CHAPTER 1

STATEMENT OF THE PROBLEM

Medical Practitioners and Allied Health Professionals regard measurement of isometric grip strength as one of the indications of upper limb strength. Improvements in grip strength are often used to infer degree of recovery after injury. Due to the amount of variation in grip strength in normal population databases, pre-morbid grip strength is difficult to determine, but some estimate is required for establishing outcome levels and for compensation purposes. Many normative databases have been published over the years, yet few of them have focused on teenagers and none of the Australian databases have been updated recently. No Australian databases have spanned the 13 to 17 year age group using the popular Jamar™-like isometric, hydraulic handgrip dynamometers. To estimate the grip strength of an injured hand two approaches are used. Firstly, the pre-morbid grip strength of the injured hand has been assumed to be equal to that of the contralateral uninjured hand, because many databases have only supplied the grip strength of one hand per participant (Häger-Ross & Rösbland, 2002; Kreipe & Gewanter, 1985). Secondly, the strength of the injured hand has been estimated via prediction equations (Hanten et al., 1999).

A variety of dynamometers and manometers have been used in grip strength studies to determine sincerity and reliability of effort, and to screen for malingerers (Dvir, 1999; Hamilton Fairfax, 1996). The number of “faking” studies aimed at identifying sincerity of effort in grip strength testing give testimony to the desire to identify and further examine those with inconsistent grip strength performance (see review by Shechtman, Gutierrez & Kokendofer, 2005).

From day-to-day, many variables affect measures of grip strength, such as amount of bed rest, pain, medication levels, position of the wrist and time of day. However, these variables do not account for more than 6 to 30% of the day-to-day variation (Haward & Griffin, 2002). Therefore other unidentified variables may also contribute, including the retest time interval, the degree of hand dominance, anthropometric proportions, and the shape of the hand being tested. It has not been clearly established whether the dominant hand can achieve higher reliability values when grip strength tested than the non-dominant hand, or whether mixed-handed people have grip
strength biases between their two hands, as is common with right-handed people (Petersen, Petrick, Connor, & Conklin, 1989), since research to date has not determined and assessed the degree of hand dominance of test participants. Hand shape has also not been examined to determine if all shapes have equal ability to produce and reproduce maximal grip strength on the most commonly used hand grip dynamometer, the Jamar™ or computer-linked Jamar™-like dynamometers, such as the GripTrack™. Although teenagers suffer from upper limb injuries, they are a group who have often been overlooked in the grip strength research. There are therefore some unresolved issues and relatively unexamined populations in the domain of grip strength research that deserve attention.

RESEARCH OBJECTIVES

Teenagers are a group that is old enough to have stabilised their hand preferences but are young enough to have experienced relatively few injuries. The aims of this research were to (a) assess the degrees of handedness in a group of randomly recruited healthy teenagers (by way of a handedness inventory which would be shown to be valid and reliable for this population), (b) assess the influence of their handedness on their grip strength, (c) establish a grip strength normative data base for Australian teenagers from this data, (d) develop grip strength prediction models, and (e) establish the level of reliability of the grip strength measurements of these teenagers.

To ascertain the reliability of their grip strength they were repeat-tested in clinically relevant time periods, such as one or four weeks. To identify the variables that influence the performance of their two hands their anthropometric measurements and background profile data (age, gender, past healed injuries, activity levels) were recorded. The reliability of the grip strength difference between the two hands (the grip strength ratio) was also examined to ascertain whether one hand could act as a stable reference point for the pre-morbid grip strength of an injured hand, taking into account the possible influences of dominance. It was anticipated that the teenagers would represent a relatively injury-free population, who were nearing their peak physical abilities, and because of the narrow age band, could be considered to be a relatively homogenous group. To confirm that this sample of teenagers were
representative of all suburban teenagers in Australia with respect to their measured independent variables (handedness, anthropometric details, etc) they were compared with existing normative databases. From this confirmation their grip strength force values and the reliability of these force values could be validly used for comparisons with other Australian teenagers, by treating clinicians and others.

To assess the validity and reliability of the handedness assessment, the test protocol was given to 658 teenagers (including the grip strength tested teenagers) and 45 of these teenagers were retested with the inventory and compared with the repeat responses of 45 adults. The handedness patterns of these teenagers were used for comparison with the grip strength tested teenagers, to ensure that the latter teenagers had the same J-shaped distribution of degrees of handedness as their peers.

**THESIS ORGANIZATION**

This thesis is divided into two sections, with the first four chapters providing background and the remaining six chapters covering original prospective-designed experimental research. First, hand anatomy and background regarding the impact of hand injuries and how they are assessed is presented. As grip strength assessment tools have developed over the last 300 years with no recently published literature review of their evolution, a historical review is presented in this thesis. Thereafter, the gender differences in relation to how grip strength is generated and the effect of handedness on maximal isometric grip strength are considered. These topics are presented in Chapters 1 to 4. The latter topic has been published in the American Journal of Occupational Therapy and is reproduced in Appendix A (Clerke & Clerke, 2001). Second, the three experiments outlined in Chapter 5 are described, along with the general methodology for these experiments. These experiments consisted of (a) evaluating the reliability and validity of the Edinburgh Handedness Inventory (Chapter 6), then (b) grip strength testing a sample of healthy teenagers and (c) repeat testing these teenagers to determine aspects of reliability of their grip strength values for their two hands over time.
Considerations related to the characteristics of the sample of teenagers are presented in Chapter 7 along with discussion regarding the variables that affect grip strength. Chapter 8 deals with the reliability of the grip strength scores of the two hands, and Chapter 9 reports the reliability of the grip strength ratio between the two hands. As the shape of the hand was found to have a significant impact on the reliability of grip strength scores it was presented in detail in Chapter 10. This finding helps to account for some of the lower reliability of grip strength tests with females, and this chapter has been published in the Journal of Hand Therapy and is reproduced in Appendix B (Clerke, Clerke & Adams, 2005). In chapter 11 a summary of the findings, and their relevance to clinicians and researchers in the field of grip strength testing, is presented.

TERMINOLOGY

Rauch et al. (2002) point out that the correct term for grip strength is “grip force” because “‘force’ is a term that is clearly defined by physics, whereas ‘strength’ is used inconsistently in the medical literature, denoting a variety of different measurements, including force, torque, and power” (paragraph 9 in online article, denoted as ¶ 9). However, the term grip strength is used widely in the hand therapy literature to mean grip force, and so it will be the term of choice in this thesis. The other terminology problem is the use of kilogrammes of force for the effort generated with handgrip dynamometers. These resultant forces should in fact be measured in Newtons, but again as the hand therapy literature uses kilogrammes of force or pounds of force, this thesis will follow convention and quote grip force in the metric units of kilogrammes of force (kg f).

FUNCTIONAL ANATOMY AND THE IMPACT OF HAND INJURIES

Before the factors that influence grip strength testing can be presented, it is necessary to review the structure and function of the hand, in order to give some reasons as to why occupational therapists, physiotherapists and medical practitioners all assess grip strength and consider it to be a valid measure of hand function.
We first discover our hands in utero. Via recent advances in diagnostic ultrasound techniques a baby at 15 weeks gestation can be viewed in utero sucking a thumb in real time (Hepper, Shahidullah & White, 1991). Once born, babies explore their environment by reaching and grasping objects. The human hand is equipped for strength, speed, dexterity and expression of emotions.

The complexity of the hand is evident upon dissection. Under the skin there are 19 bones, 17 articulations and 19 muscles. The 18 tendons that originate beyond the wrist along with the 5 tendons that insert at the level of the wrist enable the hand to be stabilised in optimal positions for grasping, manipulating and releasing. An intact nervous system helps to sense, monitor and feedback motor performance for optimal proficiency.

**Nervous system - Sensory component**

There are more sensory receptors per square millimetre in the skin of the hand than in any other part of the body, except for the lips. The hand can perspire to lose heat, grow nails to protect the distal ends of the fingers, feel the strings of a violin and detect etched lines in glass 0.00254 millimetres deep (Brand & Hollister, 1999). These abilities are mediated via the peripheral nervous system, which consists of both the somatosensory and sympathetic nervous systems. Messages are relayed to and from the cerebral cortices. The sensory and motor control regions for the body occupy large areas of these cortices, as seen in **Figure 1.1**. Of importance to grip strength testing and sense of effort is the output from the muscle spindle stretch receptors and the Golgi tendon organs, the latter in particular respond to load placed on the muscle-tendon unit. Nociceptive inputs from the skin, muscles and cutaneous mechanoreceptors also influence the achievement of maximum output for generating grip strength.
The hand has three peripheral nerves, the radial, median and ulnar nerves. They provide sensory input and motor output between the brain and the hand. The area of skin that they each innervate and the muscles that they control are best represented by a map and three tables, see Figure 1.2 and Tables C.1, C.2 and C.3 in Appendix C. As can be seen from Figure 1.2 the sensory components of the median and ulnar nerves supply all the input to the brain from the volar surface of the hand around to the nail beds of all the fingers and along the volar surface of the forearms. Sensory feedback from the cutaneous receptors in the fingertips change muscular activity.
within 50-100 milliseconds of contact with an object, thus sensory input has a key role in modulating the force that is used to grip an object (Collins, Knight & Prochazka, 1999).

**Figure 1.2. Sensory nerve distribution to the upper limbs (from Swanson, de Groot Swanson & Göran-Hagert, 1995).**

The sensory and motor branches of the peripheral nerves run in the same nerve bundles in the forearm and generally only divide at the level of the wrist. Thus injuries to these nerves at or proximal to the wrist will have elements of reduced sensitivity and muscular paralysis, and consequently will result in greater levels of hand impairment and disability than injuries in the palm or digits. The impact of an injury to a specific motor branch, as reflected in grip strength performance will be discussed next in order to highlight the roles of the various peripheral nerves.
Motor component - movement control of the hand

The planning of movement and its execution are primarily initiated in the pre-motor and motor cortices of the left and right cerebral hemispheres. The feedback loop between the sensory and motor systems provides almost instantaneous feedback about the amount of force required to lift, shift and transport objects with just the right amount of force for them not to be crushed or dropped. In addition to this, the combination of an adequate number of motor units, consistent and appropriate recruitment of these motor units, good muscle bulk, and ligament strength are all required for optimal hand strength. The wrist needs to be stabilised in approximately 30 degrees of extension for the fingers and thumb to use a pinch action most effectively (Tubiana, Thomine & Mackin, 1996), see Figure 1.3. The needle electromyography (EMG) study of Long, Conrad, Hall & Furler, (1970) summarised the interplay of the intrinsic and extrinsic muscles of the hand when gripping forces were used against an object in a power, or squeeze grip:

In power grip the extrinsics [muscle originating in the forearm] provide the major gripping force. All of the extrinsics are involved in power gripping and are used in proportion to the desired force to be used against the external force. The major intrinsic muscles [originating in the palm] of power grip are the interossei, used as phalangeal rotators and metacarpophalangeal [MCP] flexors. The lumbricals, with the exception of the fourth, are not significantly used in power grip. The thenar muscles are used in all forms of power grip except hook grip. (p. 866)

There is an optimal length-to-tension relationship between muscles, tendons and joint complexes that produce optimal force generation with grip strength measuring devices. For most adults the optimal handle size of a dynamometer to produce the greatest strength measurement is an elliptical handle shape of 13 cm circumference. This equates to handle position number 2 on most standard Jamar™-like handgrip dynamometers. Handle circumferences 2 cm above and 2 cm below this size can give “pronounced” lower strength readings (Hamilton, Balnave & Adams, 1994). When grip strength researchers refer to the “bell shaped curve” they are making comment on this phenomenon of an optimal length-tension-position for hands (Härkönen, Piirtomaa & Alaranta, 1993). For most adults, when they grip the Jamar™ (or an equivalent) in handle position 2, all the intrinsic and extrinsic muscles of the hand and forearm are at their optimal length to provide the greatest amount of force for this
power grip position. Brand and Hollister (1999) provide an in-depth discussion about this topic in their text *Clinical Mechanics of the Hand*.

**Figure 1.3. The tenodesis effect (from Brand & Hollister, 1999).**

**Effect of peripheral motor nerve damage - Median nerve palsy**

In distal median nerve injuries the muscles that are affected are abductor pollicis brevis, opponens pollicis, part of flexor pollicis brevis and the lumbricals acting on the index and middle fingers. Because so many of the key muscles are not affected, it is unusual to have any obvious deficit in movement, except for thumb positioning into abduction and opposition. Sensory losses are a more significant barrier to function, as described.

In proximal median nerve injuries there is a severe loss of function due to a loss of pronation of the forearm and flexion of the thumb and fingers. The exception to this is the flexor digitorum profundus (FDP) muscle strands to the ring and little fingers, due to their ulnar nerve supply. Grip strength is typically poor with high median nerve injuries. Brand and Hollister (1999) discuss several tendon transfer operations that can restore sufficient function for self-care tasks, but cannot provide the original grip strength. Because thumb and index finger sensation is impaired by this lesion, “most patients will use the hand only for gross grasp and leave fine finger discriminatory movements to the other hand” (p. 308).
Ulnar nerve palsy

In distal ulnar nerve injuries the intrinsic muscles are affected, with the exception of the lumbrical muscles to the index and middle fingers. These intrinsic muscles are the primary flexors of the MCP joints and they assist in extension of the interphalangeal (IP) joints. They also control adduction and abduction of the fingers. Figure 1.4 shows the appearance of a hand when a person suffers a distal ulnar nerve palsy. The other role of the intrinsic muscles is to stabilise the MCP joints during activities, so that these shallow joints are held firmly in place when external forces are encountered. If these stabilising muscles are paralysed, the ligaments holding the joint in place can become overstretched and partial subluxation may occur. A common example is seen in the MCP joints of a person with advanced rheumatoid arthritis. The intrinsic muscles are weak and wasted and the joint capsule and ligaments are weak and overstretched. Another deficit found in ulnar nerve palsy is an inability to flex and oppose the little finger. Thus cupping the hand to drink or hold a spherical object is not possible. People with this condition have a flat metacarpal arch and report a feeling of weakness when grasping large objects such as hammers and fishing rods.

Figure 1.4. Distal ulnar palsy (from Tubiana et al., 1996)

In high ulnar nerve injuries, in addition to the intrinsic muscles, the forearm muscles paralysed are the flexor carpi ulnaris (FCU) and the FDP to the ring and little fingers. Sometimes the ulnar nerve may also innervate the FDP tendon to the middle finger (Brand & Hollister, 1999). The loss of FCU does not result in deformity, but it weakens the stability of the wrist, which in turn reduces optimal grip strength (Brand & Hollister, 1999).
With ulnar nerve injury, the ring and little finger (and sometimes the middle finger) will sit in a flexed posture of the distal and proximal interphalangeal joints, called a ‘claw hand’, see Figure 1.5. “This deformity occurs because the extensor tendons overact in an attempt to extend the fingers. Because the paralysed intrinsic muscles are unable to stabilize the MCP joints on the flexor side, the extensor muscles hyperextend the MCP joints and, in that position, are unable to extend the IP joints.” (Brand & Hollister, 1999, p. 287) Positioning the MCP joints in slight flexion will allow the extensor tendons to extend the IP joints so that the long flexors can flex the fingers around an object. These types of lesions can be seen when a person suffers a laceration to the back of their arm above the elbow through such mechanisms as staggering backwards and pushing a flexed elbow into a pane of glass.

Rajan, Premkumar, Rajkumar and Richard (2005) found that out of 62 consecutive patients in a leprosy clinic, 34 had ulnar nerve involvement at the elbow level and the remaining 28 had combined median and ulnar nerve lesions at the level of the wrist. They found that as compared to their local healthy peers, grip strength was reduced by 40% for the high-ulnar-nerve involved patients and by only an additional 10% for those with both the median and ulnar nerves involved at the wrist level.

**Combined median and ulnar nerve injuries**

Combined median and ulnar nerve injuries are devastating to the function of the hand due to the sensory and motor dysfunction. Rajan et al. (2005) stated that if the combined nerve damage involved the dominant hand, it affected “performance of basic daily activities at a highly significant level.” (p.44) The study of Taylor and Schwarz (as cited in Rajan et al., 2005) “showed that 90% of holding objects is done
by oppositional pinches” (p. 44). With this combined lesion, the hand loses the ability to grip objects with an even distribution of gripping force, thus only the fingers, thumb tips and distal palmar area make contact with objects, leading to high pressure areas on these tips and consequent skin breakdown and pressure sores, see Figure 1.6.

Figure 1.6. Figure A normal contact with a cylinder, Figure B contact only with the fingertips and the metacarpal heads (from Brand & Hollister, 1999).

Radial nerve palsy

Loss of sensation to the back of the hand caused by damage to the sensory branches of the radial nerve is generally a less significant functional loss. If the motor branch is damaged near or proximal to the elbow, there is a loss of active wrist and finger extension (Hayman, Duncan, Chiou-Tan, Liu & Taber, 2001). Thus the wrist cannot be spontaneously positioned in 20 to 30 degrees of extension for an optimal grip.

Cortical control of the hand

Having reviewed the basic peripheral neuroanatomy, at this point it is relevant to discuss the cortical control of the hand. The cortical motor output map for the hand occupies nearly one third of the primary motor cortex and also occupies a large proportion of the pre-motor cortex and subcortical circuits that control movement function (Tubiana et al., 1996). Motor representation is not proportional to muscle mass, but to the precision and dexterity of the movements that it commands, see Figure 1.7. This cortical map is dynamic and can be altered by the amount of hand activity. A study using transcranial magnetic stimulation demonstrated the dynamic
nature of the cortical motor output maps for the first dorsal interosseous muscle of the 'reading' finger of experienced Braille readers (Pascual-Leone, Wassermann, Sadato & Hallett, 1995). Magnetic source imaging has documented the increased activity of the area of the sensory cortex controlling the fingers of the left hand in violinists, as compared to the left hand of right-hand dominant control subjects (Elbert, Pantev, Wienbruch, Rockstroh & Taub, 1995). Thus the sensory and motor cortical systems impact directly upon each other. Their homunculi are similar, as illustrated in Figure 1.7. These co-dependent systems are thought to be distorted in conditions of dystonia. The best known of the dystonias are ‘writer’s cramp’ and ‘musician’s cramp’ (Butterworth, Francis, Kelly, McGlone, Bowtell & Sawle, 2003). Cortical sensory and motor areas have been found to be overexcitable in the condition of chronic regional pain syndrome (Eisenberg, Chistyakov, Yudashkin, Kaplan, Hafner & Feinsod, 2005).

The research into chronic pain by Moseley has demonstrated that retraining the brain before actual hand exercises are prescribed significantly decreases hand pain in these patients (Moseley, 2005).

**Sensory feedback and sense of effort**

Feedback mechanisms from the periphery influence cortical output. Nociceptive signaling during gripping, perhaps arising from the fingers being too compressed around a hard handle, can alert the cortex to decrease the strength of grip if the testee wants to avoid pain. Other forms of sensory input also influence grip strength, such as perception of effort and proprioception. If the aim of gripping is to produce a maximal grip strength effort, it is possible that the perception of reaching maximal grip strength decreases further motor cortical output commands, even before true maximal force has been achieved. This is especially so if there are no visual cues alerting the testee to his or her performance.

It has been debated whether the perception of force magnitude is derived from peripheral receptors, such as proprioceptors in the hand, or from signals within the central motor centres. Muscle afferent feedback plays a much smaller role than what might be expected (Gandevia, Macefield, Burke & McKenzie, 1990).

Lafargue et al. studied a patient who suffered from a condition causing large-fibre
demyelination, which resulted in diminished sensory feedback. This patient plus eight healthy volunteers attempted to mimic, after an initial 3-second delay, the grip forces being exerted by one hand (the reference control hand) with the other hand (the matching hand). The patient was as able to mimic the forces to the same degree as those without such an impairment. It was considered by Lafargue et al. that the residual afferent fibres, namely the small myelinated and unmyelinated fibres were not able to contribute significantly to this mimicking ability.

Regarding the contribution of effort perception, the patient with the deafferentation appeared to indirectly perceive the muscular force of her hands through central nervous system activity only. This activity was presumably in the form of nerve impulses along pathways from the motor cortex to the sensory cortex. She did not report feelings of fatigue, or awareness of how hard she tried to perform the matches (Lafargue et al., 2003). It may be that unimpaired individuals are able to perceive their effort levels in this same manner. If so, then it is possible that some individuals are more capable of this than others, which would affect the repeatability of the maximal grip strength efforts of some people.

Thus the force achieved when aiming for maximal grip strength will depend on many factors including: input from cutaneous receptors, proprioceptors and nociceptors, perceived sense of effort, previous usage of the critical cortical areas, fatigue of muscles and emotional state.

Figure 1.7. Similarity between the motor and sensory homunculi (from Penfield & Rasmussen, 1968).
Hand dominance

The dominant hand has been defined as the strongest, the most dexterous and the most skilful hand. Most of the laterality literature will define the dominant hand as the most skilful for complex tasks. The majority of people in western countries are right hand dominant for skilled tasks, with approximately 10 to 15% of people being left hand dominant for these tasks. A small minority of people are ambidextrous and can thus use either hand for skilled tasks. There is also a percentage of people who are mixed-handed, that is to say that they perform some tasks with their right hand and other tasks with their left hand. The exact percentage of the people in each of these groups within the general population depends on the methods used to measure handedness (Annett, 1970a).

Assessing handedness is usually done via self-report questionnaires. These questionnaires need to be culture-specific and include a range of activities. For example, in some cultures there are taboos about using the left hand for one or two common activities, such as writing and eating, because the left hand is used for personal hygiene. Thus a self-report questionnaire that only listed writing and food handling tasks would find that 100% of the people in Southern Asia were right-handed, given that each person had two functional hands (Rajan et al., 2005).

Several research articles have shown that if the dominant hand is the right hand, it is usually the strongest, but its strength can range from 20% weaker to 30% stronger than the non-dominant hand. If the dominant hand is the left hand it is often of comparable strength with the right hand (Crosby & Wehbé, 1994; Petersen et al., 1989). The difficulties of assessing the impact of handedness on grip strength have been summarised in “A literature review of the effect of handedness on isometric grip strength differences of the left and right hands” by Clerke and Clerke (2001) presented in this thesis in Appendix A and as an independent chapter, with updated references.
Handedness and cerebral dominance

There is a positive correlation between handedness and cerebral asymmetry. Volkmann, Schnitzler, Witte and Freund (1998) have demonstrated that there is a significant degree of hemispheric asymmetry in the amount of space allocated on the primary motor cortex to the dominant hand as compared to the non-dominant hand. This cerebral asymmetry is highly correlated with the asymmetry of hand performance in a standardised handedness test \( r = -.76, \ p < .01 \) (Volkmann et al., 1998). The increased cortical area devoted to the dominant hand is thought to be because the dominant hand requires or demands, a more efficient processing of motor output. It is the hand that usually performs the more highly skilled tasks, whilst the non-dominant hand is used as a stabiliser and supporter.

Injury rates

An examination of injury prevalence highlights the relevance of being able to accurately assess and treat hand injuries. The hand is the most frequently injured part of the body. In 1997 the South East Queensland Injury Surveillance Unit found that in a sample of accident and emergency departments in southeast Queensland 24% of all injuries were to people’s hands or wrists (E. Miles, personal communication, June 25, 1998). Between 1992 and 1995, in a sample of U.S. hospital emergency departments, 23.9% of all injuries with the principle diagnosis of fracture, sprain, strain or open wound were suffered by people’s hands or wrists (Burt & Fingerhut, 1998). A study of the Danish population put the rate of hand and wrist injuries at 28.6% of all injuries (Angermann & Lohmann, 1993).

The Australian National Health Survey of 2001 (Australian Bureau of Statistics, 2002) found that the people who were most frequently treated for all types of injuries were children. Almost one in five (19%) children aged 5-14 years were reported to have sustained an injury. In contrast, for people aged 65 to 74 there were less than one in twenty (4.8%) who reported injuries in a given four week period. For people aged 75 years and over, however, 7% reported injuries in this period.
The impact of neurological disorders on grip strength

The central nervous system uses prediction of load variations and surface frictions before they are encountered, and regulates grip force in anticipation. This system in turn communicates with the peripheral nervous system, monitoring performance via sensory feedback. Many neurological disorders can disrupt this fine balance in input, processing and output. And although “visual information may be helpful to select appropriate force levels … sensory information provided by cutaneous mechanoreceptors from the grasping digits are the most powerful feedback source to efficiently adjust grip force to the mechanical object characteristics” (Nowak & Hermsdörfer, 2005, p. 12).

In their review article, Nowak and Hermsdörfer gave a list of pathological conditions which impact upon the ability to grasp an object with the correct amount of force needed to hold, or manipulate that object. For the nine conditions (eg. Parkinson’s Disease and Motor Neuron Disease) and two states (digit cooling and digit anaesthesia) all participants used excessive force for gripping objects. This ranged from 40 to 250% of that required to lift or manipulate the object. They concluded that “very different disorders may cause very similar deficits of finger force control … and that the cerebellum has long been associated with predictive grip force control” (Nowak & Hermsdörfer, 2005, p. 23).

Ray amputation and grip strength

When a finger and its corresponding metacarpal bone are removed (ray amputation) the hand suffers a long-term grip strength loss of approximately 27 to 35% (Masmejean, Alnot, Couturier & Cadot, 1999; Melikyan, Beg, Woodbridge & Burke, 2003; Peimer, Wheeler, Barrett & Goldschmidt, 1999). This is greater than the grip strength contribution of each individual finger, as found when the fingers have been tested simultaneously on a grip strength tool that has individual finger sensors (MacDermid, Lee, Richards & Roth, 2004; Talsania & Kozin, 1998). MacDermid et al. (2004) stated that there was yet to be an experiment, using the recently developed digital grip sensor tools, conducted to ascertain the exact relationship between loss of digital strength and loss of overall handgrip strength. Even minor congenital
variations in the anatomy of the flexor digitorum superficialis (FDS) to the little finger significantly decrease grip strength, after controlling for age, gender and hand dominance (Bowman, Laurie, Chiapetta, Mitchell, & Belusko, 2003). The severity of systemic diseases such as rheumatoid arthritis can also be expressed by the amount of reduction in grip strength and by the pain induced by the grip strength test itself (Nordenskiöld & Grimby, 1997).

**ASSESSING GRIP STRENGTH**

Having examined how various injuries may impair hand function, it is appropriate to discuss how the clinician can assess sensory input and motor output as represented by the measurement of grip strength. Optimal sensory input and precisely modulated motor output are both needed for complex hand activities. For a clinician to accurately and objectively quantify the integrity of the three sensory nerve fibre types found in the peripheral sensory nerves requires recently developed and sophisticated tools, such as the Neurometer™ (www.neurotron.com). In contrast, accurately and objectively quantifying the motor output of a patient via gross grip strength has been possible for many years with the development of grip strength dynamometers. There are now a variety of these dynamometers available for clinicians. Their history and development are outlined in Chapter 2. Grip strength is only one aspect of motor output and maximal voluntary grip strength is rarely needed. However, it is seen as “a convenient measure of muscle strength,” (Bassey, Dudley & Harries, 1986, p. 6P) and is considered to be the “single item most reasonably representative of total body strength” (Newman, Pearn, Barnes, Young, Kehoe & Newman, 1984, p. 453).

Maximal grip strength is also viewed as “an important component in the clinical evaluation of the hand” (Lagerström & Nordgren, 1998, p. 113), although it is rarely required in everyday tasks and it requires the coordinated action of many muscles simultaneously. At the 1998 Philadelphia Meeting for Surgery and Rehabilitation of the Hand, 93% of 242 therapists indicated that they used grip strength as an outcome measure when treating patients with distal radial fractures (Michlovitz, LaStayo, Alzner & Watson, 2001), so it is routine for hand therapists to evaluate outcomes of therapy by changes in grip strength over time. Thus, how maximal grip strength is measured is important in the rehabilitation and monetary compensation of hand-injured patients.
Grip strength can be defined in several ways. Napier (1956) was the first person to discuss power and precision grips in relation to loaded hand activities. He considered that gripping involved shaping the fingers and thumb around an object to transfer force to the object. He described it as static, not dynamic and as isometric, not isotonic. Four different types of power grip have been described; squeeze grip (simple hammer squeeze, screwdriver squeeze with rotation), disc grip (for tightening or loosening jar lids), hook grip (for carrying a suitcase) and spherical grip for holding a ball (Long et al., 1970). When measuring grip strength with Jamar™-like dynamometers a simple squeeze grip is required. Usually when grip strength is discussed in the hand therapy literature it is assumed that it is referring to this simple squeeze grip, unless otherwise stated. In this thesis grip strength has also been defined as the simple isometric squeezing grip force that uses all four fingers and the thumb, wrapped around two parallel handles. There are three aspects of grip strength that are most commonly examined in the literature; absolute grip strength of a population, the reliability of the values, and the variables which influence it, such as gender, age, height and hand length.

**VARIATIONS IN GRIP STRENGTH**

It is readily acknowledged that maximal isometric grip strength fluctuates from day-to-day and is influenced by such factors as bed rest, pain, time of day, pain levels and blood glucose levels (Brand & Hollister, 1999). There may also be a strong practice effect, which may be expressed to a greater extent in young males than in young females. Grip strength researchers have commented that the boys in their studies “invariably enjoyed” having their maximal strength tested and were eager to know their results (Henneberg, Brush & Harrison, 2001; Kreipe & Gewanter, 1985).

Another variable that may affect the reliability of grip strength test scores is the fact that it is not one isolated muscle that is being tested. The generation of “strength” or effort is a “complex phenomenon that has underlying [multiple] muscular, tendinous, nervous, and skeletal components” in order to hold the grip strength dynamometer steady and produce a maximal grip force (Lieber, 2002, p. 258). The efficiency of cortical motor programmes, or the patterns of muscle activation previously laid down
due to practice may also vary between individuals. The ability to recruit a maximal number muscle fibres and to keep them actively contracting will not be simple because of the multiple muscles called into action in such a task. In Chapter 3 this topic is examined in greater depth.

Grip strength can be affected by instrument error. Fess exhorts clinicians to ensure that instrument error is ruled out, by means of accurate and regular calibration checks (Fess, 1987, 1990, 1992). Healing of hand pathology (El-Karef, 2005), or inconsistent performance due to motor unit recruitment pathology, fluctuating pain, fatigue, or intentional feigning of weakness can all affect the reliability of grip strength measurements. In addition to these complicating factors, researchers have not yet simultaneously measured and considered the effects of anthropometric, temporal, lifestyle, and degrees of hand dominance/laterality factors in an attempt to determine whether one hand can truly be used as a reference point for the grip strength of the other hand. Whether there are some people who have inherently inconsistent grip strength generating abilities has not been examined.

There are people who can reproduce the same grip strength performance over time accurately; others cannot (Hamilton Fairfax, Balnave & Adams, 1995). The range of ‘normal’ variation differs from study to study. Being able to identify whether the cause of the fluctuating performance was due to the assessment instrument, the protocol used, or some intrinsic quality of the person being assessed has its obvious benefits to all the stakeholders. In this thesis the test-retest reliability of maximal voluntary grip strength values in normal teenagers is examined within the clinically relevant time intervals of one to four weeks. The assessment instrument and the protocol used were kept constant. All relevant variables such as hand dominance, weight, height, level of sporting activities, type of sport, pain, past injuries and hand dimensions were recorded. Any teenager with current upper limb pain, or pathology was excluded from the study.

Teenagers with severe hand injuries potentially suffer a greater amount of career restrictions than adults, especially with respect to the trade and service industries. To date there have been only limited and design-restricted studies which have examined the variables which impact upon grip strength in teenagers. Thus further study is
warranted, but it is important to study normal teenagers before studying those with hand injuries. The purpose of this thesis was to investigate the grip strength behaviours and variables that affect grip strength for uninjured teenagers and to create prediction models for the grip strength of teenagers. Care was taken in ascertaining that the sample of teenagers who were recruited were representative of the ‘average’ teenager in Brisbane, in terms of anthropometrics, handedness, past injuries and levels of sports participation.