing occurred before and after the subjects' scheduled classes. All testing took place in the same room, using consistent furniture, subject, observer, and equipment placement. Personal data collected on each subject included age and hand dominance.

Pilot Study

Prior to the collection of data, the observer trained with the anthropometers and the anthropometric tape measure. During training it was noted that the actual recording of anthropometric measurements required much more time than had been anticipated during the design of the study. After reading the instruments, the observer had to leave the side of the subject, move to a writing surface, and place the instrument aside before writing the measurement on the data collection sheet. During all of this time the observer also had to remember the measurement he had just taken. To reduce the possibility of errors in recording and to reduce the total time of each session, direct annotation of measurements was replaced by the use of an audio tape recorder.

Ten students were used in a pilot study to determine intraobserver anthropometry reliability. Five of those students were right handed, female occupational therapy students who were between the ages of 26 and 34. The remaining five consisted of the first five students tested during actual data collection. For the ten subjects, Pearson product-moment correlation coefficients ranged from r = .96 to .99 for all measurements except wrist breadth and middle digit length. The correlation for wrist breadth was r = .65, while the correlation for middle digit length was r = .89. Both of these measurements were then reviewed as to recommended technique and the pilot study was then continued with an additional six subjects. The observer applied the instrument with extra pressure when measuring wrist breadth and took care in placing the blades of the anthropometer on the appropriate crease when measuring middle digit length. Following the altered techniques, the correlation coefficient for the total group of 16 subjects was r = .85 for wrist breadth and r = .94 for middle digit length.

Prior to the collection of data, intraobserver tolerance limits were set at 0.2 cm for all measurements. Such a limit was based upon the smallest figure reported in the literature for any of the measured dimensions. When the difference between the first and second measurements exceeded 0.2 cm the dimension was remeasured during additional sessions. Measurements continued until two consecutive measurements fit the tolerance limit, and those were the measurements used for the data analysis.

Method of Data Collection

Collection of data for each subject occurred over five sessions. During the first two sessions both anthropometric data and strength data were collected. The last three sessions consisted of strength testing and any remeasurement of anthropometric variables which exceeded tolerance limits. Upon arrival in the testing room the subject was positioned in a comfortable standing posture. The observer stood at the right side of the subject for all measurements taken by anthropometer. For measurements taken by tape measure the observer stood facing the subject. Anthropometric measurements were taken in the order and in the position indicated on the data collection sheet (Appendix A). Landmarks for wrist circumference, wrist breadth, and hand breadth were palpated prior to instrument application.

Following any palpation, the appropriate instrument was placed on the landmarks. The observer exercised care to place the instruments lightly on the skin with no apparent indentation, except when measuring wrist breadth. In measuring wrist breadth the observer slightly compressed subcutaneous tissue with the anthropometer blades. Otherwise, all instrument application followed that recommended by Lohman, Roche, and Martorell (1988) and is illustrated in Figures 3 through 10. To reduce error, the anthropometers and tape were read to the nearest millimeter, with the observer positioned

Figure 3. Measurement of elbow to wrist length

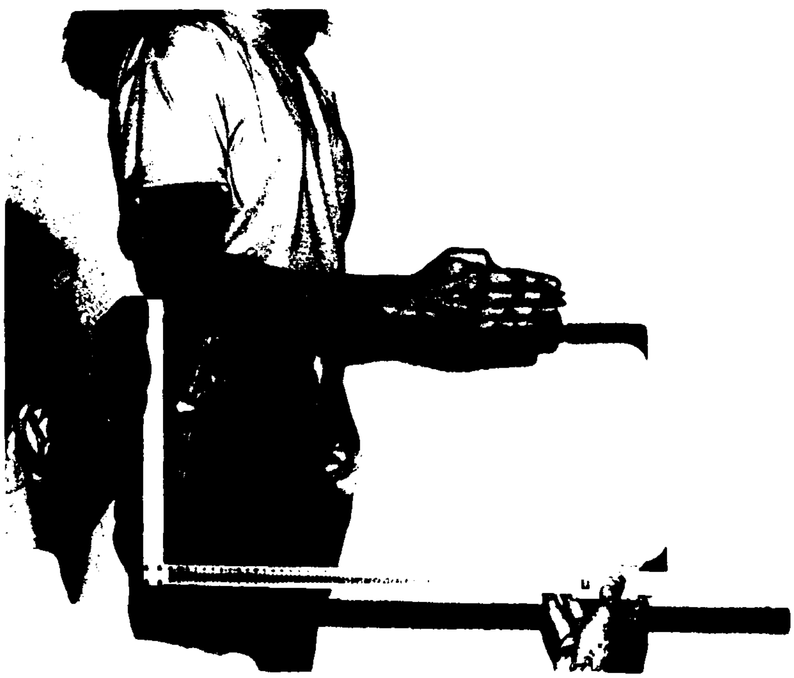

Figure 4. Measurement of forearm to hand length

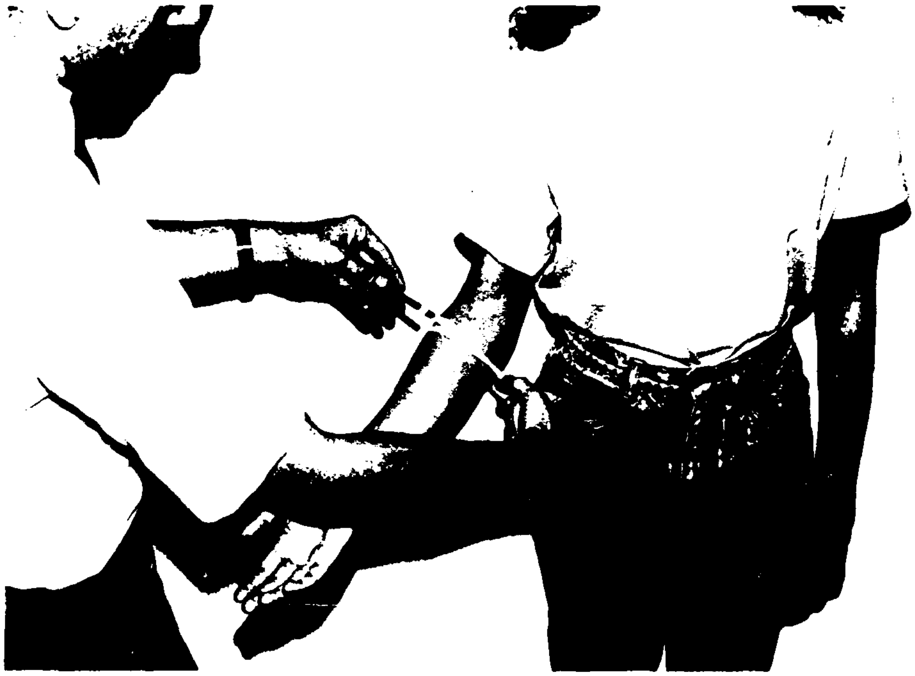

Figure 5. Measurement of forearm circumference

Figure 6. Measurement of wrist circumference

Figure 7. Measurement of wrist breadth

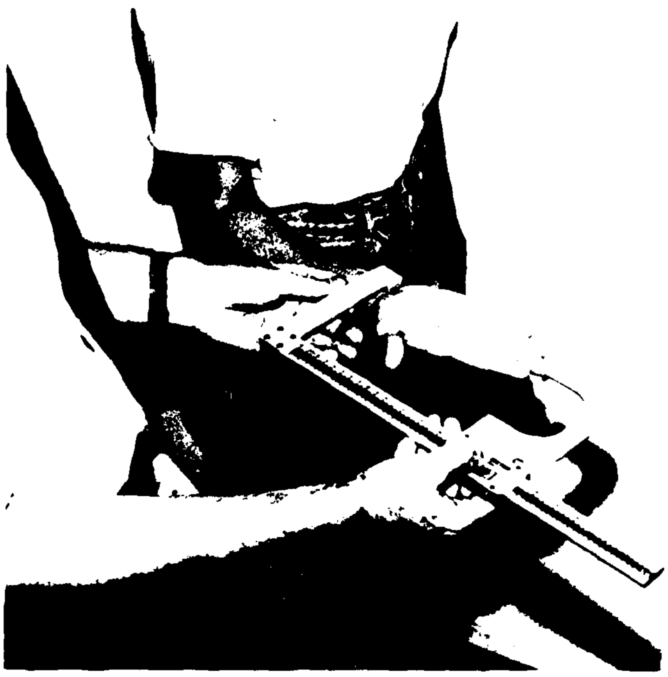

Figure 8. Measurement of hand length

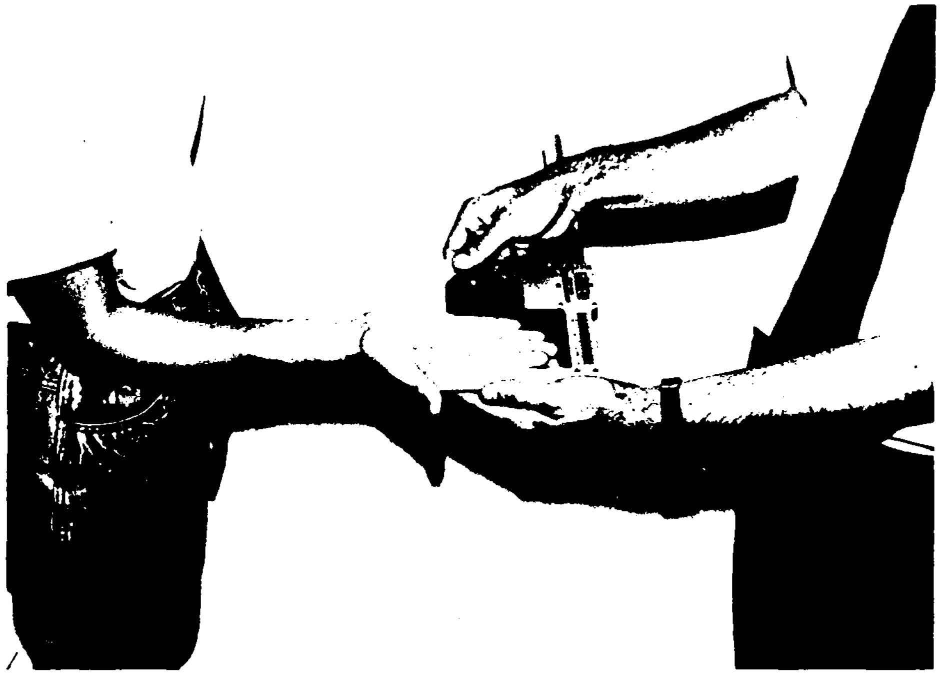

Figure 9. Measurement of hand breadth

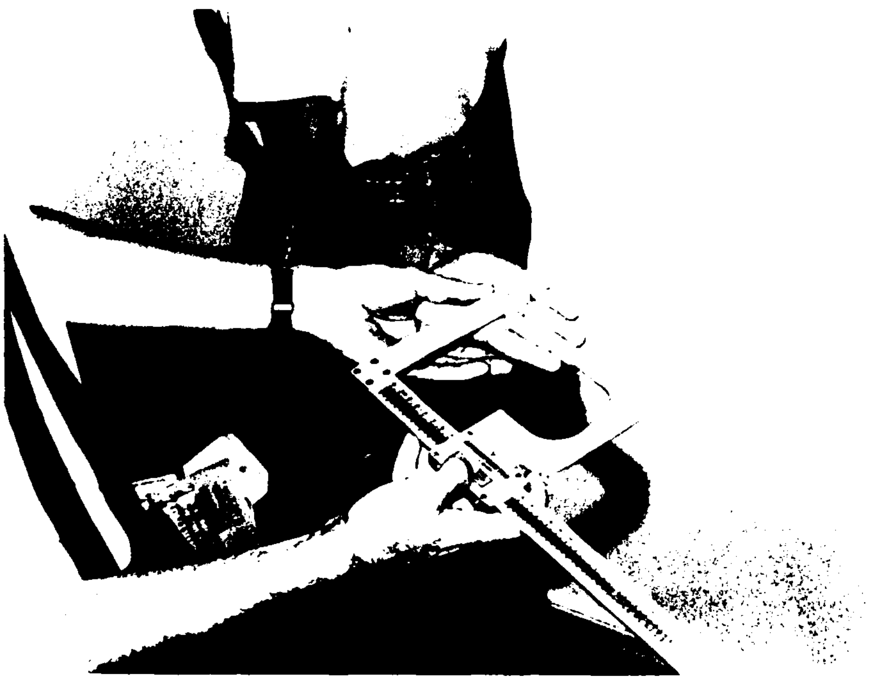

Figure 10. Measurement of digit length

perpendicular to the graduations. Measurements were initially recorded on a tape recorder, with the observer vocalizing each measurement twice. To reduce recording error, measurements were vocalized in centimeters to one decimal point, and then in millimeters. For example, the observer would call out, "twenty four point one centimeters...two, four, one." Following the test session they were transferred to the data collection sheet (Appendix A). After taking the second set of anthropometric measurements for any subject, the data were examined for any differences between replicate measurements which exceeded the tolerance limits established for this study. When it was observed that the difference between measurements exceeded those limits, the variable in question was remeasured in subsequent sessions until the difference between two measurements fell within tolerance limits. For the first two sessions, grip strength testing followed anthropometry. Subjects were assigned a sequence of handle positions based upon 5 X 5 Latin squares. Initially a 5 X 5 square was chosen in which the total number of repeated sequences within rows was minimal. In this instance this was deemed as no more than four repetitions. Perhaps a more common procedure is to randomly select one Latin square from all possible squares (Wardlaw, 1985). For a 5 X 5 square that would be impractical, due to the total number of different squares being 161,280 (Finney, 1968). In accordance with the recommendations of Fisher and Yates (1967), a 5 X 5 table was selected and all rows except the first were then permuted until eight different squares were generated. Eight squares were needed to generate a sufficient number of handle position orders (40) for the anticipated number of subjects (30) and for the pilot study (10). Dynamometer handle positions one through five were then randomly assigned to the letters A through E, for each square. Each completed table was divided into five rows, for a total of 40 rows. One row was then assigned at random to each subject. The end result was a random ordering of handle positions within and between subjects. Additionally, each handle position was uniformly distributed in sequence throughout the study, such that each position was tested first one-fifth of the time, each position was tested second one-fifth of the time, and so on.

Following anthropometric measurement the subject was seated in a standard height chair. The subject's right elbow was flexed to 90 degrees and the forearm positioned between supination and pronation. The shoulder was placed in a position of adduction and neutral rotation, such that the flexed forearm projected perpendicularly from the coronal plane of the body. The observer sat immediately in front of and facing the subject. The dynamometer was then placed in the subject's right hand, with the observer lightly cupping the dial of the instrument in his right hand and the observer lightly supporting the base of the instrument with his left hand. The observer then insured that the dynamometer was being held in such a position that the subject's wrist was extended between neutral and 30 degrees, and so that the subject's wrist was ulnarly deviated between neutral and 15 degrees (Mathiowetz, Rennells, & Donahoe, 1985). The position of the subject and observer is demonstrated in Figure 2. The observer then read the instructions from the data collection sheet (Appendix A). After stating the word "relax," the observer began timing a one-minute rest interval. The dial of the dynamometer was read, to the nearest kilogram, from a position perpendicular to the instrument. The observer recorded the value on the data collection sheet. Upon completion of the one-minute rest interval, the observer repeated the verbal instructions and proceeded for the second trial. The same procedure was repeated for the third trial.

Assumptions of Study

1. Instrument calibration remained consistent between checks of calibration.

2. Subjects exerted maximum effort during all tests of strength.

3. The procedure for randomizing orders of dynamometer handle positions controlled for any physiological or cognitive maturation which may have occurred over the course of the study.

4. The testing environment was sufficiently stable to rule out any effect due to factors such as temperature, lighting, and audience.

5. Sample selection partially controlled for the effect of vocational and avocational factors that may be related to grip strength.

Data Analysis

The anthropometric scale of measurement is ratio in nature, as is the scale of measurement for grip strength. Dynamometer handle settings comprise an interval scale. Statistics which are common in the analysis of the associations of anthropometric dimensions include the Pearson product-moment correlation coefficient (Malina, 1975) and partial correlation coefficients (Hutchinson & Haslegrave, 1980). Due to the composite nature of many of the anthropometric measurements and the number of dimensions being analyzed, linear regression analysis (Hechter, 1959) and multiple regression analysis may often be more appropriate in clarifying the nature of the relationships and in deriving predictive equations. Complex relationships may also be explored through a method known as discriminant analysis.

The questions were tested in their null forms at a 5% level of significance. All analysis was performed using the Statistical Analysis System (SAS). Descriptive statistics included mean, frequency, and distribution. The first and second research questions explored the relationships between anthropometric dimensions and grip strength. These were analyzed with the Pearson product-moment correlation coefficient. The third and fourth questions explored the effect of handle position on strength. These were addressed by analysis of variance to identify any differences among the means. Tukey's Studentized Range (HSD) Test was used to reduce the chance of a Type I error, at alpha = .05. The fifth and sixth questions explored the differences in the means of anthropometric measurements between groups of individuals that obtained maximum strength values at different handle positions. These were subjected to multiple analysis of variance of the means, using Wilks' criterion.

Questions seven and eight were analyzed through predictive discriminant analysis. Klecka (1987) described discriminant analysis as "a broad term which refers to several closely related statistics (p. 8)." It may be used to predict group membership and as a means of describing the results of multiple analysis of variance (Huberty & Barton, 1989). For question seven, subjects were grouped on the basis of optimal handle position for CIGS. For question eight, subjects were grouped on the basis of optimal handle position for MIGS. The ability of the anthropometric variables to discriminate membership into those groups was then analyzed. A linear rule with unequal prior probabilities and pooled covariance was employed.

Questions nine and ten addressed prediction of CIGS, MIGS, HICIGS, and HIMIGS. The coefficient of determination, r^2, which is the square of the correlation coefficient, was employed to evaluate the ability of individual or combinations of anthropometric variables to predict CIGS, MIGS, HICIGS, and HIMIGS, and to determine which variables or combinations of variables would best predict those strengths.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter reports and discusses the results of the study and is divided into four sections. The first section describes the statistical characteristics of the subjects who comprised the sample. The second section answers each research question through presentation of statistical results. The results are then discussed in the third section, which is organized into the relationships involved and the prediction of dependent variables. Reliability data for the dynamometer used in the study are briefly reported in the fourth section, followed by limitations of the study and suggestions for further research.

Characteristics of Subjects

Thirty female subjects comprised the initial sample of subjects. All were students enrolled at Virginia Commonwealth University as occupational therapy majors. Five subjects were used only in the pilot study. Three subjects initiated the series of measurement sessions but did not complete all five sessions. Thirty subjects completed all five measurement sessions and composed the final sample. The age range for the 30 subjects who completed the study was from 21 years to 25 years, with a mean of 22 years. All subjects were right handed.

Measurements for the study were completed over a period of seven weeks. The length of time between consecutive measurement periods ranged from 1 day to 34 days, with a mean of 8.6 days. Due to an error by the observer in selecting the correct dynamometer handle position, one subject completed six sessions. The data from the errant session was not included in analysis. Descriptive data for the anthropometric and highest strength measures are presented in Table 3.

Research Questions Results

Relationship Between Anthropometry and Grip Strength

Research questions one and two examined the relationships between the eight anthropometric dimensions and CIGS, and between the eight anthropometric dimensions and MIGS. Pearson product-moment correlation coefficients for those relationships are reported in Table 4 and Table 5.

For the relationships between the anthropometric dimensions and CIGS the values of the correlation coefficients were highest for the smaller anthropometric dimensions such as measurements of the hand and wrist. Of the eight anthropometric dimensions, hand breadth, wrist breadth, wrist circumference, and forearm circumference

Table 3

Strength and Anthropometric Measurements of Subjects

	Statistic		
Variable	Mean	SD	Range
Anthropometry (cm)			
Elbow to wrist length	25.5	1.1	23.6 - 28.1
Forearm to hand length	43.2	1.8	39.6 - 47.5
Forearm circumference	23.2	1.5	20.7 - 27.0
Wrist circumference	14.6	.7	13.3 - 16.0
Wrist breadth	4.8	.2	4.4 - 5.2
Hand length	17.2	.8	15.5 - 18.9
Hand breadth	7.3	.4	6.6 - 7.9
Digit length	7.3	.4	6.4 - 8.0
HICIGS (kg)	32.1	4.4	17.3 - 38.7
HIMIGS (kg)	33.5	4.6	18.0 - 42.0

Note. *N* = 30. HICIGS = highest individual clinical isometric grip strength; HIMIGS = highest individual maximum isometric grip strength.

Table 4

Pearson Product-Moment Correlation of Anthropometry and Clinical Isometric Grip Strength (CIGS)

	Clinical isometric grip strength (CIGS)				
	Handle position				
Dimension	1	2	3	4	5
Elbow to wrist	-.230	.148	.282	.259	.342
Forearm to hand	-.322	.169	.334	.377*	.436*
Forearm circ	.090	.424*	.446*	.395*	.364*
Wrist circ	.089	.448*	.522**	.389*	.399*
Wrist breadth	.095	.477**	.555**	.436*	.464**
Hand length	-.323	.113	.360*	.474**	.489**
Hand breadth	.049	.529**	.572***	.542**	.482**
Digit length	-.131	.268	.479**	.603***	.593***

Note. N = 30. First two dimensions are length.

Circ = circumference.

*$p<.05$, **$p<.01$, ***$p<.001$

Table 5

Pearson Product Moment Correlation of Anthropometry and Maximum Isometric Grip Strength (MIGS)

	Maximum isometric grip strength (MIGS)				
	Handle position				
Dimension	1	2	3	4	5
Elbow to wrist	-.249	.092	.186	.297	.334
Forearm to hand	-.322	.116	.234	.405*	.432*
Forearm circ	.145	.408*	.379*	.445*	.348
Wrist circ	.094	.422*	.436*	.423*	.379*
Wrist breadth	.094	.442*	.527**	.454*	.449*
Hand length	-.297	.075	.320	.491**	.484**
Hand breadth	.029	.481**	.499**	.540**	.452*
Digit length	-.113	.202	.443*	.614***	.586***

Note. N = 30. First two dimensions are length.

Circ = circuference.

*$p<.05$, **$p<.01$, ***$p<.001$

correlated significantly with CIGS in the greatest number of handle positions, lacking a significant relationship with only handle position number one. Digit length and hand length demonstrated significant correlations with CIGS in handle position three, position four, and position five, while forearm to hand length demonstrated significant relationships to CIGS in handle positions four and five. Elbow to wrist length was not significantly related to CIGS in any handle position. While several dimensions were negatively correlated with CIGS in position one, there were no significant relationships for any factor and CIGS in handle position one. In general, as handle size increased, the number of significant correlations increased.

The eight anthropometric dimensions displayed similar relationships to MIGS as they did to CIGS. As with their relationships to CIGS, breadth and circumferential dimensions displayed the greatest number of significant relationships with MIGS. Elbow to wrist length was not related significantly with MIGS in any handle position and MIGS in handle position one was not significantly related to any anthropometric dimension.

When grouped with related factors, the anthropometric dimensions followed similar patterns. Length dimensions generally displayed significant correlations with CIGS or MIGS in handle positions four and five while breadth and circumferential dimensions generall` had significant relationships with CIGS or MIGS in handle positions two, three, four, and five.

Pearson product-moment correlation coefficients were also computed for the relationship between the anthropometric dimensions and HICIGS, and for the relationship between the anthropometric dimensions and HIMIGS. The strongest relationships were found between strength and breadth dimensions. Circumferential dimensions were not as strongly related to strength as dimensions of breadth. The relationships between length dimensions and strength were not significant. Coefficients for the relationships between strength and the anthropometric dimensions are reported in Table 6.

Difference in Strength Values Across Handle Positions

Research questions three and four asked if there were significant differences in grip strength values at the different handle positions of the Jamar dynamometer. Descriptive strength data are presented in Table 7. Analysis of variance of the means revealed significant differences with values of F = 81.01 for CIGS and F = 76.09 for MIGS, at $p<.0001$ with 4 degrees of freedom. When the group means were ranked from highest to lowest, the handle positions were ordered as position three, position two, position four, position five, and position one. Though the mean values for both CIGS and MIGS were higher in position three than in position two,

Table 6

Pearson Product-Moment Correlation of Anthropometry and Highest Individual Grip Strength

Anthropometric measurement	HICIGS	HIMIGS
Elbow to wrist length	.249	.099
Forearm to hand length	.273	.122
Forearm circumference	.420*	.365*
Wrist circumference	.476**	.419*
Wrist breadth	.528**	.483**
Hand length	.253	.139
Hand breadth	.588***	.516**
Digit length	.356	.264

Note. *N* = 30. HICIGS = highest individual clinical isometric grip strength; HIMIGS = highest individual maximum isometric grip strength.

*$p<.05$, **$p<.01$, ***$p<.001$

Table 7

Strength Characteristics of Subjects

Handle position	Mean	SD	Range
	Statistic		
Clinical isometric grip strength (kg)			
1	21.3	4.0	11.7 - 29.7
2	30.7	4.5	17.3 - 38.7
3	31.2	4.5	16.0 - 38.0
4	27.8	5.2	13.0 - 37.3
5	23.6	4.5	9.7 - 33.3
Maximum isometric grip strength (kg)			
1	22.2	4.1	13 - 31
2	31.7	4.7	18 - 42
3	32.4	4.6	18 - 41
4	28.7	5.1	14 - 38
5	24.5	4.5	11 - 34

Note. N = 30. SD = standard deviation.

Table 8

Tukey's Studentized Range Test for Comparison of Group Means

Handle Position	Mean (kg)	Grouping[a]
	Clinical isometric grip strength (CIGS)	
3	31.18	A
2	30.75	A
4	27.80	B
5	23.61	C
1	21.31	D
	Maximum isometric grip strength (MIGS)	
3	32.40	A
2	31.73	A
4	28.67	B
5	24.53	C
1	22.20	D

Note. N = 30.

[a]Groups having the same letters show no significant difference between them at alpha = .05.

Tukey's Studentized Range Test revealed this difference was not statistically significant (see Table 8). Differences between all other positions were found to be statistically significant for both CIGS and MIGS.

Difference in Anthropometric Measurements Between Groups

Questions five and six addressed the differences in the group means for the anthropometric dimensions of subjects when grouped according to their optimal handle position for CIGS and MIGS. The distribution of optimal handle positioning is presented in Table 9. For CIGS and MIGS, the optimal handle position was most frequently handle position three, followed by handle position two. Handle position four was rarely found to be optimal, and handle positions one and five were not found to be optimal for any subject.

In the design of the study, it had been anticipated that all subjects would obtain HICIGS and HIMIGS in only one position, producing only one optimal position. However, several subjects had more than one optimal position. For purposes of data analysis, data were analyzed twice by alternating the assignment of optimal handle position for those subjects with multiple optimal positions. In both analyses the two subjects who obtained HIMIGS across the second, third, and fourth position were assigned to position three. In both analyses the subjects who obtained HIMIGS across position three and position four were assigned to position three. Those subjects who

Table 9

Distribution of Optimal Handle Position

	CIGS		MIGS	
Handle Position	f	%	f	%
2	9	30.0	8	26.7
3	17	56.7	15	50.0
4	2	6.7	--	--
2 and 3[a]	2	6.7	3	10.0
3 and 4[b]	--	--	2	6.7
2, 3, and 4[c]			2	6.7

Note. N = 30. CIGS = clinical isometric grip strength; MIGS = maximum isometric grip strength.

[a] Includes those subjects who obtained highest individual clinical isometric grip strength (HICIGS) or highest individual maximum isometric grip strength (HIMIGS) in position 2 and position 3. [b] Includes those subjects who obtained HIMIGS in position 3 and position 4. [c] Includes those subjects who obtained HIMIGS in position 2, position 3, and position 4.

had HICIGS or HIMIGS in position two and position three were assigned to position two in the first analysis and to position three in the second analysis.

The results of multiple and univariate analysis of variance are presented in Table 10 for CIGS. Table 11 presents the results of the same analyses for MIGS. For both CIGS and MIGS, and for both the first and second analyses, multiple analysis of variance revealed significant differences between the means of the anthropometric dimensions for subjects grouped as to optimal position. When strength was measured as CIGS, univariate analysis of variance revealed significant differences in all length dimensions among the groups. Breadth and circumferential dimensions showed no difference between groups. This was true for the first and second analyses. When strength was measured as MIGS, univariate analysis of variance demonstrated significant differences in all anthropometric dimensions between groups and for both analyses.

Predictive Discrimination of Optimal Handle Group Membership

Research questions seven and eight explored the degree to which the eight anthropometric dimensions could be used to predict or classify which optimal handle position group any subject would belong to. As with the previous analyses, data were analyzed more than once,

Table 10

Differences Between Optimal Position Groups for Clinical Isometric Grip Strength (CIGS)

	Analysis 1		Analysis 2	
Dimension	*F*	*p*	*F*	*p*
Elbow to wrist length	6.94	.0006	3.51	.0325
Forearm to hand length	7.74	.0013	7.53	.0008
Forearm circumference	0.28	.7566	0.27	.7642
Wrist circumference	0.17	.8474	2.40	.0946
Wrist breadth	0.24	.7859	1.71	.1847
Hand length	13.41	.0001	19.86	.0001
Hand breadth	0.40	.6708	0.54	.5856
Digit length	16.77	.0001	24.24	.0001
Multiple ANOVA[a]	5.42	.0001	10.05	.0001

Note. *N* = 30. Subjects who obtained HICIGS in position two and position three were assigned to position two for the first analysis and to position three for the second analysis. HICIGS = highest individual isometric grip strength.

[a]Wilks' Criterion.

Table 11

Differences Between Optimal Position Groups for Maximum Isometric Grip Strength (MIGS)

	Analysis 1		Analysis 2	
Anthropometric factor	*F*	*p*	*F*	*p*
Elbow to wrist length	22.21	.0001	21.80	.0001
Forearm to hand length	31.93	.0001	29.99	.0001
Forearm circumference	9.50	.0001	9.77	.0001
Wrist circumference	8.64	.0003	5.97	.0032
Wrist breadth	6.86	.0014	3.12	.0471
Hand length	41.04	.0001	37.07	.0001
Hand breadth	15.44	.0001	11.16	.0001
Digit length	41.04	.0001	29.01	.0001
Multiple ANOVA [a]	8.20	.0001	8.88	.0001

Note. *N* = 30. Subjects who obtained HIMIGS in position two and position three were assigned to position two for the first analysis and to position three for the second analysis. HIMIGS = highest individual maximum isometric grip strength.

[a]Wilks' Criterion.

alternating the assignment of optimal handle position for those subjects with multiple optimal positions. Since the results reflected that optimal strength was found in either the second or third handle position for 28 of the 30 subjects, and in that previous research reflects similar findings, additional analyses were carried out with all subjects grouped into either the second or third handle position. In all analyses subjects having HICIGS or HIMIGS across any combination of positions which included the fourth position were assigned to the third position. The three-group classification tables are presented in Tables 12 and 13, while the two-group classification tables are presented in Tables 14 and 15.

The ability of the prediction equation to accurately assign subjects to the correct groupings, or the "hit rate," was higher when subjects were assigned to two groups. For two groups the prediction rule was able to correctly assign 24 of the 30 subjects to their actual optimal handle position, whether for CIGS or for MIGS. This did not vary from the first to the second analysis. For three groups the hit rate varied from a low of 21 out of 30 subjects for MIGS, to 23 out of 30 subjects for CIGS. The proportion of subjects correctly assigned to optimal handle positions compared with the proportion that could be expected by chance alone is presented in Table 16. Prediction of subjects was generally 20% to 30% better than by chance alone.

Table 12

Prediction of Optimal Handle Position for Clinical Isometric Grip Strength with Three Possible Positions

	Predicted position			
Actual position	2	3	4	Sum
	First analysis			
2	7[a]	4	1	12
3	2	14[a]	0	16
4	0	1	1[a]	2
Total	9	19	2	30
Prior probability	.40	.53	.07	
	Second analysis			
2	7[a]	2	0	9
3	3	16[a]	0	19
4	1	1	0[a]	2
Total	11	19	0	30
Prior probability	.30	.63	.07	

Note. *N* = 30. If subject's optimal position was both position two and three, then she was assigned to two for the first analysis and to three for the second analysis.

[a]Correctly assigned to actual handle position.

Table 13

Prediction of Optimal Handle Position for Maximum Isometric Grip Strength with Three Possible Positions

	Predicted position			
Actual position	2	3	4	Sum
	First analysis			
2	7[a]	4	0	11
3	2	12[a]	1	15
4	0	2	2[a]	4
Total	9	18	3	30
Prior probability	.37	.50	.13	
	Second analysis			
2	5[a]	3	0	8
3	3	14[a]	1	18
4	1	2	2[a]	4
Total	8	19	3	30
Prior probability	.27	.60	.13	

Note. N = 30. If subject's optimal position was both two and three, then she was assigned to two for the first analysis and to three for the second analysis.

[a]Subjects correctly assigned to actual handle position.

Table 14

Prediction of Optimal Handle Position for Clinical Isometric Grip Strength with Two Groups

	Predicted position		
Actual position	2	3	Sum
	First analysis		
2	8[a]	4	12
3	2	16[a]	18
Total	10	20	30
Prior probability	.40	.60	
	Second analysis		
2	7[a]	2	9
3	4	17[a]	21
Total	11	19	30
Prior probability	.30	.70	

Note. N = 30. If subject's optimal position was both two and three, then she was assigned to position two for the first analysis and to position three for the second analysis.

[a]Subjects correctly assigned to actual handle position.

Table 15

Prediction of Optimal Handle Position for Maximum Isometric Grip Strength with Two Groups

	Predicted position		
Actual position	2	3	Sum
	First analysis		
2	7 [a]	4	11
3	2	17 [a]	19
Total	9	21	30
Prior probability	.37	.63	
	Second analysis		
2	5 [a]	3	8
3	3	19 [a]	22
Total	8	22	30
Prior probability	.27	.73	

Note. N = 30. If subect's optimal position was both two and three, then she was assigned to position two for the first analysis and to position three for the second analysis.

[a] Subjects correctly assigned to actual handle position.

Table 16

Accuracy of Prediction of Optimal Handle Position Versus Chance Alone

	Number of possible handle positions	
	2	3
Clinical isometric grip strength (CIGS)		
% of subjects correctly predicted	.80, .80	.73, .77
% correctly assigned by chance alone	.53, .57	.43, .50
Maximum isometric grip strength (MIGS)		
% of subjects correctly predicted	.80, .80	.70, .70
% correctly assigned by chance alone	.53, .60	.40, .47

Note. *N* = 30. First number given represents the first of two analyses. The number which follows the comma represents the second analysis. If the subject's optimal position was position two and three, then she was assigned to position two for the first analysis and to position three for the second analysis.

The Prediction of CIGS, MIGS, HICIGS, and HIMIGS

Research questions nine and ten addressed the ability of the anthropometric dimensions to predict grip strength. By step-wise regression, the coefficient of determination, $\underline{r}^2$, was determined for the relationships between strength and the eight anthropometric dimensions. The value $\underline{r}^2$ was derived for CIGS and MIGS at each of the five handle positions, for HICIGS, and for HIMIGS. Values ranged from $\underline{r}^2 = .06$ to $\underline{r}^2 = .58$. Those dimensions which would be most useful in predicting grip strength are presented in Table 17 and Table 18. Values for $\underline{r}^2$ rose as the number of variables increased, and plateaued with combinations of four variables. For CIGS, $\underline{r}^2$ values were higher for handle position two then for handle position three. For MIGS, highest $\underline{r}^2$ values occurred with handle position three. In all cases the values of $\underline{r}^2$ were higher for CIGS than for MIGS. Due to the low values of $\underline{r}^2$, prediction equations were not derived.

Dimensions of the hand comprised the most important dimensions for combinations of three or less. Addition of further variables did little to improve prediction. Wrist breadth became important as a fourth variable. Wrist circumference and forearm to hand length became important with the addition of a fifth and a sixth variable, although not necessarily in that order. Elbow to wrist length and forearm circumference were included only in combinations of six or more variables.

Table 17

Variables Most Influential in Prediction of Clinical Isometric Grip Strength (r^2)

Rank	Position 2	Position 3	HICIGS
First	hand br (.38)	hand br (.28)	hand br (.27)
Second	hand lg (.41)	digit lg (.40)	wrist br (.38)
Third	digit lg (.45)	wrist br (.47)	digit lg (.44)
Fourth	wrist br (.51)	hand lg (.52)	hand lg (.49)
Fifth	elbo-hnd (.53)	wrist c (.53)	wrist c (.51)
Sixth	elbo-wrs (.55)	elbo-hnd (.53)	elbo-hnd (.53)
Seventh	wrist c (.58)	elbo-wrs (.53)	elbo-wrs (.54)
Eighth	forarm c (.58)	forarm c (.53)	forarm c (.54)

Note. N = 30. The r^2 given represents a cumulative value. HICIGS = highest individual clinical isometric grip strength; br = breadth; lg = length; c = circumference; hnd = hand; wrs = wrist; elbo = elbow; forarm = forearm.

Table 18

Variables Most Influential in Prediction of Maximum Isometric Grip Strength (r^2)

Rank	Position 2	Position 3	HIMIGS
First	hand br (.23)	wrist br (.28)	hand br (.27)
Second	hand lg (.27)	digit lg (.35)	wrist br (.30)
Third	digit lg (.36)	hand lg (.44)	hand lg (.39)
Fourth	wrist br (.41)	hand br (.46)	digit lg (.45)
Fifth	elbo-hnd (.42)	wrist c (.49)	wrist c (.48)
Sixth	elbo-wrs (.44)	forarm c (.49)	elbo-hnd (.48)
Seventh	wrist c (.47)	elbo-hnd (.49)	elbo-wrs (.49)
Eighth	forarm c (.47)	elbo-wrs (.49)	forarm c (.49)

Note. N = 30. The r^2 given represents a cumulative value. HIMIGS = highest individual maximum isometric grip strength; br = breadth; lg = length; c = circumference; hnd = hand; wrs = wrist; elbo = elbow; forarm = forearm.

Discussion

The Relationship of Grip Strength to Anthropometric Dimensions

The relationships between grip strength and the eight anthropometric dimensions were low to moderate, regardless of whether grip strength was measured as CIGS, MIGS, HICIGS, or HIMIGS. Although a large number of the relationships were significant, the value of r for those significant relationships was as low as $r = .37$ and never exceeded $r = .62$. The range of values confirmed Malina's (1975) description of the general relationship between body dimensions and grip strength as being moderate, at best. When compared to similar studies conducted by Bowers (1961), Montoye and Faulkner (1964), and Roberts et al. (1959), the relationships between anthropometric dimensions and strength were generally lower than previously reported. A comparison of results of the studies is made in Table 19. The lower values of coefficients in this study may be a function of variance within the populations which have been studied. With the exception of Roberts et al. (1959), previous studies have used samples having both sexes with a greater range of years of age.

As most previous studies have incorporated dynamometers with non-adjustable handles or with uniform handle settings, it may be most appropriate to compare

Table 19

Relationship of Grip Strength and Anthropometry (r)

Reith[a]	Bowers[b]	Roberts[c]	Montoye & Faulkner[d]
	Hand Breadth		
.52, .59	.40 -.44	--	.81 -.85
	Hand Length		
.14, .25	.31 -.42	.47	.65 -.84
	Digit Length		
.26, .36	.41 -.49	--	.84 -.86
	Wrist Circumference		
.42, .48	.52 -.60	--	--
	Forearm Circumference		
.36, .42	.57 -.64	.38	--

[a]This study, N = 30, college-aged females. [b]Study by Bowers (1961) of 100 college-aged males and females. [c]Study by Roberts et al. (1959) of 75 male navy personnel. [d]Study by Montoye and Faulkner (1964), 63 females, children and adults.

those studies with data obtained from HICIGS, HIMIGS, or strength obtained in handle positions two or three. In terms of the strength of the relationship between grip strength and individual dimensions, similar patterns existed between HICIGS, HIMIGS, and strength measurements obtained in handle positions two or three. Breadth and circumferential dimensions displayed significant, low to moderate values, while length dimensions had no significant relationships with HICIGS, HIMIGS, or CIGS and MIGS in handle position two. This consistent pattern may have been related to the fact that 83.3% of the sample obtained HICIGS in position two or three, and 100% of the sample obtained HIMIGS in position two or three.

The relationship of grip strength to anthropometric dimensions demonstrated similar patterns among dimensions of the same class. The length dimensions of hand length and digit length demonstrated the strongest relationships of all dimensions to CIGS and MIGS in the largest handle positions. For the length dimensions, the association with strength diminished markedly as the handle size decreased below position three, resulting in negative relationships to strength in handle position one. Though these negative relationships were insignificant, this consistent pattern suggests that long fingers and hands are associated with greater strength as the span of grasp is increased.

The association of greater strength in the larger handle positions for those with longer hands and fingers, and less strength in the larger handle positions for those with shorter hands and fingers may be the result of a biomechanical advantage. It was noted that as a subject attempted to grasp the dynamometer when it was set at larger handle positions, wrist extension and metacarpal-phalangeal joint flexion decreased. The amount of this decrease would be greatest for those subjects with the shortest hands.

Loss of extension at the wrist reduces the efficiency of the long flexors of the digits (Kapandji, 1982). This may be the result of losing the fulcrum that is normally provided as the tendons pass over an extended wrist. Further, loss of flexion at the metacarpal-phalangeal joint deprives the long flexors of another fulcrum, that provided by the pulleys of the flexor tendon system that are proximal to the proximal interphalangeal joint of the finger. The relationship between loss of wrist extension and loss of grip strength has also been explained as having a physiological basis, in that the flexors may be at their optimum length for producing tension when the wrist is in extension (Brunnstrom, 1979).

The relationships between breadth and strength and the relationships between circumferential dimensions and strength displayed less variance from handle position to handle position than did the relationships between grip strength and length factors. The values of the correlation coefficients related to hand breadth varied less than .04 across handle positions two, three, four, and five. The values of correlation coefficients related to wrist breadth, wrist circumference, and forearm circumference varied less than .12 across handle positions two, three, four, and five. This presented a markedly different pattern than that for length factors, which varied as much as .38 across handle positions two, three, four and five. The difference in these patterns suggests that the relationships between breadth factors and grip strength, and the relationships between circumferential factors and grip strength are less affected by changes in handle position than are the relationships between length factors and grip strength.

The high number of significant relationships between anthropometric dimensions and grip strength in handle positions two, three, four, and five, and the lack of any significant relationships with grip strength in handle position one may suggest that strength in the first position is not related to the physical dimensions of the subject or that strength in the larger handle positions is proportional to the length of a subject's hand and fingers.

The dimension of forearm to hand strength was a composite measurement of elbow to wrist length, hand length, and digit length. The lack of any significant relationships between elbow to wrist length and grip strength, and only two significant relationships between forearm and hand length and grip strength being at position four and five suggests that the relationships between forearm to hand length and grip strength in positions four and five are a function of hand or digit length.

Grip Strength and Handle Positions of the Jamar Dynamometer

Highest mean values for CIGS or MIGS occurred at position three but these values were not significantly different than mean values obtained at position two. Mean strength then diminished from position three to position two, then to position four, then to position five, with position one having the lowest mean strength. This pattern reflected the biomechanical curve described previously by Fess (1982; 1984).

Twenty-eight of the thirty subjects obtained HICIGS or HIMIGS in handle position two or handle position three. These results support the findings of Petrofsky et al. (1980), who reported that greatest strength values could be obtained at grip spans of between 5 cm to 6 cm. For the Jamar dynamometer, the span of grip at handle position two measures 4.70 cm and the span of grip at handle position three measures 5.97 cm.

These findings also echo previous results which have reported that highest grip strength values are obtained at handle position two or three of the Jamar dynamometer (Matheson et al., 1988; Niebuhr & Marion, 1987) and support those studies which measured grip strength at either handle position two or handle position three of the Jamar dynamometer (Fike & Rousseau, 1982; Hinson & Gench, 1989; Kellor, Kondrasuk, Iversen, Frost, Silberberg, & Hoglund, 1971; King & Berryhill, 1988; Mathiowetz et al., 1984; Mathiowetz, Kashman, Volland, Weber, Dowe, & Rogers, 1985; Mathiowetz, Rennells, & Donahoe, 1985; Mathiowetz et al., 1986). The lack of any significant difference between mean strength values in handle position two and mean strength values in handle position three lends support to the recommendations of the ASHT, who have established handle position two as the appropriate handle position for strength testing.

Prediction of Optimal Handle Position

Prediction of the handle position at which a subject would obtain HICIGS or HIMIGS was only slightly more accurate with two possible positions than with three possible positions. In both cases, however, it was possible to exceed the number of subjects that could be accurately assigned by chance alone. Varying the method in which borderline subjects were assigned to optimal positions usually improved the number of correct assignments to one position at the cost of reducing the number correctly assigned to another. Overall, varying the method of assigning borderline subjects did not alter the total number of subjects assigned correctly.

Analysis of variance based upon the same subject assignment used in the discriminant analysis served to identify tho e anthropometric dimensions which may be most useful in predicting optimal handle position. The highly-significant _F_ values obtained with multiple analysis of variance, regardless of how subjects were assigned, indicates that significant differences existed between the group means for anthropometric dimensions. Univariate analysis revealed that there were significant differences between groups for all dimensions when strength was measured as MIGS. When strength was measured as CIGS, only length dimensions varied significantly. This may reflect less variability in data that is taken as an average of three trials.

The difference in length dimensions among groups when strength was measured as CIGS may clarify the relationship between dimensions of length and grip strength across the handle positions. The relationship between breadth dimensions and strength demonstrated little variance in the value of _r_ across handle positions two, three, and four. Length dimensions displayed much more variance in their relationship to strength across those handle positions. This may suggest that the most useful dimensions for prediction of optimal position may be dimensions of length. This finding opposes that of

Montoye and Faulkner (1964) who reported that hand width was the most important criterion in adjustment of the dynamometer handle, and supports studies of Fess (1982) and Bowers (1961) who suggested that length factors of the hand we e most important.

The practicality of predicting optimal handle position is limited. While length dimensions appear promising as a means of predicting whether an individual will obtain maximum strength in handle positions two or three, analysis of variance demonstrated no significant difference between those two handle positions. For the clinician seeking a maximum strength value, it is of little value to know whether handle position two or handle position three should be used, if it is known that the vast majority of subjects obtain maximum strength values in either of those two positions and that there is no significant difference between the two.

Prediction of HICIGS, HIMIGS, CIGS, and MIGS

Based upon the low to moderate $\underline{r}$ values obtained, prediction of grip strength seems questionable. Step-wise regression provided some insight into the value of single and various combinations of variables in predicting strength; however, $\underline{r}^2$ never exceeded .58 for CIGS or .47 for MIGS. It was demonstrated, however, that the most important dimensions were hand breadth, hand length, digit length, and wrist breadth. While it is possible to derive predictive equations, the low values of $\underline{r}^2$ would hinder the accuracy of such predictions and would preclude practical clinical use.

Reliability of the Jamar Dynamometer

The dynamometer used in this study was tested as to reliability immediately before and after the seven-week measurement period, rendering correlation coefficients of $\underline{r}$ = .9998 both before and after testing. These values exceeded the acceptable performance levels established by Fess (1987).

Limitations of the Study

The size and characteristics of the sample limit generalization of the results to the general population. Grip strength studies have employed diverse populations, various types of dynamometers, and differing measurement procedures. The value of comparing the results to other studies which have employed anthropometric measurement is limited by a lack of standard terminology, equipment, and technique. Comparison of the results of this study to similar studies should be made with an awareness of those differences. Perhaps the most closely related studies are those of Mathiowetz et al. (1984; 1986), Mathiowetz, Kashman, Volland, Weber, Dowe, and Rogers (1985), and Mathiowetz, Rennells, and Donahoe (1985).

Use of the discriminant analysis procedures used in this study is limited by factors related to the sample used. Being a single sample, internal rather than external classification was required, limiting the value of prediction. The small size of the sample also restricts the value of prediction, as do the characteristics of the population. Finally, the relatively high number of borderline subjects further limits the predictive value.

Recommendations for Further Research

1. The finding of female subjects with maximum strengths in handle position four, and the apparent relationship between length dimensions and grip strength across handle positions may warrant research with male subjects, as that population has longer fingers and hands. While the results appear to support current clinical procedures for testing grip strength, optimal positioning should be verified in males and for other age groups.

2. Repetition of the study with a dynamometer which could be read more precisely, such as the Jamar digital model, would decrease the incidence of subjects with equal strength in multiple handle positions. Such data would clarify the predictive ability of discriminant analysis procedures by eliminating borderline subjects. The use of more than one sample would also enhance the value of prediction by allowing external classification.

3. Additional research with controls for morphology, relative amount of body fat, vocations, avocations, and other variables related to grip strength may clarify the true relationships between anthropometric dimensions and grip strength.

CHAPTER FIVE

SUMMARY AND CONCLUSIONS

This chapter summarizes the attempts of this study to clarify the relationships between several anthropometric variables, grip strength, and handle adjustment of the Jamar dynamometer. The first section reviews the study in terms of the literature appropriate to the variables of interest, procedures, and results. Conclusions of the study are stated in the second section.

Review of the Study

Literature Review

Since the last century, researchers from numerous and diverse fields have sought an increased understanding of the relationships between various human characteristics and isometric grip strength. Increased understanding of these relationships along with the ease with which grip strength can be measured has led to the use of grip strength testing to assess normal growth and development in children, to assess ergonomic factors in work activities (Kiser & Rodgers, 1983), and for purposes within the health professions. Common medical uses have centered about assessment of hand function; however, they have grown to include diagnostic and prognostic uses.

Continued research has been focused on the relationship of several human variables to grip strength. These have commonly included age, gender, weight, height, body composition, and morphology. In the adult population, the correlations between grip strength and weight, or grip strength and height have been reported as being from r = .30 to r = .60 (Fisher & Birren, 1947; Lunde et al., 1972; Pierson & O'Connell, 1962; Tinkle & Montoye, 1961; Wessel & Nelson, 1961).

The introduction of the adjustable dynamometer in the 1950's introduced a new factor--span or size of grasp. Early research demonstrated a definite, though unquantified relationship between the span of grasp and grip strength, as authors noted a variation in grip strength which occurred with variation in handle spacing, or with variations in the size of the hand (Bechtol, 1954; Everett and Sills, 1952; Kirkpatrick, 1956). Several studies later demonstrated that an optimal 1 cm span of grasp existed for each individual and that greatest strength occurred at handle spans which ranged from approximately 4.5 cm to 6.0 cm (Bowers, 1961; Montoye & Faulkner, 1964; Petrofsky et al., 1980).

Anthropometric dimensions offered some promise in determining appropriate adjustment of the dynamometer handle for each individual. The relationship between the various dimensions of the upper extremity and grip strength in adults have generally been reported as ranging from $\underline{r}$ = .30 to $\underline{r}$ = .65 (Bowers, 1961; Little & Johnson, 1986; Roberts et al., 1959). For a population of adults and children the relationship between measurements of the hand and grip strength were reported as exceeding $\underline{r}$ = .80 (Montoye & Faulkner, 1964). Generally, authors have concluded that no anthropometric factor was strong enough in its relationship to grip strength to serve as a predictor of grip strength. Further, authors have generally concluded that precise adjustment of the dynamometer was probably not necessary. If adjustment of the dynamometer handle is desirable, authors have recommended the use of finger length or hand length (Bowers, 1961), long finger length (Fess, 1982), or hand width (Montoye & Faulkner, 1964).

The value of earlier studies in determining appropriate adjustment of a dynamometer is limited by much variance as to which body dimensions were measured, varying definitions for the same dimensions, and differing measurement techniques. Common anthropometric measurements of the upper extremity have been defined by numerous authors (Cameron, 1984; Comas, 1960; Hrdlicka, 1939; Lohman, Roche, & Martorell, 1988; Weiner & Lourie, 1969); however, even these authors have varied in the number, landmarks, description, and definition of the dimensions. Additionally, the lack of consistent methods, equipment, and procedures may contribute to a problem of consistency that has been noted by professional anthropometrists (Cameron, 1984; Gavan, 1950; Malina, 1975). The consistency of observers in earlier grip strength studies may be questioned, as most made no mention of techniques to control consistency, such as the use of uniform statistics, repeated measurements, or tolerance limits.

The growing use of grip strength assessment by occupational therapists and other professionals reinforces the need for insuring that the equipment and methods that are used to assess grip strength are reliable and valid. The Jamar dynamometer remains the most common dynamometer used within occupational therapy clinics (Smith & Benge, 1985). Research has demonstrated the reliability and validity of the Jamar dynamometer and has supported the standard subject positioning recommended by the ASHT. The optimal span for obtaining maximum grip strength which has been reported by previous studies would correspond most closely with handle positions two and three of the Jamar dynamometer. Clinicians and researchers are not in agreement, however, as to whether handle position two or handle position three is most appropriate for testing, or even if any distinction should be made.

The validity of applying earlier research which used dynamometers other than the Jamar model, to the Jamar model is questionable. There is a need to study the relationship of grip strength to handle position of the Jamar dynamometer. If grip strength varies significantly between handle positions, there is a need to determine the adjustment of the handle position for each individual. The usefulness of earlier studies of grip strength and anthropometry is limited by the lack of standard anthropometric technique. There is therefore a need to clarify the relationship of anthropometry of the upper extremity to optimal positioning of the Jamar dynamometer handle, and to grip strength, using recently established anthropometric guidelines. Such a study may indentify anthropometric predictors of optimal handle placement.

Procedures

A study was conducted to determine the relationships between isometric grip strength and eight anthropometric dimensions of the upper extremity, and the relationship between isometric grip strength and handle position of the Jamar dynamometer. Additionally, the study explored the potential for predicting optimal positioning of the Jamar dynamometer handle, based upon anthropometric dimensions.

Isometric grip strength was measured at each handle position of the dynamometer as the average of three trials to incorporate common clinical practices and the recommendations of the ASHT. For this study, such strength was termed CIGS. Due to research findings which have indicated that isometric strength deteriorates with repeated trials (Kroll, 1962; Kroll, 1963) isometric grip strength was also measured as the highest of the first two trials. This was termed as MIGS. The highest CIGS and MIGS for any subject, regardless of handle position, was termed HICIGS and HIMIGS, respectively. Eight anthropometric dimensions were selected based upon use in previous studies, and for their potential and logical relationships to grip strength. Anthropometric measurements were defined and measured in accordance with published anthropometric standards.

A pilot study was conducted to determine intraobserver reliability and to train the observer in the use of anthropometers and tape measure. During the pilot study measurements were practiced until the consistancy of the observer exceeded $\underline{r} = .85$. For six of the eight measurements values ranged from $\underline{r} = .96$ to $\underline{r} = .99$. Prior to and following data collection the Jamar dynamometer was checked for reliability in accordance with the recommendations of Fess (1987). The Pearson product-moment correlation coefficient exceeded .9998 on both occasions.

A sample of 39 subjects was drawn from an urban university located in the middle Atlantic region of the United States. Six subjects exceeded the age limit of 25 years and were used only in the pilot study. Three subjects did not complete the study. The final sample consisted of 30 right-handed, female university students, ranging in age from 21 years to 25 years, with a mean age of 22 years.

Data were collected over a period of seven weeks. Each subject attended five measurement sessions. All sessions were at least one day apart. Anthropometric measurements were made at each session, until measurements taken on two consecutive days fell within a tolerance limit of .2 cm. This limit was established from the data of previous anthropometric studies. For the 30 subjects in the main study, a total of 240 measurements were taken twice. To adhere to the tolerance limit, 44 measurements (18.3%) were repeated an additional time. All measurements were taken from the right upper extremity. Grip strength of the right hand was measured at each session, with each session consisting of three trials in one handle position. A random order of handle positions for each subject was determined by the use of permuted Latin squares. One minute of rest was allowed between trials. Position of the subject, instrument, and verbal protocol followed the clinical standards of the ASHT and those used by Mathiowetz et al. (1985).

Results

Significant correlation coefficients existed between all dimensions, except elbow to wrist length, and grip strength, whether measured as CIGS or MIGS. Length dimensions were not significantly related to strength in handle position one or two, and significant coefficients for handle positions three to five ranged from *r* = .36 to *r* = .61, being highest in the larger handle positions and highest for digit length. Breadth and circumferential dimensions were related to CIGS and MIGS with significant coefficients at handle positions two through five. Values for *r* ranged from .38 to .57. For HICIGS and HIMIGS significant relationships existed between breadth dimensions and grip strength, and between circumferential dimensions and grip strength, ranging from *r* = .37 to *r* = .59.

Ranked as to mean value, the greatest mean CIGS or MIGS occurred at handle position three, followed by handle positions two, four, five, and one. Analysis of variance of the means revealed significant differences in strength among groups ($p<.0001$), whether measured as CIGS or as MIGS. Multiple comparison confirmed that there was no significant difference between strength at handle position two and handle position three, although significant differences existed between all other positions, at alpha = .05.

When subjects were grouped as to optimal handle position for MIGS, analysis of variance revealed significant differences between the group means for all eight anthropometric dimensions. When subjects were grouped as to optimal handle position for CIGS, significant differences existed between the group means for only the dimensions of length.

Predictive discriminant analysis of optimal handle position correctly assigned more subjects to their actual optimal position than would occur by chance alone. The "hit rates" ranged from 21 out of 30 subjects correctly assigned, to 24 subjects out of 30 correctly assigned. Highest hit rates occurred when all subjects were assigned to two possible handle positions, those being handle position two or handle position three. Lowest rates were associated when all subjects were assigned to three possible positions, those being handle position two, handle position three, and handle position four.

The coefficient of determination $\underline{r}^2$ was derived by step-wise regression for the relationship between the anthropometric dimensions and CIGS at handle positions two and three and the relationship between the anthropometric dimensions and MIGS at handle positions two and three. It was also determined for the relationship between the anthropometric dimensions and HICIGS and HIMIGS. For all definitions of strength, values of $\underline{r}^2$ were highest for the single dimension of hand breadth ($\underline{r}^2$ = .27 - .38). The values for $\underline{r}^2$ were slightly higher for CIGS than for MIGS, and for HICIGS than for HIMIGS. Values of $\underline{r}^2$ began to peak at multiples of four variables or less. For multiples of four variables or less, values were highest for the dimensions of hand breadth, hand length, digit length, and wrist breadth.

Discussion

The relationships between the eight anthropometric dimensions and strength were moderate in strength, at best, and fell within the rangesof coefficients that have been reported in previous studies. This was true when analysis was conducted with strength defined as CIGS, MIGS, HICIGS, or HIMIGS. In general, the dimensions of breadth appear to be most strongly related to strength when measured in handle position two or handle position three. The fact that breadth dimensions also show the strongest relationship to HICIGS and HIMIGS is most likely related to the fact that 83.3% of the subjects obtained HICIGS in either handle position two or three, and 100% of the subjects obtained HIMIGS in either handle position two or three. Length factors appear to be strongest in relationship to grip strength in handle positions four and five. Further, the relationships between length dimensions and grip strength appeared most affected by changes in handle position.

The high percentage of subjects who obtained greatest grip strength (i.e., HICIGS or HIMIGS) in either handle position two or handle position three supports earlier studies which have suggested that greatest strengths were obtained at a grip span that ranged from 2.5 cm to 6.0 cm. These measurements correspond with handle positions two and three of the Jamar dynamometer. The lack of any significant difference between mean strength at handle position two and mean strength at handle position three lends support to the clinical assessment recommendations of the ASHT that strength should be assessed in handle position two.

The presence of significant differences in the mean values of anthropometric dimensions between subjects grouped according to optimal handle position suggests that anthropometric dimensions could serve as predictors of optimal handle position. However, the statistic employed may have detected even minute significant differerces in group means despite there being great overlapping of group membership. Such overlapping impairs discrimination.

The ability of predictive discriminant analysis techniques to correctly predict optimal handle position for more subjects than could be correctly predicted by chance alone lends some support to prediction of group membership. However, the ability to generalize such data is limited by the fact that the classification of subjects in this study was internal, that is, subjects were classified as to optimal handle position based upon a linear formula that was derived from data on the same subjects. Additionally, several subjects had optimal strength in more than one handle position. The presence of these borderline subjects diminishes the value of prediction. In light of the fact that the great majority of subjects obtained their greatest strength in position two or position three and since there was no significant two or position three and since there was no significant difference between mean strength in those positions, prediction of optimal handle position appears to be unnecessary.

The results of step-wise regression suggest that the anthropometric dimensions of hand breadth, hand length, digit length and wrist breadth might be the best of all eight dimensions for predicting grip strength. However the values of $\underline{r}^2$ obtained were less than necessary for meaningful prediction of grip strength.

Although grip strength was defined as an average of three trials (CIGS) and as the highest of the first two trials (MIGS), data analysis did not appear to vary greatly between the two definitions. Regardless of how strength was defined, the analysis of the data did not seem to be greatly impacted.

Conclusions

1. The results of this study suggest that there is only a moderate relationship between anthropometric dimensions of the forearm and hand and isometric grip strength as measured by the Jamar dynamometer.

2. While no single anthropometric dimension appears to be strong enough in its relationship to grip strength to serve as an adequate predictor of grip strength, hand breadth appears most promising.

3. For the Jamar dynamometer, greatest isometric grip strength in young female adults is obtained in handle

position two or handle position three. There is no significant difference between strength in those positions. Assessment of the maximum isometric grip strength of young female adults should be done with the Jamar handle placed in either position two or position three. Specific adjustment of the handle for each individual seems unnecessary; however, if adjustment is desired it should be based upon hand length or length of the long digit.

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Appendix A

Data Collection Form

Subject's Initials |__|__| Subject Number |_|_|
Age |_|_| Last 4|_|_|_|_| Date (MDY) |_|_|-|_|_|-89
Time (24 hour) |_|_|_|_|

Right Hand Grip Strength

Random order for subject |_|_|_|_|_|_| (Matrix #___)
Position tested today |_|
Instructions: "I'm going to measure your grip strength now. I want you to hold the handle like this and squeeze as hard and as fast as you can." The observer will then demonstrate and place the dynamometer in the subject's hand. "When I ask you to 'squeeze,' squeeze the handle as hard and as fast as you can. You will not be able to feel the handle move, but keep squeezing as hard as you can until I tell you to 'relax.' Do you understand the instructions? Are you ready? Squeeze!...harder!...harder!...relax." The instructions are repeated on the second and third trials.

Trl 1:|__|__| kg // Trl 2:|__|__| kg // Trl 3:|__|__| kg
CIGS: |_|_|.|_| kg MIGS: |_|_| kg

Anthropometry

Date (MDY) |_|_|-|_|_|-89 Time (24 hour) |_|_|_|_|
Position of the subject for measurements 1 and 2: Elbow flexed to 90 degrees, forearm in neutral supination/pronation, wrist and fingers in neutral extension.

1. Elbow to wrist length: |___|___|.|___|cm
2. Elbow to long finger tip length: |___|___|.|___|cm

Position of subject for measurement 3: Arm suspended loosely at the side with muscles relaxed.

3. Maximum forearm girth: |___|___|.|___|cm

Position of subject for measurements 4 and 5: Elbow flexed to 90 degrees, forearm in neutral supination/pronation, relaxed hand.

4. Wrist girth: |___|___|.|___|cm
5. Wrist breadth: |___|.|___|cm

Position of subject for measurements 6, 7, and 8: Elbow flexed to 90 degrees, forearm and hand supinated such that the plane of the hand is parallel to the floor, wrist and fingers in neutral extension, thumb abducted in the plane of the hand.

6. Hand length: |___|___|.|___|cm
7. Hand breadth: |___|.|___|cm

8. Length of long digit: |___|.|___|cm

Appendix B

Subject Consent Form

Subject Consent Form

Title of Research: The relationship of isometric grip strength, optimal dynamometer settings, and certain anthropometric factors.

Introduction: My name is Michael Reith. I am a registered occupational therapist and a graduate student. I am conducting research to improve the value of grip strength measurements, in partial fulfillment of the requirements for a Master of Science degree at Virginia Commonwealth University. My study involves comparing various measurements of the arm and hand to measurements of grip strength. Various lengths, widths, and circumferences of your arm and hand will be measured twice. You will then be asked to perform three trials of grip strength over different settings of a device which registers your maximum strength. The measurements will be divided over five different days.

Benefits: The information that is gathered during this study may lead to a consistent method of measuring the grip strength of medical patients and increase the value of measurements that are taken. It may also increase the understanding of how grip strength is related to the size of the human hand and arm.

Alternative Therapy: This is not a treatment or therapy but merely an assessment.

Risks, Inconveniences, Discomforts: There are no risks, inconveniences, or discomforts related to this study.

Costs of Participation: There are no expenses to you that are related to your participation in this study, other than your time.

Pregnancy: This area is not applicable to this study.

Research Related to Injury: There are no invasive procedures involved in this study. However, in the event of physical and/or mental injury resulting from your participation in this research project, Virginia Commonwealth University will not offer compensation.

Confidentiality of Records: During the recording of measurements you will be identified only by your first and last initials and the last four digits of your social security number. You will not be able to be identified in the reporting of study results.

Initials:______

Withdrawal: Your participation is entirely voluntary. You may withdraw from the study at any time. If you have any questions concerning your participation in the study, you may ask them at any time during the study, or contact me at (804) 740-2334.

I, ____________________________, agree to participate in a study of grip strength and arm measurements. I understand that my participation is voluntary, that I may withdraw from the study at any time, and that any questions I have will be answered by the researcher. I also understand that in the event of any physical or mental injury resulting from my participation in this research project, Virginia Commonwealth University will not offer compensation. A copy of this form has been provided to me.

_________________________________ __________
Signature Date

____
Witness

Vita

Michael S. Reith was born in Nurnburg, Germany and is an American citizen. He graduated from Richfield High School, Waco, Texas, in 1973. He received his Bachelor of Science in Occupational Therapy from the University of Texas at San Antonio and the University of Texas Health Science Center at San Antonio in 1982. Following brief practice as an occupational therapist with the Veteran's Administration Medical Center at Waco, Texas, he was commissioned in the Biomedical Sciences Corps of the U.S. Air Force. He has since served in U.S. Air Force hospitals in Texas and Alaska.