

**PRECISION GRASPING IN PEOPLE: A DETAILED
ANALYSIS OF THE CENTRAL AND EXTERNAL
PROPERTIES OF PRECISION GRASPING FROM THE
YOUNG TO THE ELDERLY.**

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ABSTRACT

To understand the grasping abnormalities in Parkinson's or stroke patients, normal grasping must be examined, and whether that normality is determined by biological factors or experiential influence must also be considered. The purpose of this thesis is to determine what normal variations of precision grasping exist in healthy, normal adults, children and elderly people.

Using Eshkol-Wachmann Movement Notation, five types of contact strategies were interpolated, based on the digit that contacts the object first, and whether that digit dragged or stabilized the object for grasping. Each contact strategy was associated with an ideal graphical representation of the thumb and index finger velocities.

There were seven variations of purchase patterns, based on the digits used to contact the objects, and four variations of postures of the non-grasping digits on top of the five contact strategies. Object size affected purchase pattern preference: smaller objects elicited the pincer grasp more than the larger objects. The purchase pattern distribution of variation is similar in adults and children, although children exhibit an extra purchase pattern, and older adults exhibit less variation purchase patterns.

The findings from this thesis suggest that central factors, such as gender and handedness, as well as external factors, such as size of the object, determine individual preference of grasping. The loss of variation with age can be attributed to the developing corticospinal tract in children as well as the deterioration of normal hand function in the elderly.

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CHAPTER ONE

GENERAL INTRODUCTION

Background

Human hand use can be separated into two types of grasping behaviours: 1) power grasping, in which the palm and digits hold an object; and 2) precision grasping, in which the digit pads are the only surfaces that hold the objects. Precision and power grasping have many variations, determined by object features. Grasping, especially precision grasping is considered to be “critical in many daily living activities” (Lowe 2001), and hence is of considerable interest to the public and experimenters alike.

A central problem in understanding the use of skilled grasping movements relates to the question of whether they are inherited movement patterns or learned. Thus, grasping movements like many other behaviours, can be a product of our genes or our experiences. The objective of the present thesis will be to assess the normal variation of precision grasping in healthy adults, children and older adults. In this introduction I will describe (1) background literature of the use of the hands in grasping, (2) the use of the hands in grasping by other animals, (3) the anatomical basis of grasping, (4) and electrophysiological evidence related to how the brain controls grasping. In each of these sections, emphasis will be placed on the importance of variation as it may be related to the nature-nurture dichotomy.

History – Early Studies

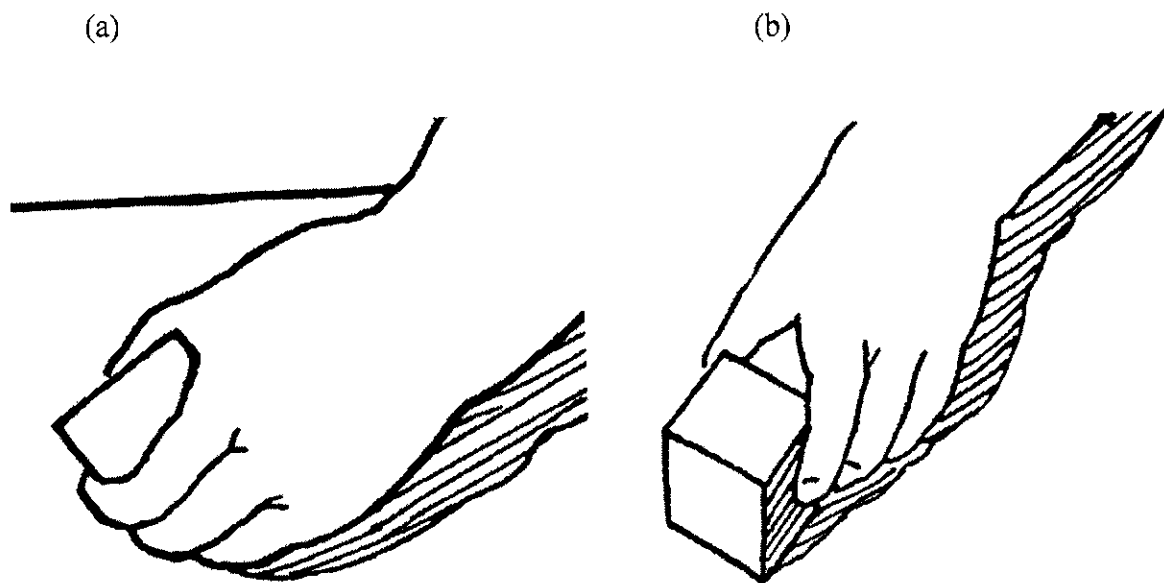
The first studies into grasping behaviours focused on three main aspects of grasping: (1) development, (2) neural basis and (3) taxonomy.

Development

The earliest English account of grasping was in 1915 by Myers. Myers documented the grasping, reaching and handling movements of a single child, from the time of birth until the baby reached 400 days of age. Myers placed a stimulus in the baby's central palm, and noted the kinaesthetic reflex of a whole hand grasp, where the fingers closed around the stimulus that was in the palm. This response occurred within the first few days after birth. Myers continued to document an improvement of grasping in the child; from a kinaesthetic grasping reflex that could not be inhibited, to the grasping of objects after visual acknowledgement of stimuli, and from primitive whole hand grasping to precise "volar" or precision grasping (Myers 1915), in which the thumb opposes the other digits to grasp an object between thumb and fingers. He reported that an infant progressed first from automatically grasping stimuli placed in the palms, to being able to pick up objects and release them (Myers 1915) (see Figure 1.1).

In 1931, Halverson described ten types of precision grasping in infants. Using motion-picture analysis, he filmed infants 16 weeks to 52 weeks old being presented with 3 cubes, one after another. He measured: the nature of visual attention, manner of approach, and manner of grasp. He described three power grasps, and three precision grasps. He did not, however, elaborate on the distinctions between the patterns.

In 1932 Castner, following up Halverson's study on infant prehension, studied human hand use by analyzing the development of fine prehension (or grasping of small objects) in infants. By recording "motion pictures" of infants grasping objects in a controlled environment, Castner recorded and analyzed the pictures frame-by-frame to determine the different postures of hand movements involved in reaching for



(Figures reproduced from Castner 1932.)

Figure 1.1. Grasping patterns of a child: (a) Palmar Grasp (left) (b) Pincer Grasp (right).

objects. He was able to describe the development of different stages of precision grasping. Combined with an extensive literature review, Castner described aiming and targeting components of reaching and grasping. These included 3 types of approaching behaviours, and 4 types of fine prehension. The four types of precision grasps included (from younger ages to older ages, respectively): 1) whole hand closure, as the “most primitive type of closure”, in which the hand clasps an object via a closed fist, without the use of the thumb; 2) palmar prehension in which the digits drag the object to the heel of the hand; 3) scissors closure, in which the thumb is drawn to the side of the forefinger that flexes under the hand; and 4) pincer prehension, where the thumb and the forefinger oppose to meet the object. (See Figure 1.2).

Neural Basis

In 1927, Adie and Critchley described case studies of frontal lobe damage, in which patients reverted to the grasping reflex seen in infants, and could not inhibit the reflex nor voluntarily open the hand after the reflex had occurred. Hence, this was one of the first papers to associate grasping within the nervous system, the neocortex in particular. Adie and Critchley proposed that this “forced groping” is due the disturbance of an inhibitory process (processes that inhibit the grasping reflex in normal individuals) by damaging cortical structures or the subcortical structures associated with them. Subsequently, there have been other studies describing “forced grasping and groping” as a symptom of various types of frontal lobe damage (Freeman and Crosby 1929; Walshe and Robertson 1933; Fulton 1934; Magnani et al. 1987; De Renzi and Barbieri 1992; Hashimoto and Tanaka 1998; Wu, Leong et al. 1999). These studies show that the critical region is the supplementary

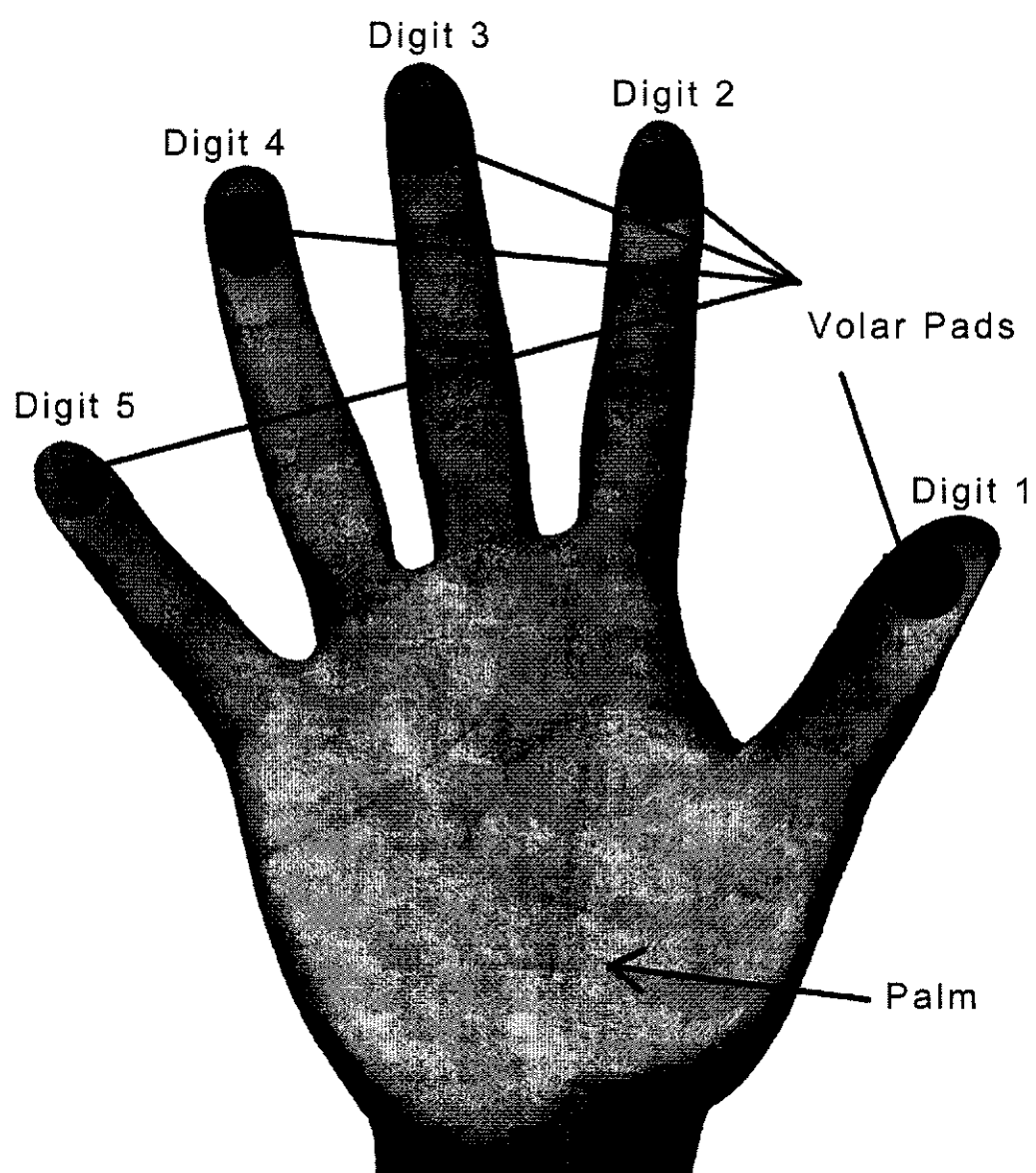


Figure 1.2. The hand. Each digit is numbered starting with the thumb. The circled areas indicate the volar pads (that are used in precision grasping).

motor area. This conclusion is supported by the finding that there is similar damage to the SMA in primates that results in forced grasping (Smith et al. 1983).

Taxonomy and grasping components

Following the studies of infant grasping, a number of studies focused on precision grasping in adults (Napier 1956; Elliott and Connolly 1984; Cutkosky 1989; Siddiqui 1995). Napier (1956) provided the first classification of grasping in adults by describing two types of grasping: 1) power grasps, in which an object is clamped between the palm and the digits of a hand, and 2) precision grasps, in which an object is grasped between the digits and the opposing thumb of one hand. This distinction has been fundamental to subsequent research. Elliot and Connolly (1984) described the difference between intrinsic movements (coordination of the hand and digits to grasp an object) and extrinsic movements (the total movement of both the hand and the object grasped). They also described two different intrinsic synergistic movements required to stabilize grasping, “simultaneous” and “sequential” intrinsic movements. The “simultaneous” intrinsic movements include 3 “simple synergies”: the pinch, the dynamic tripod (used for writing), and the squeeze. Cutkosky (1989) took grasping to a technological level, and classified grasping for the use of robotic arms. He separated power grasping into 9 types of grasps and precision grasping into 7 different types. The distinctions depended on the shape of the object, and the number of digits used to contact the object. Siddiqui (1995) studied prehensile ability in children and developed a 6 part classification system similar to Elliot and Connolly’s precision grasping taxonomy, based on the number of digits children use to pick up objects.

Present Studies

Current methods that examine grasping include kinematic measures, in which the grasping pattern studied is more formal, rather than spontaneous. These studies tend to focus on precision grasp pattern and the pincer grasp. Many papers examine the pincer grasp, and the normal reach-to-grasp components and force and grip loads are well defined, and are usually used for comparisons of normal people to Parkinson's patients and others with neurological conditions (Edin et al. 1992; Johansson and Cole 1994; Johansson et al. 1999; Hosseini et al. 2000). Visual and mass/density variables are also included to examine the effects of these variables on grasping components (Servos et al. 1992; Castiello 2001; Milner et al. 2001; Gentilucci 2002; Jackson et al. 2002; Smeets et al. 2002). Kinematic methods are useful for understanding the reach-to-grasp components and the trajectories of reaching, but they do not measure the existing frequencies and range of normal grasping behaviours in humans. Combined with ethological approaches, such as those currently used in non-human studies, kinematic methods can provide us with a detailed insight into grasping behaviours.

Non-human Grasping

Grasping is a type of prehension that is very important in the repertoires of animals. In many papers, prehension is not confined to involve the use of the forelimb, but may include other structures, such as beaks of pigeons and chickens, monkey tails, and elephant trunks (Bermejo et al. 1989; Yo et al. 1997).

Iwaniuk and Whishaw (2000) suggest that food handling has determined and shaped the evolution of skilled movements such as precision grasping in many animals. By comparing skilled forelimb use in non-primates and primates, and the forelimb structure of several tetrapod taxa, from Amphibia to Mammalia, and

plotting the phylogeny and presence or absence of skilled forelimb movements, they argue that skilled forelimb movements did not arise in primates, but originate in the earliest terrestrial vertebrates. Skilled movements, nevertheless were lost, or elaborated in different vertebrate orders. Iwaniuk and Whishaw's explanation also suggests that grasping evolved for feeding rather than for climbing.

Grasping in rats have perhaps been studied more than in any other species. For example, Whishaw and Gorny (1994) examined the prehensile ability of rats. By using a box, in which there was a slit to reach through to a shelf for pellets, Whishaw was able to video-record the grasping movement in the rat. They found that rats are capable of grasping small and large food pellets with a single paw, are able to adjust their grasp patterns to accommodate for pellet size. In fact, some rats are able to use Digit 5 in a similar manner as humans use their opposing thumbs, to stabilize grasping of very small food pellets.

The studies into non-primate grasping help develop methods of measuring the effect of neural changes on behaviour. By changing the rat cortex with lesioning or drug administration, the grasping behaviour is altered, and hence providing a way of measuring neural control of grasping. For example, Miklyaeva et al (1994) depleted dopamine in the nigrostriatal bundle in rats (simulating Parkinson's Disease in humans) and measured the reaching behaviour in rats, as described in Whishaw's experiment above. They found that the impaired limb (contralateral to the lesion) was less successful at reaching for food pellets, and impaired in 3 out of 10 reaching components, in which each component is qualitative aspect of reaching, such as aiming, posture and limb use. Hence, in rat models both the lateralization and the localization of skilled prehensive movements can be investigated.

Primate Grasping

Primates are studied because they are very similar to humans in physiology as well as in behaviour (in terms of neural basis and precision grasping), and hence are convenient for neurological research (Napier 1961). In fact Napier defined prehensility and opposability in the hands of both old and new world primates in 1961:

“Prehensility is an expression of the effectiveness of convergence in terms of the hand as a whole in grasping...[and] opposability is a form of prehensility in which the converging pollex undergoes an axial rotation so that at the end of the movement the thumb is facing towards the remaining digits.” (Napier 1961).

Grasping in apes and monkeys is not only studied ethologically, but also kinematically and physiologically/pharmacologically. For example, tool use for obtaining food is extensively studied ethologically in gorillas, and many observational studies examine the prehensive abilities of baboons, squirrel monkeys, rhesus macaques and many other non-human primates during feeding behaviours (Costello and Fragaszy 1988; Natale, Poti et al. 1988; Byrne and Byrne 1991; Byrne and Byrne 1993; Nakamichi 1998; Nakamichi 1999; Harrison and Byrne 2000; Byrne, Corp et al. 2001; Parnell 2001; Corp and Byrne 2002). These and other grasping studies are examined below.

New World Monkeys

Primate grasping behaviour is very similar to human grasping behaviour and hence is frequently studied by primatologists and psychologists alike. Napier suggests that convergent fingers and an opposable thumb is characteristic of most primates (Napier 1961). New world monkeys (such as capuchins and squirrel

monkeys) have pseudo-opposable thumbs, which can move in the same plane on a very wide angle away from the other digits but can not rotate to fully oppose them, unlike old world monkeys with opposable thumbs and therefore are very useful in comparing prehensibility in these different hand types (See Figure 1.3).

Costello and Fragaszy (1988) examined the importance of pseudo-opposability in two types of new world monkeys, squirrel monkeys (*Saimiri sciureus*) and tufted capuchins (*Cebus apella*), both of which have pseudo-opposable thumbs. By video-recording the reaching for small objects of different sizes, they found that only the capuchins were able to use precision grips (using the digits 1 and 2 or digits 1, 2 and 3) and squirrel monkeys were unable to use any precision grips at all. Therefore, the pseudo-opposability of the thumbs did not limit the use of precision grips. Costello and Fragaszy propose that the difference in neuronal wiring of the cortical spinal tract determine the ability of a monkey to have independent digit use (Costello and Fragaszy 1988).

Old World Monkeys

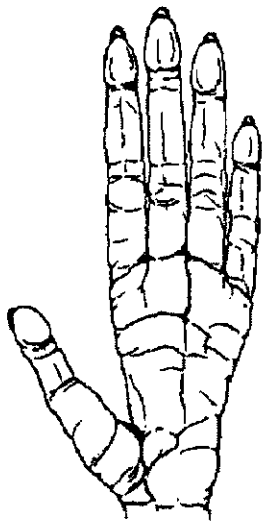
Old world primates include monkeys such as macaques, baboons, colobus monkeys, chimpanzees, apes and humans. These monkeys and apes have truly opposable thumbs (in which the thumb pad can rotate to fully oppose the index finger). In fact one of the earliest studies involved the development of a rhesus macaque reaching. Jensen studied the development of the precision grasp in a single monkey by observing it from 25 days to 195 days of age. Jensen found 5 stages of development of grasping, starting with looking at the object. The other four stages included: a precarious and non-precarious radial-palmar grasp, where the first two



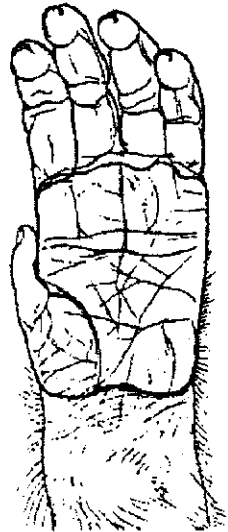
(a) Tree Shrew



(b) Macaque



(c) Gibbon



(d) Chimpanzee



(e) Man

(Figures are reproduced from Smith et al. 1983.)

Figure 1.3. Hands of various primates. Note the differences in the lengths of the thumb compared to other digits.

digits and the palm clamp the object; an index-palmar grasp (not seen in humans), where only the index and the palm clamp the object; and the primitive and the neat pincer grasps, where the thumb opposes or slightly opposes the index finger to contact the object. He found that the macaque did indeed have similar (but not identical) developmental stages of grasping and showed a similar amount of variability in the types of grasping as compared to humans (Jensen 1961).

Butterworth and Itakura (1998) studied the development of precision grasping in chimpanzees, by video recording eleven chimpanzees reaching for apple cubes measuring 0.5 to 2.0 cm in size. They categorized the grips into four major groups: (1) precision grips (pincer grip); (2) index and middle finger grip (scissors or 'cigarette' grip); (3) imprecise grips, where the thumb is slightly opposed and abducted against the index finger above the first distal joint; and (4) power grips. These are the same variations as found in humans. Butterworth and Itakura found that younger chimpanzees tended to use power grips, and older chimpanzees used more precision grips, with the smaller apple cubes eliciting more precision grips.

Neural Control of Grasping

An extensive literature identifies the motor cortex and the corticospinal tract as important in the control for voluntary movement (See Figure 1.4). The motor cortex consists of many different areas, including the supplementary motor area, the primary motor cortex, cingulate motor areas, and other various areas of pre-motor and pre-supplementary motor cortex. Each of these areas is assumed to have their own "somatotopic" organization, hence creating a multitude of motor maps in the brain that control the body (See Figure 1.5). The primary motor cortex controls simple features of voluntary movement, and neurons there move single joints when stimulated. The premotor areas also project to the primary motor cortex and partly to

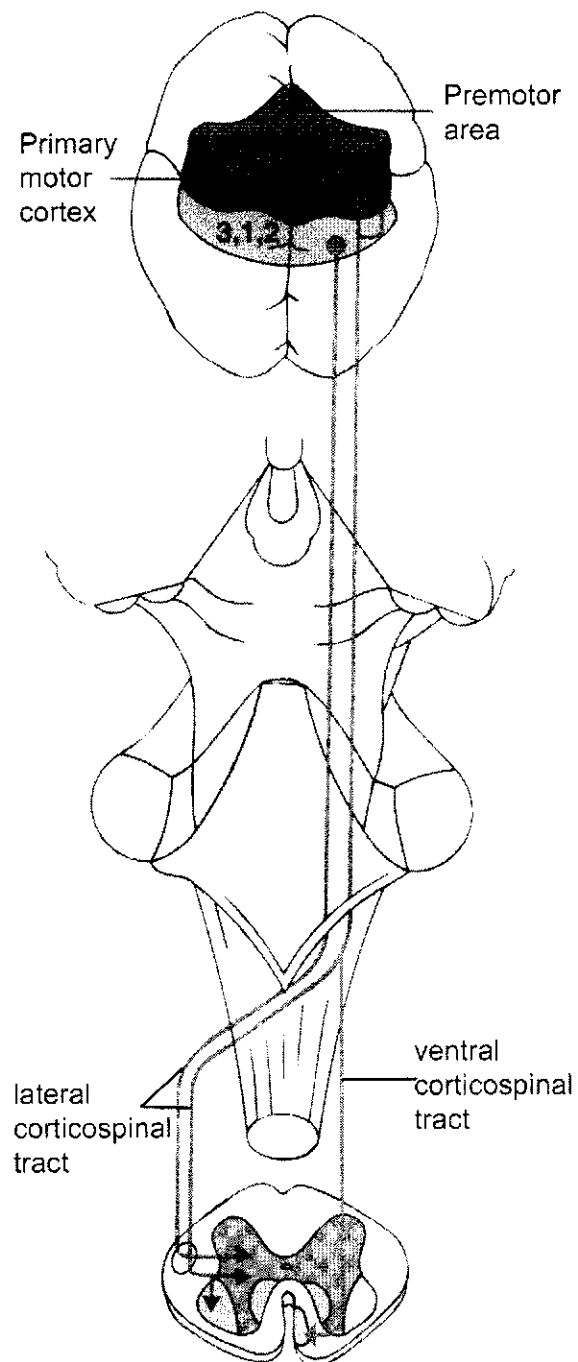
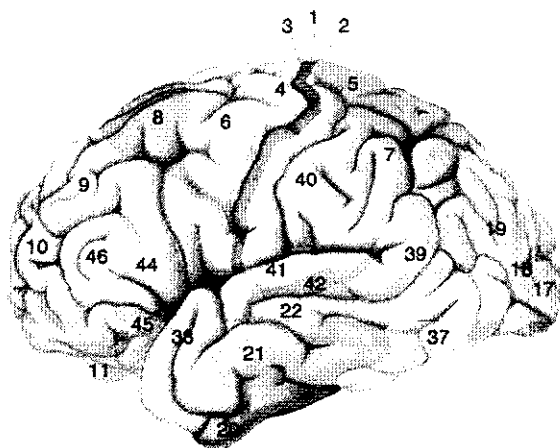


Figure 1.4. Corticospinal Tract. Picture modified from *Human Physiology* Rhoades and Pflanzner 1996.

(a) Figure from ©Lipincott and Williams 2001



(b) Motor homunculus

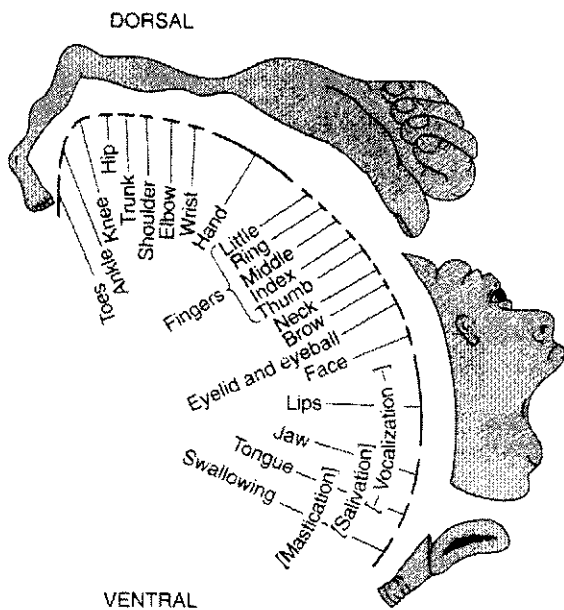


Figure 1.5. (a) Brodmann’s Areas and (b) the motor homunculus. Note the somatotopic organization of the homunculus.

the spinal cord, and control more complex movements involving multiple joints. The SMA plays a role in coordinating and planning movements, as movements initiated internally involve primarily the SMA. Damage to the supplementary motor area affects not only motor control, but also language. Transcortical motor aphasia develops after damaging the left SMA, as a result from loss of tongue and lip motor control. The supplementary motor area (SMA), one of the premotor areas, is assumed to play a role in bilateral movements and also has projections to the primary motor cortex as well as direct projections to the motor neuron pools in the spinal cord through the corticospinal tract. (Kandel et al. 1991).

The corticospinal tract descends from the motor and premotor cortex, down the spinal cord (Zigmond et al. 1999). Most fibers decussate in the hindbrain to form the lateral spinal tract, projecting to motor neuron pools innervating distal limb muscles. A few fibers do not cross, and stay in the ipsilateral side to innervate the medial region of the spinal cord, controlling the axial muscles of the body (Kandel et al. 1991) (see Figure 1.4). Heffner and Masterton (1975) were the first to combine knowledge about pyramidal tract from many species of mammals and to compare that information with the digital dexterity of each mammal. They found that the size and number of fibres in the corticospinal tract had little correlation to how dexterous an animal was, but also found that dexterous animals did have spinal tracts that descended farther and projected to deeper laminar layers of the spinal gray matter (layers V and VI compared to layers III and IV) than non-dexterous animals (Heffner and Masterton 1975). Iwaniuk and Whishaw (2000) have questioned the general conclusion while not disputing the idea that the pyramidal tract is important for reach and grasping, because of the bias towards a large proportion of primates included in the study.

Brain damage and Prehension

As mentioned above, cortical involvement in grasping was first noted by (Adie and Critchley 1927) who studied patients that had frontal lobe damage. By examining the presence of reflex grasping, Adie and Critchley were the first to discover that grasping behaviour was influenced by the neocortex. They found that damage to the frontal cortex led to forced grasping and groping movement patterns, similar to the reflexes found in babies.

Subsequently, this area became known as the supplementary motor area by (Smith et al. 1983). Smith et al found similar forced grasping and groping behaviour in monkeys that had their supplementary motor area damaged. Some studies have shown that certain neural structures, such as the supplementary motor area (SMA), only appears to be present only in animals that have well developed postural prehensile abilities, like the raccoon, porcupine, and various primates (Smith et al. 1983).

Electrical Stimulation and Recording

Modern investigation of functional localization of motor skill began with Luigi Galvani's findings on "Animal Electricity". Galvani stimulated nerves in frogs causing muscled contraction. From this, the science of electrophysiology arose, leading the first successful, controlled study of electrical stimulation by Fritsch and Hitzig in 1870 (Penfield and Boldrey 1937). Fritsch and Hitzig applied a galvanic current from bipolar electrodes into the anterior portion of a dog's cortex and found movements in the contralateral side of the animal's body.

Penfield and Brodley (1937) were the first to use the same method of electrical stimulation in the somatosensory and motor cortex of humans. By electrically stimulating the cortical areas in epileptic patients undergoing surgery for treatment of

epilepsy, Penfield was able to observe the effects of stimulating certain areas of the motor cortex, and hence create a “map” of the motor and somatosensory cortices (Penfield and Boldrey 1937) (See Figure 1.5).

Current studies of electrical stimulation involves the use of electrical probes being inserted into cortical areas of interest and then stimulated with either a low frequency or a high frequency biphasic pulse (Smith, Frysinger et al. 1983; Graziano, Taylor et al. 2002) for a couple of milliseconds.

The location of distinct areas for each hand and digit is greatly debated. There are a couple of theories presented in the paper by Graziano and colleagues (2002) that summarized Fulton’s 1938 publication. These are: 1) the primary motor cortex is topographical map of the body, 2) each point on the map specifies one muscle of a particular body part that is represented in that area, and 3) the cortical motor areas are hierarchical (See Figure 1.6). However, Schieber’s review on Fulton’s original hypotheses shows that they are flawed. Rather, there are gradual somatotopic gradients of representation in the primary motor cortex, where smaller body parts are widely distributed and overlap extensively within the face, arm or leg representations (Schieber 2001).

In addition to electrical stimulation studies, electrical recording studies are also used to examine the relations between neurons and their associated body parts. Iwamura and Tanaka electrically recorded 109 neurons in the somatosensory area (area 2 and caudal part of postcentral gyrus) in four monkeys while they reached and grasped objects. They found that of the four things they measured: (1) reaching, (2) grasping with precision grasping, (3) grasping with the power or whole hand grip, and (4) scratching or touching an object; the neurons that were associated with precision grasping were found in the lateral part of the digit region compared to the other three

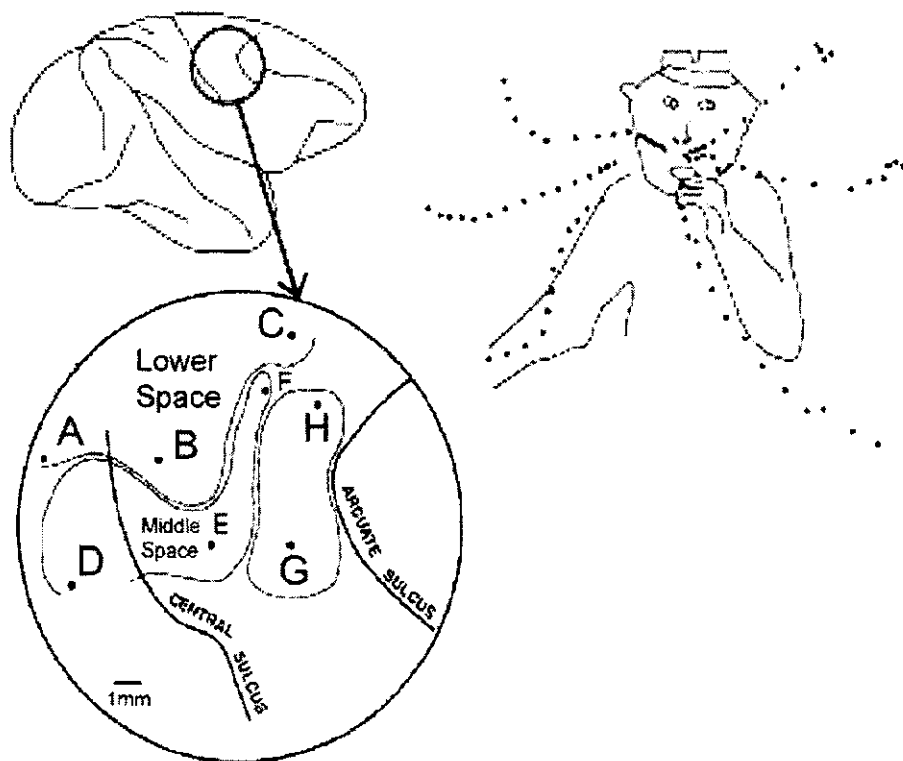


Figure 1.6. Diagram of the premotor cortex and associated movements in space. For example, stimulation of areas A, B or C causes reaching into the lower space of the monkey. Figure from Graziano et al. 2002.

behaviours, in which the responding neurons were located in the medial region (Iwamura and Tanaka 1996). This finding supports the idea that there are multiple complex maps in the cortex that are associated with behaviours and not single muscle groups.

Graziano and colleagues produced an interesting finding in 2002, by looking at the behavioural responses of monkeys to electrical stimulation of the precentral cortex. By stimulating the precentral cortex (the motor and the premotor cortex) with a low frequency for 500 milliseconds (half a second), Graziano was able to record the behavioural responses of the monkey (Graziano et al. 2002). The duration of stimulation used by Graziano is longer than in previous studies, in which the stimulation lasted only a couple of milliseconds. From that, instead of finding the movement of certain muscles, as expected from the three theories proposed above, Graziano found that certain complex movements, such as grasping, could be evoked in certain areas of space around the body. Therefore, the topographical mapping in the precentral cortex may represent areas of space around body and movement within this space, as opposed to certain muscle groups.

Issues

Some electrical stimulation and recording research has led to the findings that single muscles produce single outputs, and that grasp patterns are also controlled by the association of single neuronal inputs (Wassermann et al. 1998). These findings imply that there is a genetic component that determines the wiring of neural circuits associated with grasping from birth. This may not be the case, because other studies show that synergistic representations may be represented by specific neurons in the brain (Graziano et al. 2002). These synergistic representations may be the underlying basis for individual variations of grasp preferences in humans and may be due to the

neural plasticity involved with learning the most efficient ways of precision grasping. In kinematic studies, individual variation and preferences for determining grasping patterns are completely ignored, and the only precision grasp that is focused on in these kinematic studies is the pincer grasp. Without knowing the normal variance of grasping patterns, how can we say that only this one pattern is correct?

Methods

Ethological Methods versus Kinematic Methods

Kinematic analysis is a way of describing the motion of grasping in terms of the reach trajectories and velocities, whereas dynamic analysis is a way of measuring the force and grip loads that are involved in keeping an object grasped. These two methods of analysis are very useful in determining intrinsic properties, such as velocity profiles of limb segments and muscle force of the digits, of the reach-to-grasp trajectory and the grasp components of precision grasping. Kinematics and dynamics are rigid in their application, in which the subject is instructed to use a certain type of precision grasp, and cannot be used to assess individual preferences of grasping patterns. These instructions restrict the ability to determine whether there is more variation than that would be expected if grasping is due to purely genetic “hard-wiring” of neural circuitry.

Ethological methods, in which behaviors are purely observed and not manipulated, are needed in order to determine different variations of precision grasp patterns. The advantage of ethological study is that it is relatively non-invasive to simply observe behavior, without experimental manipulation or other interferences. Therefore, more natural movements and individual variance by subjects may be recorded, and the results can be compared to primates to determine the evolutionary development of grasping. Non-human primates are studied ethologically, because it

is difficult to assign certain tasks to primates without extensive motor skill training. One type of ethological analysis is “motion-picture analysis”, used by Castner in 1932. Capturing motion pictures of behavior, at 16 frames (or pictures) per second at that time, allowed Castner to analyze grasping in detail frame-by-frame. The current methods of recording “motion-pictures” now involve the use of 1/250 to 1/1000 shutter speed (250 frames to 1000 frames per second) high-speed digital video cameras that allow us fully analyze movements without the use of “psychometrics” or kinematics.

A disadvantage of using just behavioral analysis is that we are unable to determine the intrinsic properties of every variation of a particular behavior that is uncovered. For this reason we require both kinematic and ethological analysis in order to precisely study precision grasping.

Eshkol-Wachman Movement Notation (EWMN)

Another method of analyzing the observed behaviour of precision grasping is scoring movement in a notated form in such detail that a reader may be able to fully re-enact the sequence without ever having seen it performed. Eshkol-Wachman Movement Notation is a form of movement notation developed in 1958 by Noa Eshkol and Abraham Wachman (Eshkol and Wachman 1958) for recording and notating dance. It allows for a detailed description of the subject’s limbs in relation to one another, the subject’s orientation to the surrounding environment and other movers. Without external factors, EWMN can be applied to limb segments, using the their positions in space as well as the limbs in relation to each other. The use of EWMN has been limited to a few studies on animal behaviors. When applied to grasping, this method provides a detailed analysis of the positions of the digits, wrist, and arm and their movement patterns with respect to each other and the object used

for retrieval. In this thesis, in order to simplify the notation, the actual absolute positions of the arm, digits and hand are not notated, but rather, the movements of each part are represented by a “bow”. By representing the time of movement for each digit, we can better understand the strategies involved in bead retrieval.

Why study precision grasping?

There are many implications looking at the normal variance of grasping preferences in normal children, adults and elderly people. For example, knowing normal hand grasping patterns can help in the building of new prosthetic hands and arms as well as robotic arms. Normal commercial prosthetics consist of one type of grasp pattern, the pincer grasp, which is not very helpful for behaviours needing stronger or more stable grips. To have a more useful prosthetic, Light and Chappell (2000) have proposed to build a multiple-axis prosthetic, and hence knowing the normal variance of grasping patterns would be very informative and helpful (Light and Chappell 2000).

The purpose of this thesis is to determine normal variations of precision grasping of in healthy individuals. There is a little variance across all individuals with similar choice of patterns among each individual. This suggests that there is a combination of genetic and experiential factors that determine the similar grasp patterns across all individuals. In order to find out whether development or aging of precision grasping is more learning- and experience-based as opposed to genetically determined, a single reaching task is used in several experiments.

In this thesis, I will address, using a single reaching task, the variations of precision grasping that exist in normal adults, children and the elderly. Four questions were addressed in this thesis: 1) What can be interpreted from the detailed analysis of the movement of a single pincer grasp? 2) What are the kinematic

properties of each contact strategy used for precision grasping? 3) What are the variations of precision grasping that exist in adult humans and to what extent do they use each? 4) Do children exhibit more varied and different precision grasp patterns as compared to adults? 5) What is the natural variation in healthy elderly people without motor diseases, and how do they compare with healthy normal adults?

The first question addresses in detail the movements and strategy involved in bead retrieval using pincer grasp. From this, we can determine other variations of strategies and precision grasps that can be used for grasping small objects.

The second question addresses the movements involved in the contact strategies that was brought forth by Eshkol-Wachman Movement Notation analysis. Using kinematic analysis, a detailed analysis of the velocity and trajectory of movement for the thumb and the index fingers provides details into the voluntary planning and movement associated with precision grasping.

The first two experiments show that there is more than one type of strategy for bead retrieval. Therefore, there must exist other variations of grasp type. Using the same frame-by-frame analysis techniques derived from Eshkol-Wachmann Movement Notation we can isolate variations of precision grasping from video.

For the third question, the different variations of precision grasps were isolated from video of normal adults reaching for 5 different sized beads.

The final question addresses the problem that many motor diseases (such as Parkinson's Disease, strokes, etc...) affect fine motor skills in the elderly. If the aging process itself is to be ruled out as a factor that affects fine motor skills, then the variation that is present in the elderly should be similar to those of younger adults. If not, then only the most efficient precision grasp patterns would be retained, and there will be a narrower range of variation compared to normal adults.

CHAPTER TWO

ESHKOL WACHMANN MOVEMENT NOTATION: A DETAILED ANALYSIS OF THE PINCER GRASP AND CONTACT STRATEGY

Abstract

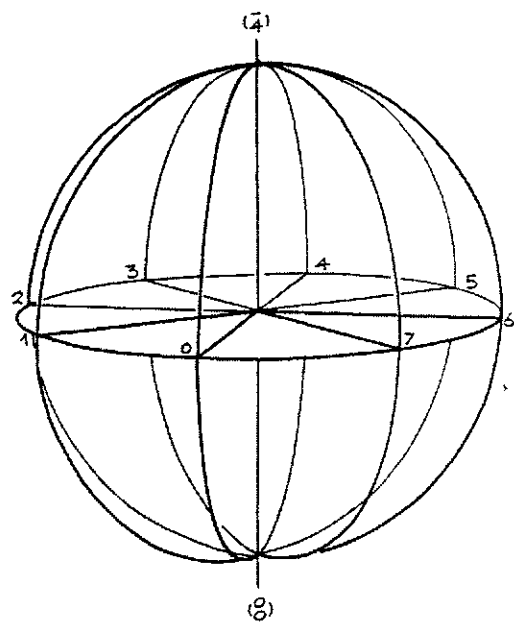
Eshkol-Wachmann Movement Notation was used to notate, in detail, the strategy involved in a single pincer grasp was notated used to grasp a single bead. The subject used, what is later described as, the *thumb stay* contact strategy, one of five possible strategies for bead retrieval. When analyzed in detail, the *thumb stay* strategy is characterized by the thumb contacting the bead first and stabilizing the bead for the index finger to contact the bead.

Introduction

Eshkol – Wachmann Movement Notation (EWMN) was originally conceived to notate dance (Eshkol and Wachman 1958).

It is a method of characterizing and describing movement in detail using frame-by-frame video analysis. This is a useful tool that allows description and repetition of movement without direct observation of movement. It uses a spherical reference in order to describe movements of each joint of the body. The sphere is divided into 8 points (the difference between two points = 45 degrees) horizontally and 8 points vertically (See Figure 2.1). The position of the joint can either be described in absolute space, or relative to the “heavier” body part that it is attached to (body-wise), in terms of the 8 horizontal and 8 vertical positions, similar to cartesian coordinates. An Eshkol-Wachman Movement analysis of a random precision grasp from the second experiment was used to examine the details of the pincer grasp, and provide a basis for the third (Kinematic) study.

a) Horizontal Plane and Vertical Planes of the System of Reference. 1 = 45 degrees.



b) Horizontal plane of the system of reference, in reference to a the human body in “zero position”.

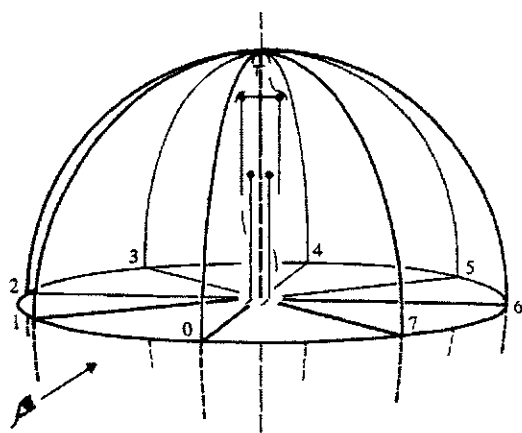


Figure 2.1. Eshkol Wachman Movement Notation. Figures from (Eshkol 1971).

Methods

A pilot study on grasping was run on one subject in order to determine the details of the pincer grasp movement in a normal adult. For detailed movement analysis, one random precision grasp (a pincer grasp) was selected, and analyzed using frame-by-frame analysis and notated using Eshkol-Wachman Movement Notation (based on location of forearm and digit in a spherical reference) in order to examine the specific components of a single contact strategy involved in precision grasping.

Subject

A single male subject, 22 years old and right handed, was recruited from the Canadian Centre for Behavioural Neuroscience building at the University of Lethbridge.

Apparatus

The apparatus was a Plexiglas board (35 cm x 45 cm) was positioned over a box (28.2 cm x 31.8 cm x 21.9 cm). The front of the box was open and faced the camera. A mirror (30.5 cm square) positioned on a forty-five degree angle away from the camera was fixed within the box (Figure 2.2 A). A black plastic board was placed behind the box as a contrasting background to the bead and hand (Figure 2.2 B). Thus, when the subject grasped an object on the apparatus, his grip pattern could be viewed from a horizontal perspective and from a ventral perspective.

Stimuli

Beads of five different diameters of 3, 6, 10, 12 and 16 millimeters were used. They were aligned on the apparatus in a horizontal row, in random order or in sequence, depending on the experiment. Beads were chosen to control for the object

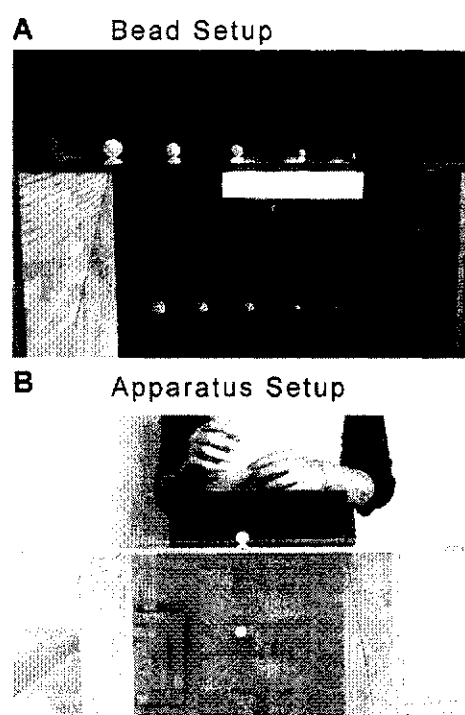


Figure 2.2. Bead and Apparatus Setup: A) Targets. Beads of 16, 12, 10, 6 and 3 millimeter diameters aligned horizontally on plexiglas board. The reflection of the beads is shown in the mirror on the bottom. B) Plexiglas board and mirror box setup. The subject stands behind the box and reaches. Reaches are filmed from frontal and ventral perspectives.

shape and texture, and eliminate as many confounding external object variables as possible.

Video Recording

Filming was done with a Canon MC50RZ Digital Camcorder, at a 1/500 second shutter speed with lamps to increase the lighting.

Procedure

The subject was instructed to reach for the beads one at a time first with his left hand, and then with his right and place them into a box.

Results

Using the Eshkol-Wachman Movement Notation, a video clip of a single pincer grasp, reaching for the largest bead, was analyzed in detail. Each frame was notated according to the position of each digit, the hand and wrist and the forearm for each of the sixty frames of video (at 30 frames/second, and 2 seconds of video). Figure 2.3 shows a simplified notation of movement for each digit and the hand for the contact strategy, *thumb stay*, for the most common purchase pattern, *proper pincer*. The notated movement indicates that there is maximum movement of the index finger compared to the thumb, with movement of the forearm and wrist only to transport the hand towards the bead.

Detailed Description of Pincer Grasp

At the start of the movement sequence (Frame 21:04:25), the left arm is relaxed at the side, in the zero rotated position, with each digit in a relaxed, and slightly flexed position. When the movement starts, the forearm moves up one and a half units and rotates 2 units until the back of the hand faces up towards the ceiling and the palm towards the box (21:05:04). The pinky, ring and middle digits also start to move towards the palm at the beginning, until the hand stops rotating, and the pads of the

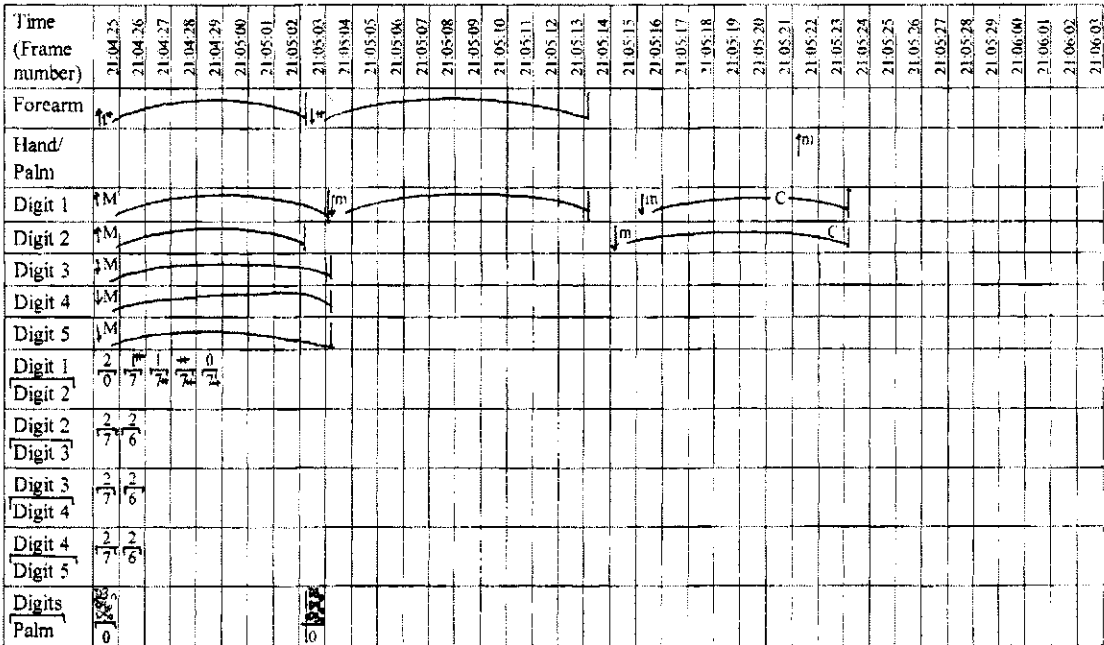


Figure 2.3. Simplified Notation of the Contact Strategy *Index Drag* for the Proper Pincer Grasp. Each bow represents movement for each frame of video.

digits are touching the palm (these digits remain in this position until the end of the movement sequence). The thumb moves outwards minimally to prepare for grasping, and stops when the hand stops rotating. The index also starts moving outward with the other digits, and stops moving one frame before the rest of the digits/hand stops moving, at 21:05:03. The forearm moves down half a unit, right after it stops rotating, and at the same time the thumb moves inwards minimally, and both parts stop moving at 21:05:14. The wrist adjusts at the same time, moving minimally downwards and upwards. Just when the thumb stops moving, the index starts to move inwards one frame after (21:05:15), to grasp the bead, and the thumb also starts moving inwards to grasp right after, at 21:05:16. The thumb first contacts the bead, and continues to apply pressure, while the index moves in to stabilize the grasp, and full contact is made after the thumb has applied full contact.

Discussion

Eshkol-Wachman Movement Notation is used in some scientific studies by Whishaw and colleagues in order to examine the skilled forelimb movements of rats (Whishaw and Pellis 1990; Whishaw, Pellis et al. 1992; Iwaniuk and Whishaw 1999; Metz and Whishaw 2000; Whishaw, Suchowersky et al. 2002; Whishaw, Gorny et al. 2003). When applied to humans, a detailed analysis of the pincer grasp can showed that there was a certain strategy applied to the grasping of small objects (in this particular strategy, the thumb moved minimally compared to the index finger).

From the notation, the contact strategy used can be labeled as *thumb stay* since the index finger is observed to drag the bead towards the thumb. From this, it can be interpolated that four other contact strategies exist, based on the combinations of the movement from the thumb and index fingers. These other four combinations are

characterized by whether the index finger or the thumb stabilizes or drags the bead toward the opposing digit.

When the contact strategies were defined after extensive video analysis, a detailed kinematic analysis of the different contact strategies was needed to determine if these contact strategies are actually purposeful or a remnant of visual feedback mechanisms (described below).

CHAPTER THREE
A DETAILED KINEMATIC ANALYSIS OF THE CONTACT STRATEGIES
INVOLVED IN PRECISION GRASPING

Abstract

The grasping kinematics of finger use during fine prehension are rarely studied compared to the reach-to-grasp trajectories of reaching and the dynamics of precision and power grasps. An ethological study on normal adult control subjects may give insight into the thumb and index trajectories during precision grasping. This experiment addresses the question of what the grasping kinematics of the thumb and index fingers are by examining their use during precision grasping of small objects. Subjects were filmed and recorded using a motion-capture system reaching for 5 different sized beads. We observed five variations of contact strategies, depending on whether the thumb or the index dragged or stabilized the bead for grasping and retrieving the beads. There was a significant preference for the “index drag” strategy over the rest, and there were no significant effects of sex, bead or hand size on which strategy was preferred. We also compared the peak velocity and the time to reach peak velocity for the two most common contact strategies (in terms of the percent of grasp between the maximum aperture between the thumb and index fingers and the lift component). Bead size did not affect maximum velocity of the thumb or the index, but there was a significant increase in the number of fluctuations in velocity for both the index and the thumb with smaller bead sizes. Each contact strategy had a unique, descriptive pattern of index and thumb velocities, although the maximum velocities between the two fingers were not predictive of the contact strategy. These results show that further analysis, by averaging the local maximum and minimum peak velocities of the thumb and index, may provide a more accurate description of

the thumb and index tips during precision grasping, and hence contributing to the understanding of the neural control of grasping.

Introduction

The Eshkol-Wachmann Movement Notation analysis of the pincer grasp provided a basis for the detailed study of the strategies involved in precision grasping. There were five different strategies of bead retrieval that could be interpolated from the EWMN results. The first strategy was described in detail (where the index finger dragged the bead towards the thumb). The combinations that could have arisen are: the thumb drags the bead towards the index finger; the index finger stabilizes the object and the thumb moves towards the object and the index finger; the thumb stabilizes the object and the index finger moves toward the object and the thumb; both the thumb and the index move towards and contacts the object at the same time.

Methods

Ethics

Ethics approval was obtained from the University of Lethbridge Human Subjects Research Council, and signed consent was obtained from all subjects.

Subjects

Volunteers were recruited from an introductory kinesiology class at the University of Lethbridge. Participants included 13 females, 4 males (ages 19 – 39, all right handed) with a mean age of 23.5 years.

Stimuli

Beads of five different diameters of 3, 6, 10, 12 and 16 millimeters were used. Each bead was placed one at a time on the Plexiglas in a random order (according to the participant) to eliminate predictive value of the size of the stimuli.

Motion Capture Apparatus

Reflective markers were placed on each subject's wrist ulnar styloid, just below the distal interphalangeal joint and near the tip of the index finger, and near the tip of the thumb (to prevent interference with grasping) on both left and right hands (an 8 marker set). Six infrared cameras that recorded the location of the markers were set up around a raised table with a Plexiglas insert for the table-top such that the bead and the grasp could be filmed from a digital camera below (Canon MC50RZ Digital Camcorder, at 1/250 shutter speed to accommodate for dark lighting). Positional data and video were collected at 120 Hz using a Peak MOTUS motion analysis system (Peak Products, Englewood, CO). The length for each trial was 5 seconds.

Procedure

First, the subjects had their digit lengths and widths measured before testing, and markers placed on the appropriate locations on the index and thumb of both hands. The subjects were instructed to stand at a comfortable distance behind the table such that they could easily reach the bead placed on the table. For each trial, the bead was placed in on the table in front of the subject before the trial started. The subjects were then instructed to start with their hand in a relaxed position, and to first use their non-dominant hand to grasp the bead, and place it in a cup directly ahead of the bead. Each grasp was repeated once for each bead size (in a random order) for each hand, giving a total of 20 trials for each subject. Subjects were informed to reach for the bead as quickly and as naturally as possible when given the start signal.

Three Dimensional Marker Reconstruction and Analysis

Each reach was analyzed using frame-by-frame video analysis of the captured video from the Peak MOTUS 2000 software, to determine the type of contact strategy that was used to grasp the stimuli.

Positional data were collected at 120 Hz using a Peak MOTUS motion analysis system (Peak Products, Englewood, CO). Three-dimensional marker position reconstruction and interpolation was performed with Peak MOTUS software. Displacement data were filtered using a dual pass, 4th-order digital Butterworth filter with a cut-off frequency of 10 Hz. Graphing of wrist, thumb and index marker 2 dimensional (x and y plane) trajectories and the kinematic properties of the index finger and thumb was done with SigmaPlot 8.0. The grasping interval was defined starting from the time of maximum grip aperture between the index and the thumb tips and ending at the lift component, where the index and thumb move off the plane of table.

Behavioural and Data Analysis

Statistical analysis of the variation of each contact strategy was computed using SPSS 11.0 (University of Lethbridge) institutional package, using repeated measures, bivariate 2-tailed Pearson correlations and multivariate analysis. Factor analysis was performed on the index and thumb lengths and widths to create a regression score of general digit size.

Results

Kinematic Analysis

For the kinematic analysis, the peak velocity for each peak, as well as the time to reach peak velocity (relative to grasp duration, from maximum aperture of thumb and index finger to the lift component) for each peak was measured.

A correlation showed that bead size had no significant effect on the overall peak velocities of the thumb ($r = 0.044$, Signif. = 0.570) and index finger ($r = -0.063$, Signif. =) (See Figure 3.1). Bead size did have a linear effect on the time to reach peak velocity for the thumb ($r = -0.166$, Signif. = 0.030) and the index finger ($r = -$

0.0167, Signif. = 0.030), and as shown in Figure 3.2, the smaller bead sizes showed a longer time to reach peak velocity. As well, the number of fluctuations in velocity (acceleration and deceleration phases) for the thumb ($r = 0.512$, Signif. = 0.000) and the index finger ($r = 0.506$, Signif. = 0.000) were significantly greater for the smaller beads compared to the larger beads (Figure 3.3).

To minimize statistical error, only the two most common strategies were compared (*thumb* and *index drag* strategies) in terms of thumb and index peak velocities and the time to reach peak velocity. A one-way ANOVA showed that there were no significant differences between the peak velocities for the thumb ($F_{(1, 99)} = 0.000$, $P = 0.984$) and index finger ($F_{(1, 99)} = 0.073$, $P = 0.787$) between the *index drag* and the *thumb drag* strategies. There were also no significant differences for the time to reach peak velocity for the thumb ($F_{(1, 99)} = 0.459$, $P = 0.500$) and the index finger ($F_{(1, 99)} = 0.123$, $P = 0.726$) between *index drag* and the *thumb drag* strategies.

Although there were no significant differences in peak velocity or in the time to time to reach peak velocity, qualitatively, the velocity charts were quite different, as described below: (The following are graphs of a random subject that shows the expected/ideal velocity patterns for the thumb and index for their respective strategies).

Index Drag

Figure 3.4 shows the thumb and index velocities for the *index drag* contact strategy. For the *index drag* strategy there is minimal movement of the thumb as expected, and there is more movement of the index finger. The local maximum and minimum values of index speed are visibly quite larger than that of the thumb.

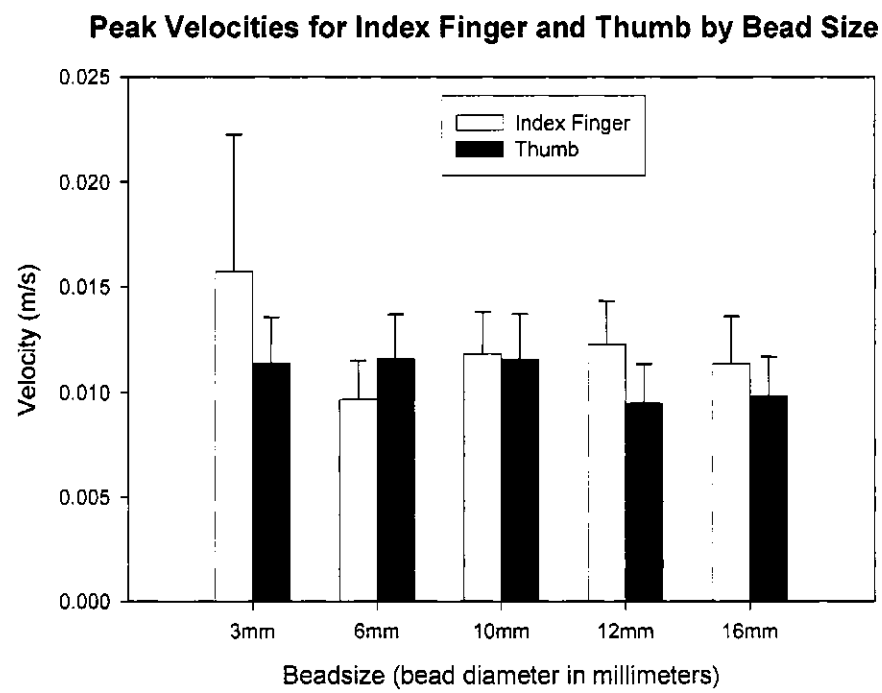


Figure 3.1. Kinematic results. Peak velocities for the thumb and index finger for each bead size.

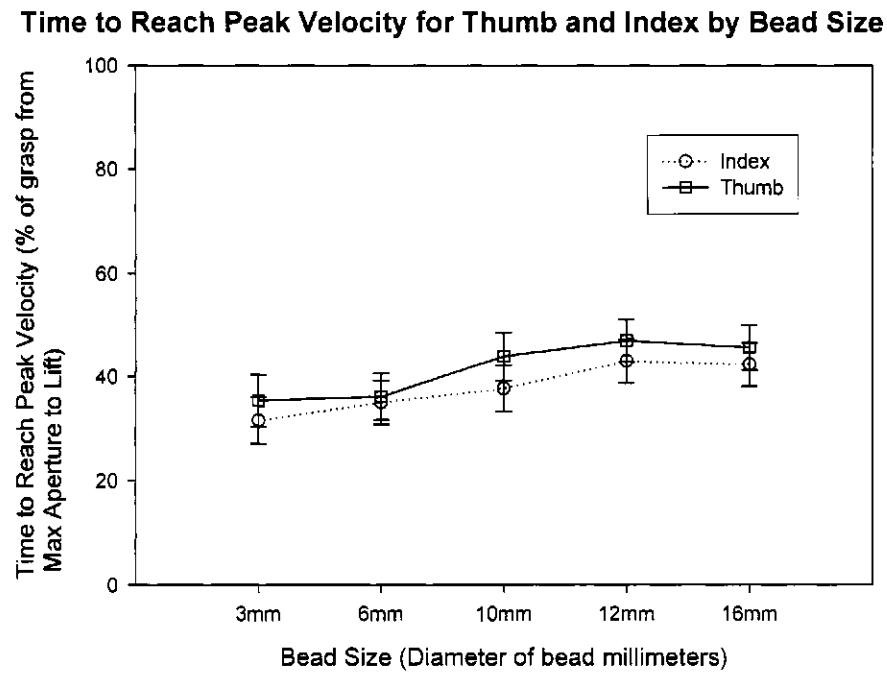


Figure 3.2. Kinematic Results. Time to reach peak velocity for both thumb and index fingers.

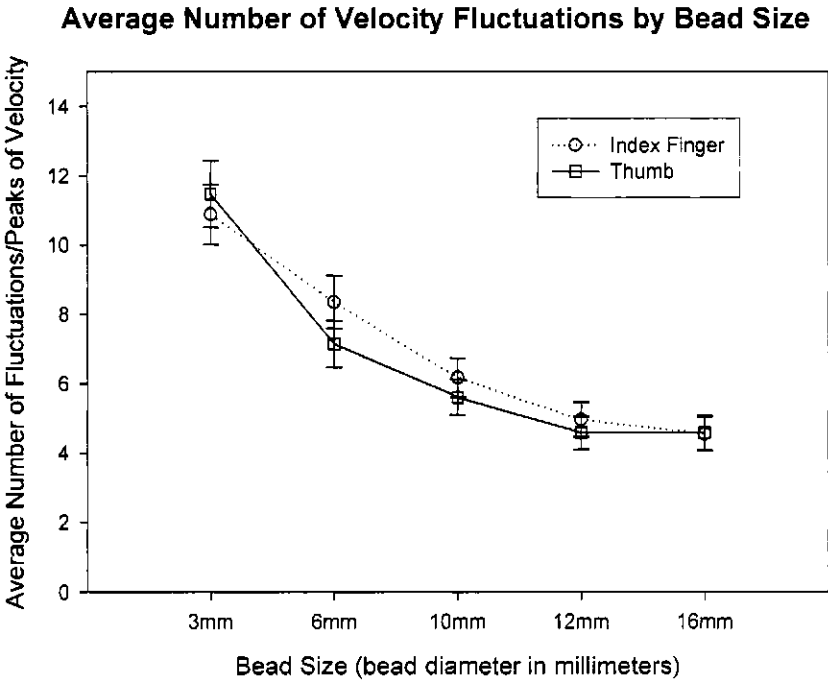


Figure 3.3. Kinematic Results. Average number of fluctuations in thumb and index finger velocity by bead size.

Thumb Drag

Figure 3.5 shows the thumb and index velocities for the *thumb drag* contact strategy. The opposite of the *index drag* strategy is seen for the *thumb drag* strategy, and the local maximum and minimum values of the thumb velocity are quite visibly larger than that of the index finger.

Both

Figure 3.6 shows the thumb and index finger velocities for the contact strategy “*both*”. Both the index and the thumb move relatively the same amount in the *both* contact strategy, reaching similar peak velocities and at relatively the same time.

Index Stay

Figure 3.7 shows the thumb and index finger velocities for the *index stay* contact strategy. For the *index stay* contact strategy, the index finger has minimal change in velocity, and the thumb reaches higher peak velocities than the index finger. As well, the thumb reaches peak velocity before the index finger.

Thumb Stay

Figure 3.8 shows the thumb and index finger velocities for the *thumb stay* contact strategy. For the contact strategy *thumb stay*, there is minimal movement of the index finger compared to the thumb. The index finger reaches higher peak velocities than the index finger.

Discussion

Previous studies have examined the dynamics of grasping, the kinematics of reach-to-grasp trajectories, the role of vision, as well as modeling natural movements using computer models and robotics. Only one recent study by Kamper and Colleagues has addressed the kinematics of finger movement in an ethological manner (Kamper, Cruz et al. 2003). Here, by using a limited range of objects of similar shapes and sizes, the

Thumb and Index Peak Velocities for Index Drag Contact Strategy

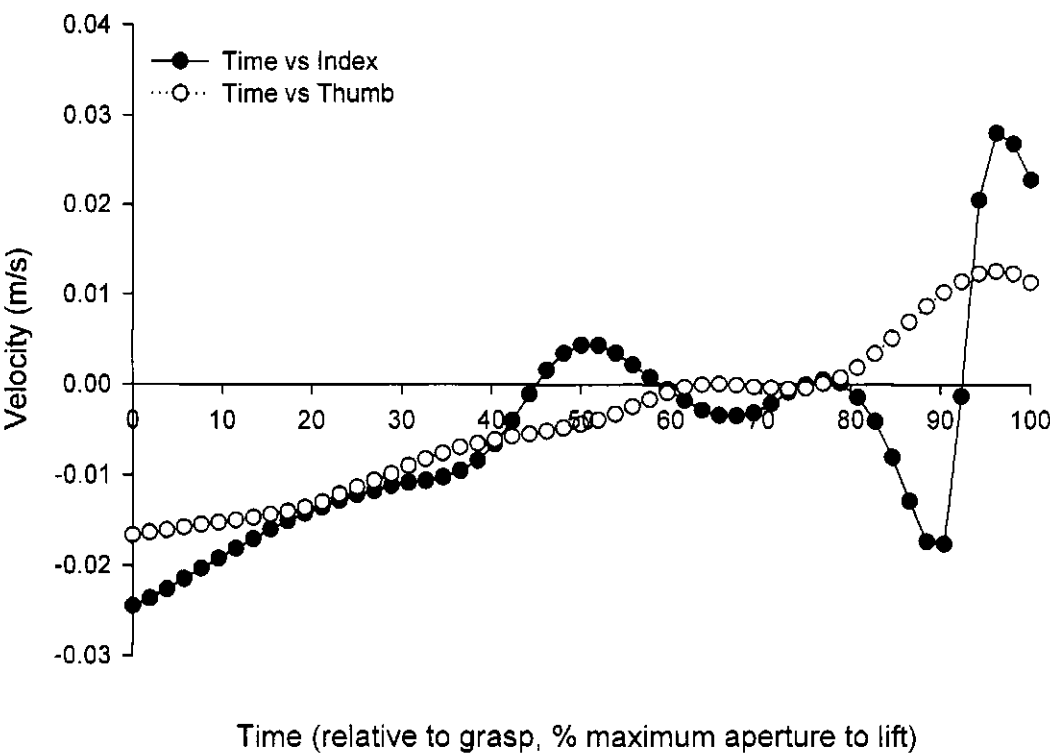


Figure 3.4. Kinematic Results. The thumb and index velocities from a random *index drag* contact strategy. The time is measured in terms of the percent of the whole grasping movement, starting from the maximum aperture between the index finger and the thumb, and ending at lift component of the grasp.

Thumb and Index Peak Velocities for Thumb Drag Contact Strategy

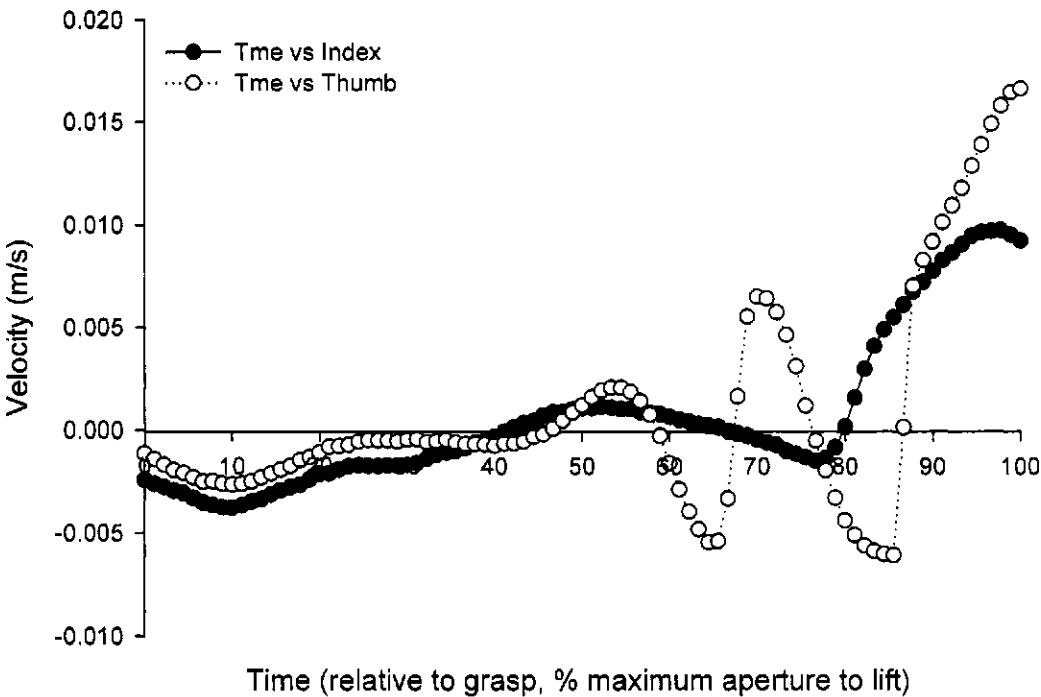


Figure 3.5. Kinematic Results. The thumb and index velocities from a random *thumb drag* contact strategy. The time is measured in terms of the percent of the whole grasping movement, starting from the maximum aperture between the index finger and the thumb, and ending at lift component of the grasp.

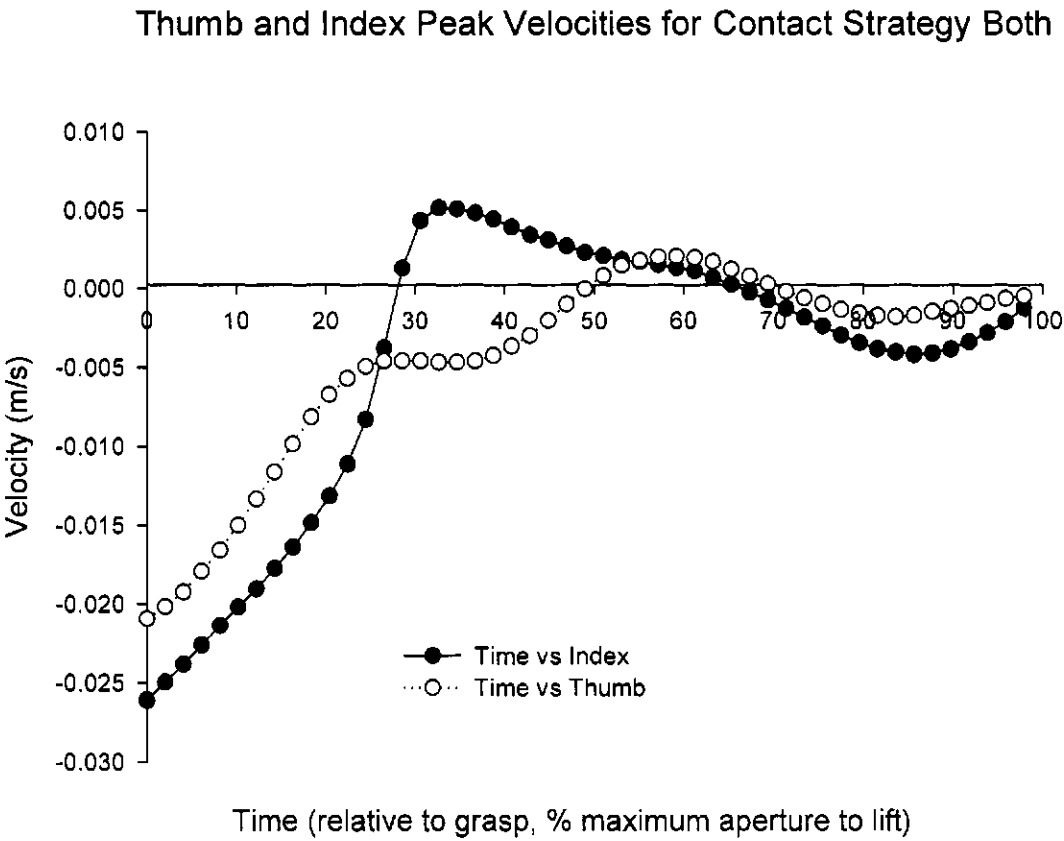


Figure 3.6. Kinematic Results. The thumb and index velocities from a random contact strategy, *both*. The time is measured in terms of the percent of the whole grasping movement, starting from the maximum aperture between the index finger and the thumb, and ending at lift component of the grasp.

Thumb and Index Peak Velocities for Index Stay Contact Strategy

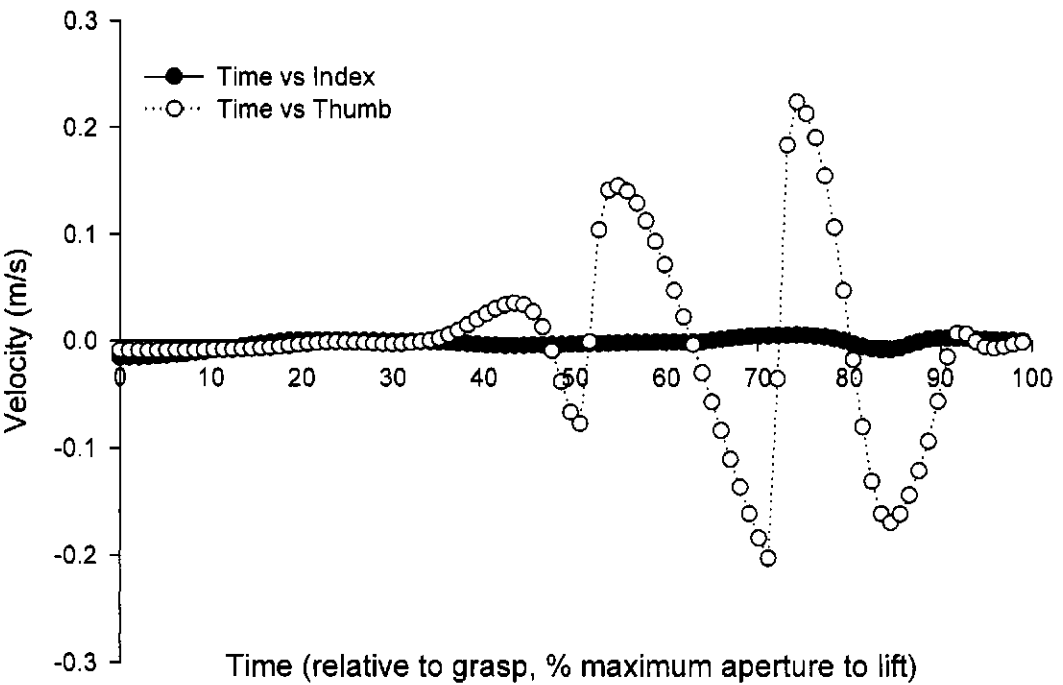


Figure 3.7. Kinematic Results. The thumb and index velocities from a random *index stay* contact strategy. The time is measured in terms of the percent of the whole grasping movement, starting from the maximum aperture between the index finger and the thumb, and ending at lift component of the grasp.

Thumb and Index Peak Velocities for Thumb Stay Contact Strategy

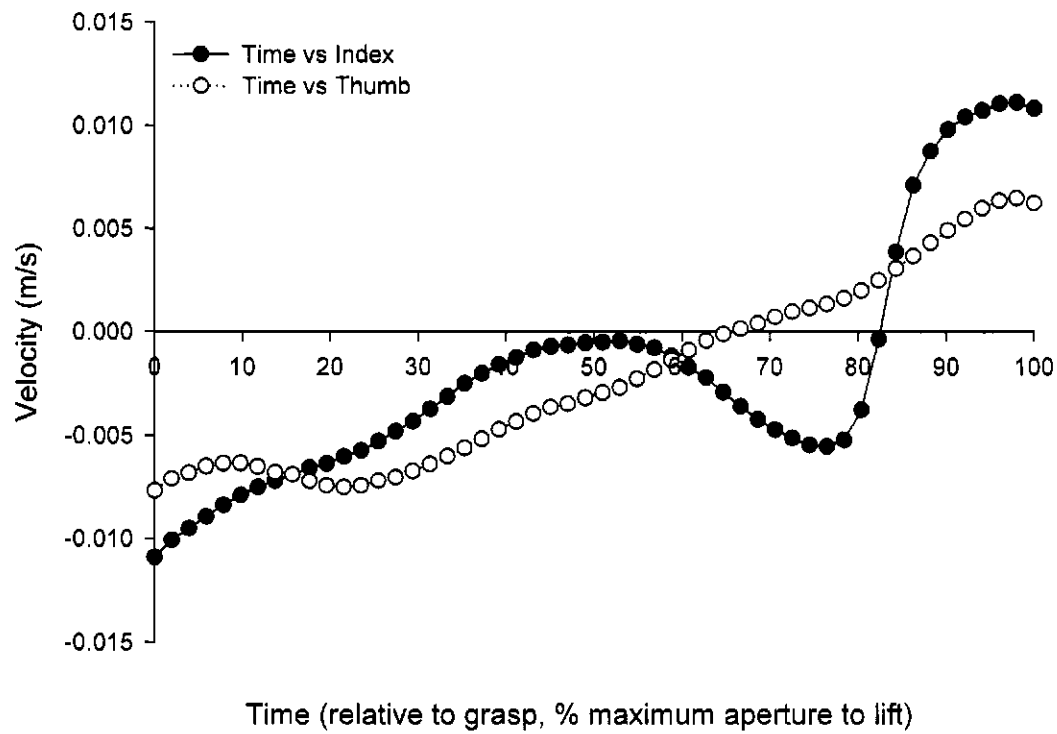


Figure 3.8. Kinematic Results. The thumb and index velocities from a random *thumb stay* contact strategy. The time is measured in terms of the percent of the whole grasping movement, starting from the maximum aperture between the index finger and the thumb, and ending at lift component of the grasp.

possible contribution of intrinsic factors to the kinematics of individual finger movements in precision grasping is described. Using video and motion capture, subjects were recorded reaching for small beads, having the same shape and texture, but differing in size, and the resulting video and motion capture data analyzed using frame-by-frame video analysis and Peak MOTUS software for 3-dimensional marker reconstruction.

There were five contact strategies used to retrieve the beads based on whether the index or the thumb stabilized or dragged the object towards the opposing digit. The kinematic properties, such as the time to reach peak velocity and the number of fluctuations of the velocity of the thumb and index finger are significantly affected by the size of the object that is being grasped. Jeannerod's visuomotor theory hypothesized that visuomotor mechanisms (specific feedforward mechanisms) extract limited visual information and generates corresponding motor responses (Jeannerod 1986). This seems logical, since the smaller sizes generally require more visual processing (Kudoh and colleagues, 1997), and may require more visual feed-forward processing, and hence causing more fluctuations in thumb and index finger velocity in order for accurate grasping. Gentilucci also notes that final reach lengthens when reaching for objects of smaller sizes (Gentilucci 2002), and hence a longer time to reach maximum aperture between the thumb and the index finger. This may account for a shorter time-to-reach-peak-velocity for the smaller sized beads (since the time frame begins at maximum aperture).

The peak velocities of the digits are not affected by bead size. Smeets et al (2002) noted that changing the extrinsic property of the location of an object affected the transport speed of the reach to grasp movement, and changing the intrinsic property of object size affected the grip aperture during grasp (Smeets, Brenner et al.

2002). Therefore the transport speed of the digits may follow the same pattern as the transport speed of the reach-to-grasp movement, and may not change when object size is altered. The velocities and the time to reach peak velocity between the two most common strategies were not significantly different. This may be because the absolute value of the maximum velocity of the index and the thumb are similar and occur at similar times during the beginning of the grasp, causing the recorded maximum velocity of each digit to be similar for both contact strategies of *index drag* and *thumb drag*. Marc Schieber (2002) notes that each contact strategy may not be a strategy at all, but rather variations in the accuracy of finger placements from trial to trial, and thus variability in the endpoints of the trajectory may be due to uncertainty in visual analysis or motor planning (unpublished resource). This does not account for the fact that the kinematic properties of the thumb and index finger are different for strategies that require more index movement or thumb movement. While conventional single measures of peak velocity are useful in describing the kinematics of single-peak trajectories such as the reach-to-grasp behaviour, a different method of analyzing kinematic profiles for contact strategies may be more informative in determining the differences for each contact strategy, including combining behavioural video analysis and use of movement notations to isolate movements of digits.

CHAPTER FOUR

A NEW CLASSIFICATION OF THE VARIATION IN PRECISION GRASPS IN OLDER AND YOUNGER ADULTS AND CHILDREN

Abstract

The evolutionary origins and variations of the precision grip, in which an object is held between the thumb and other digits, are poorly understood. This is surprising because the neural basis of this grasp pattern, including the motor cortex and pyramidal tract have received extensive study. Most previous work has shown that features of an object to be grasped (external factors) determine grasp patterns. The objective of the present study was to investigate individual differences (central factors) in use of the pincer and other precision grips. The grasping patterns of male and female young adults, older adults and children were examined as they reached (with both left and right hand) for 5 small beads (3-16 mm dia). Frame-by-frame analysis of grasping indicated a high degree of variability in digit contact strategies, purchase patterns and digit posture both within and between subjects. (1) The contact strategies consisted of five variations, depending on whether the thumb or the index finger dragged or stabilized the bead for grasping. (2) Purchase patterns consisted of seven different types of precision grips, involving the thumb and various combinations of other digits. (3) There were four variations stemming from the posture of the non-grasping digits. Grip patterns of the left and right hands were correlated in individual subjects, as were strategies used for different bead sizes. Females displayed slightly more variability in grasp patterns than did males, and digit width (obtained from photocopies of the subjects' hands) was weakly correlated with the grasp patterns used. Although it was expected that the pincer would be used for all objects, it was preferentially used for only the smallest object except for older adults

who used the pincer grasp on most objects. The variability in digit contact strategies, purchase patterns, and posture of the non-grasping digits indicates that central factors (innate or learning-induced architecture of the left parietal cortex) make important contributions to the selection of a grasping pattern. These individual differences are discussed in relation to the neural control of grasping and its potential contribution to understanding the evolution, development, and pathology of the precision grip.

Introduction

Prehensile movements, which include various hand and digits movements for grasping and manipulating objects, are divided into two main groups, power and precision grips. In the power (or palmar) grip, the palm forms a jaw of a clamp with the other digits as another jaw. In the precision grip, only the digit pads are used and typically the thumb is held in opposition with the other digits (Napier 1956; Landsmeer 1962; Elliott and Connolly 1984). One precision grip, the pincer grip, in which an object is grasped between the thumb and the index finger, has been considered the "most important hand function" of all prehensile movements (Dickson and Nicolle 1972). It is used by many animal species in various orders, including rodents (Whishaw and Gorny 1994), monkeys (Jensen 1961), apes (Vauclair 1984), and humans (Napier 1961; Lawrence 1994). It is also the only prehensile grip that is used in commercially distributed prosthetic hands, even though the hand itself has approximately 28 degrees of freedom and many more grasp patterns (MacKenzie and Iberall 1994). At present, the way in which particular grips and their variations are selected for use is not fully understood. Several studies suggest that the grasping patterns used by humans and primates are based on such external features as the size shape of, and pliancy of the object that is grasped (Napier 1956; Landsmeer 1962; Elliott and Connolly 1984; Johansson and Westling 1984; Cutkosky 1989;

Butterworth and Hopkins 1993; Gentilucci 2002; Santello et al. 2002). According to this notion, extrinsic properties of the object to be grasped determine the grasping pattern that will be used.

Although there are many classifications of grasping synergies (patterns of hand and digits) used by humans (Rearick and Santello 2002), and many studies of the kinematics of arm and hand movements (Napier 1956; Liepert et al. 1998), there is but one ethological study of the variations in grasping types used by humans. (Burton and Dancisak 2000) describe the grasp patterns used by children in holding a pencil, and report that writing is somewhat better when a pincer-grasp pattern is used. The absence of ethological descriptions is surprising because hand synergies are affected by changes in vision including monocular viewing (Servos et al. 1992; Jackson et al. 2002), arthritis (Eberhardt and Fex 1995; Dellhag et al. 2001), and many nervous system disorders including stroke (Netz et al. 1997; Liepert et al. 1998), Parkinson's disease (Muller and Abbs 1990; Whishaw et al. 2002), and Huntington's chorea (Fellows et al. 1997). An understanding of the variations in normal hand use could prove useful in understanding the effects of such conditions and could also be useful in developing rehabilitation procedures. An understanding of normal hand use is also relevant to studies of nervous system organization. Studies of the motor cortex and its projection to the spinal cord via the pyramidal tract have been especially focused on the use of the pincer grasp but must also underlie other grasp patterns (Bennett and Lemon 1996; Lemon et al. 1996). In addition, some stimulating, recording, and lesion studies of the neurons of the motor cortex in primates have been directed toward answering the question of whether hand movements are organized in terms of muscles or synergies, with synergies proposed to be determined by the genetically specified

organization of the motor cortex (Nudo and Milliken 1996; Nudo et al. 1996; Friel and Nudo 1998; Schieber 1999; Schieber 2001).

The present study comprises an ethological examination of the grasping patterns used by children and young and old adult male and female subjects reaching for small beads. The beads were of such a size that it was expected that the pincer grasp would be the main grasp pattern used (see Napier 1980, pp. 56) (Napier 1980). Subjects were given no special instructions except that they were to pick up the beads, first with one hand and then the other while their movements were video-recorded. There were a number of questions that were of primary interest in the study: is there variation in use of the hand and digits as a function of (1) the size of the object, (2) as a function of the sex of the subjects, (3) of the hand used to pick up the object, (4) of digit size, and (5) of age group?

Methods

Four sets of experiments were performed, differing only in the set of subjects that participated: 1) Normal Adults - Sequence, 2) Normal Adults – Random, 3) Children, and 4) Aged. Each experiment used the same method, camera type, setup and apparatus.

Ethics

Ethics approval was obtained from the University of Lethbridge Human Subjects Research Council, and signed consent was obtained from all subjects or their legal guardians if they were not of legal age. See Appendix 1 for Consent forms.

Subjects

Four sets of subjects were recruited for each experiment:

- 1) For “Normal Adults (sequential order of beads)”, healthy volunteers without motor diseases or disorders were recruited from students, staff and faculty

within the Psychology and Neuroscience building at the University of Lethbridge. The participants included 22 females, 19 males (ages 15 – 50, 2 left handed males) with a mean age of 24.3 years.

- 2) For “Normal Adults (random bead order)” healthy volunteers without motor diseases or disorders were again recruited from introductory psychology classes as well as from students, staff and faculty at the Psychology and Neuroscience Building at the University of Lethbridge. Participants included 18 females, 13 males (ages 18 – 49, all right handed) with a mean age of 27.6 years.
- 3) For “Children (random bead order)” healthy volunteers with parental or legal guardian consent were recruited from Gerald B. Probe Elementary School in Lethbridge. Participants included 20 females, 28 males (ages 5 – 12, 1 left handed female, 2 left handed males, and one ambidextrous male) with a mean age of 8.7 years.
- 4) For “Aged (random bead order)” healthy volunteers without motor diseases or disorders were recruited from the Lethbridge Senior Citizens Organization, and from a University of Lethbridge recreational class. The participants included 11 females, 5 males (ages 56 – 77, all right handed) with a mean age 66.6 years.

Questionnaire

Questionnaires were given to each participant in the Children and the Aged groups to assess manual dexterity and the presence of medical disorders. Manual dexterity indices were calculated based on the amount of fine motor activities, such as drawing, playing musical instruments and needlework, each volunteer participated in and the frequency of each activity. There were no participants with motor disorders (Parkinson’s, stroke, etc...) that affected hand movement. In the aged group, there

were participants that had non-motor medical disorders, such as arthritis in the knee or lower back pain. (See Appendix 2).

Apparatus

The apparatus used was the same as in Chapter 2, which was a Plexiglas board (35 cm x 45 cm) was positioned over a box (28.2 cm x 31.8 cm x 21.9 cm). The front of the box was open and faced the camera. A mirror (30.5 cm square) positioned on a forty-five degree angle away from the camera was fixed within the box (Figure 2.2 A). A black plastic board was placed behind the box as a contrasting background to the bead and hand (Figure 2.2 B). Thus, when subjects grasped an object on the apparatus, their grip pattern could be viewed from a horizontal perspective and from a ventral perspective.

Stimuli

Beads of five different diameters of 3, 6, 10, 12 and 16 millimeters were used. They were aligned on the apparatus in a horizontal row, in random order or in sequence, depending on the experiment. Beads were chosen to control for the object shape and texture, and eliminate as many confounding external object variables as possible (See corresponding procedures for each experiment).

Video Recording

Filming was done with a Canon MC50RZ Digital Camcorder, at a 1/500 second shutter speed with lamps to increase the lighting.

Hand measurement

Subjects right and left hands were either photocopied or measured (using calipers) after each task, and for each hand, digit lengths and widths were measured. The length of each digit was measured from the crease at the base of the phalanges to the tip of the finger (not including the nail). The width of each digit was measured

across the widest part of the volar pads (see Fig. 4.1). For the children, the hands were traced, and measured in the same way.

Behavioural and Data Analysis

Each reach was captured using Pinnacle Studio 7 and analyzed frame by frame to determine grasping/purchase patterns, strategies and postures. Statistical analysis of purchase patterns was done using SPSS 11.0, using multivariate analysis and curve estimation. Factor analysis was performed on the digit widths and lengths as an estimate of hand size. Analysis of significance between gender and posture of non-grasping digits was done using Chi-squared analysis. One-way ANOVAs were used to determine the effect of age, gender, medical conditions and dexterity indices on the contact strategy, purchase pattern and posture. Within-subject factors included sex, hand used (right vs. left) and bead size. A partial correlation controlling for subjects was performed on the purchase pattern results for the mid-sized beads (6 to 12 millimeters in diameter) to determine if the grasp patterns were random across individuals or were due to individual differences. Additional correlations were used to determine if the grasp patterns and contact strategies were also correlated. Figures were plotted using Sigmaplot 8.0.

Procedure

Experiments 1 and 2

- 1) Normal Adults – Sequenced
- 2) Random Bead Order

Only the ordering of the bead sizes differentiated the two experiments (Sequenced and Random Bead Order). In the Sequenced Bead Order experiment, the bead sizes were arranged from largest to smallest left to right. Subjects were instructed to pick up the beads, one at a time, at their own pace starting from the largest bead and place them in

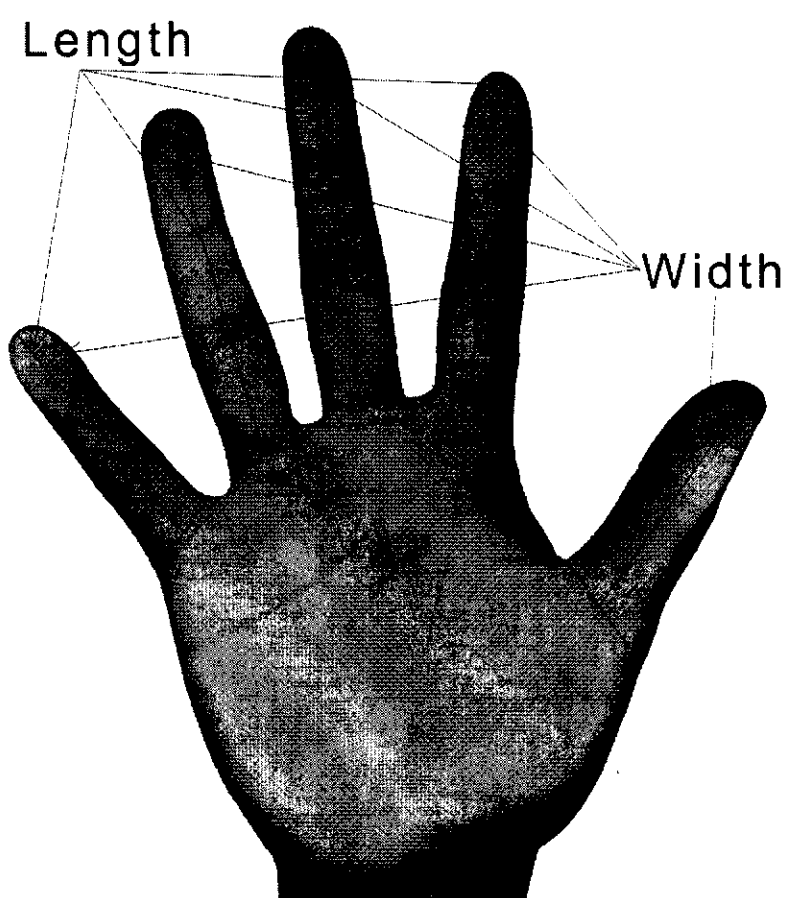


Figure 4.1. A picture of a hand, and associated measurements.

a box (beside them), starting with their dominant hand (determined as the hand used for writing) and then their non-dominant hand. In the Random Bead Order experiment, the beads were randomly arranged on the apparatus with respect to size. The subjects then again reached sequentially first with the non-dominant hand and then with the dominant hand. Ten reaches per subject were filmed, one reach per bead for each hand. Afterwards, the hands of each subject were then photocopied and measured in order to determine digit lengths and widths. The videos were then analyzed and all reaches examined to create a classification system that consisted of: (1) the digit contact strategy, (2) the purchase pattern and (3) the posture of the non-grasping digits.

(3) Developmental – Children (Random Bead Order)

The procedure for this experiment is essentially identical to experiments 1 and 2. The subjects were instructed to reach for beads arranged in a random order on the apparatus, starting first with their non-dominant hand and then their dominant hand (the hand used for writing). The subjects were specifically told to go at their own pace, and use whatever grasps were most comfortable and naturally. Ten reaches per subject were filmed, one reach per bead for each hand. Afterwards, the hands of each subject were then traced and measured in order to determine digit lengths and widths, and a questionnaire was completed to determine their digital dexterity.

(4) Older Adults (Random Bead Order)

The procedure from Experiments 1, 2 and 4 are repeated for elderly subjects. Before the task, a questionnaire assessing their digital dexterity and medical conditions was given. Digital dexterity was rated on a scale from 0 to 7, where 7 is the most dexterous. Again, the subjects were instructed to reach for randomly ordered

beads from behind the apparatus, first with their non-dominant hand, and then their dominant hand, at their own pace. The hands of each subject were measured afterwards using calipers.

Results

Classification Systems

In order to determine the variations of precision grasping that exist in normal adults, the first and second experiments (sequential ordering and random ordering of the beads, respectively) were performed on a group of normal adults, as pilot studies to come up with three classification systems that incorporated all types of grasping patterns, postures and strategies used by most people. The results of the first and second experiments were pooled because both experiments did not have any significantly different results.

Digit Contact Strategy

There were 5 variations of strategies used to grasp and retrieve the beads, based on the digit that contacted the bead first, and the whether that digit moved the bead towards the opposing digit or stabilized the bead while the other digit moved towards it and the opposing digit:

- (1) *Both* - Both thumb and digits contacted the bead at the same time.
- (2) *Index Stay* - The index or the middle finger contacting the bead first and remained in place (stabilizing the bead) while the thumb approached the bead and the finger.
- (3) *Thumb Stay* - The thumb contacted the bead first and then stayed in place while the index approached the bead.
- (4) *Index Drag* - The index or middle finger contacted the bead first and dragged the bead towards the thumb.

- (5) *Thumb Drag* - The thumb contacted the bead first and dragged the bead towards the opposing fingers.

Normal Adults

Figure 4.2 shows the probability of occurrence of each of the contact strategies along with an illustration of each strategy. A Chi-square analysis ($\chi^2 = 133.375$ d.f. = 4) indicated there was a significant strategy preference. This was due to the greater use of *both* (30%) and *index drag* (37%) strategies versus the *index stay* (10%), *thumb stay* (17%), and *thumb drag* (6%) strategies. ANOVAs indicated that there were no sex, hand, or bead size differences ($F < 1.0$, $P > 0.05$). Hand size had no effect on most digit contact strategies except for the *index drag* strategy ($F_{(4,33)} = 2.096$, $P = 0.018$), although there was no significant linear relation between hand size and the use of the *index drag* strategy.

Children

Figure 4.3 shows the probability of occurrence of each of the contact strategies used by the children. A Chi-square analysis ($\chi^2 = 137.000$, d.f. = 5) indicated a significant strategy preference. This was due to the greater use of both the *thumb drag* (32.7%) and *index drag* (24.8%) strategies versus the *index stay* (10.6%), the *thumb stay* (14.2%) and *both* (15.6%) strategies. Some children (2.1%) failed at bead retrieval compared to no failures of bead retrieval for normal adults and the aged. Gender, age and dexterity index had no significant effect on any of the contact strategies (between or within groups).

Older Adults

Figure 4.4 shows the probability of occurrence of each of the contact strategies used by the older subjects. A Chi-square analysis ($\chi^2 = 37.375$, d.f. = 4) indicated a significant strategy preference. This was due to the preference of the *index drag*

Table 1: Contact Strategies

Contact Strategy	Description
1) Index Drag (Id)	The index or middle digit contacts the bead first and drags the bead towards the thumb.
2) Thumb Drag (Td)	The thumb contacts the bead first and drags the bead towards the opposing digit(s).
3) Index Stay (Is)	The index or middle digit contacts the bead first and then stabilizes the bead (without moving) while the thumb moves toward the bead and the opposing digit(s).
4) Thumb Stay (Ts)	The thumb contacts the bead first and then stabilizes the while the index moves toward the bead and thumb.
5) Both (B)	The thumb and opposing digit(s) contact the bead at the same time.

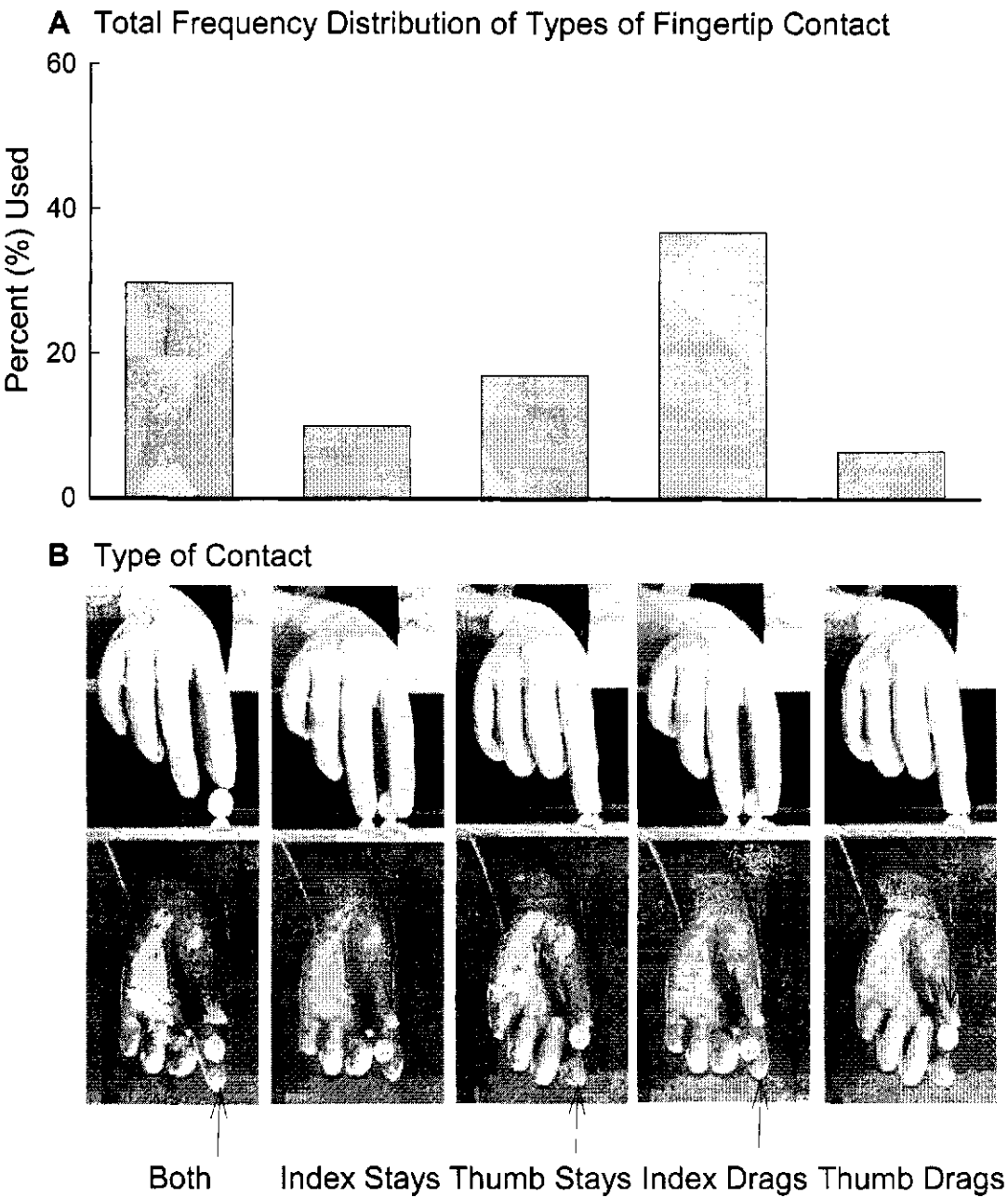


Figure 4.2. A) Total Frequency Distribution (percent of total grasping) of Contact Strategies for Normal Adults. B) Diagrams of the five contact strategies. Note: arrows indicate direction of movement for indicated finger.

(32.5%), *thumb drag* (26.9%), and *both* (23.1%) contact strategies over the *index stay* (9.4%) and *thumb stay* (9.1%) strategies. Gender, presence of medical conditions and the dexterity index had no significant effect on any of the contact strategies ($P > 0.05$). For all contact strategies except for the *index drag* strategy, there was no significant effect of age. There was a significant effect of age on the *index drag* strategy ($F_{(5, 15)} = 5.167, P = 0.042$).

Purchase Patterns

There were 7 variations of patterns used to grasp and retrieve the beads, based on the digits used to contact the beads during the grasping phase (See Table 2):

- (1) *Proper Pincer* – the thumb and the index digits were used
- (2) *Improper Pincer* – the thumb and the middle fingers were used.
- (3) *Supported Pincer* – the thumb, index and middle digits were used, but either the index or the middle finger was only used for support.
- (4) *Triangular Grasp* – the thumb, index and middle digits were used, with shared contact and equal support from the index and middle fingers.
- (5) *Improper Triangular Grasp* – the thumb, middle and ring fingers were used.
- (6) *4-digit (flower) Grasp* – the thumb, index, middle and ring fingers were used, with most support from the thumb and the middle finger.
- (7) *5-digit (flower) Grasp* – all five fingers are used, with most support from the thumb and the middle finger.

Normal Adults

A Chi-square analysis ($\chi^2 = 955.968$ d.f. = 6) indicated there was a significant pattern preference. As illustrated in Figure 4.5, Type 1 or the *proper pincer* grasp, was the most common pattern (51.3%) and type 7, the five-digit grasp, was the

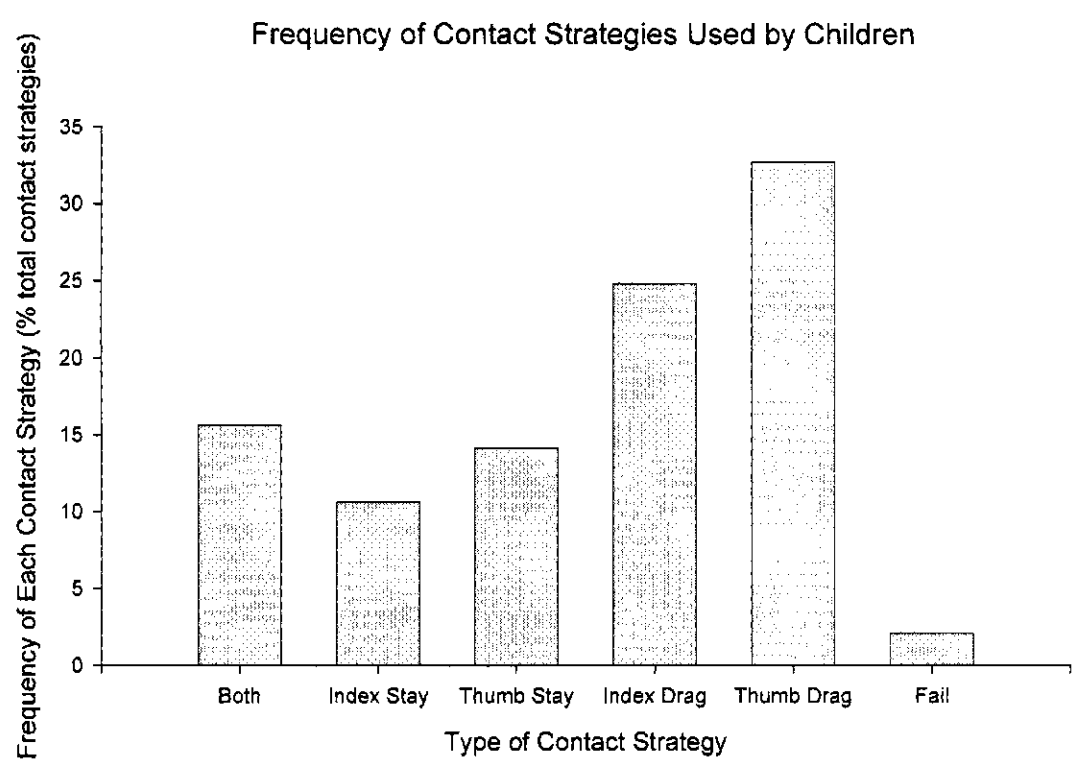


Figure 4.3. Total Frequency Distribution (percent of total grasping) of Contact Strategies for Children.

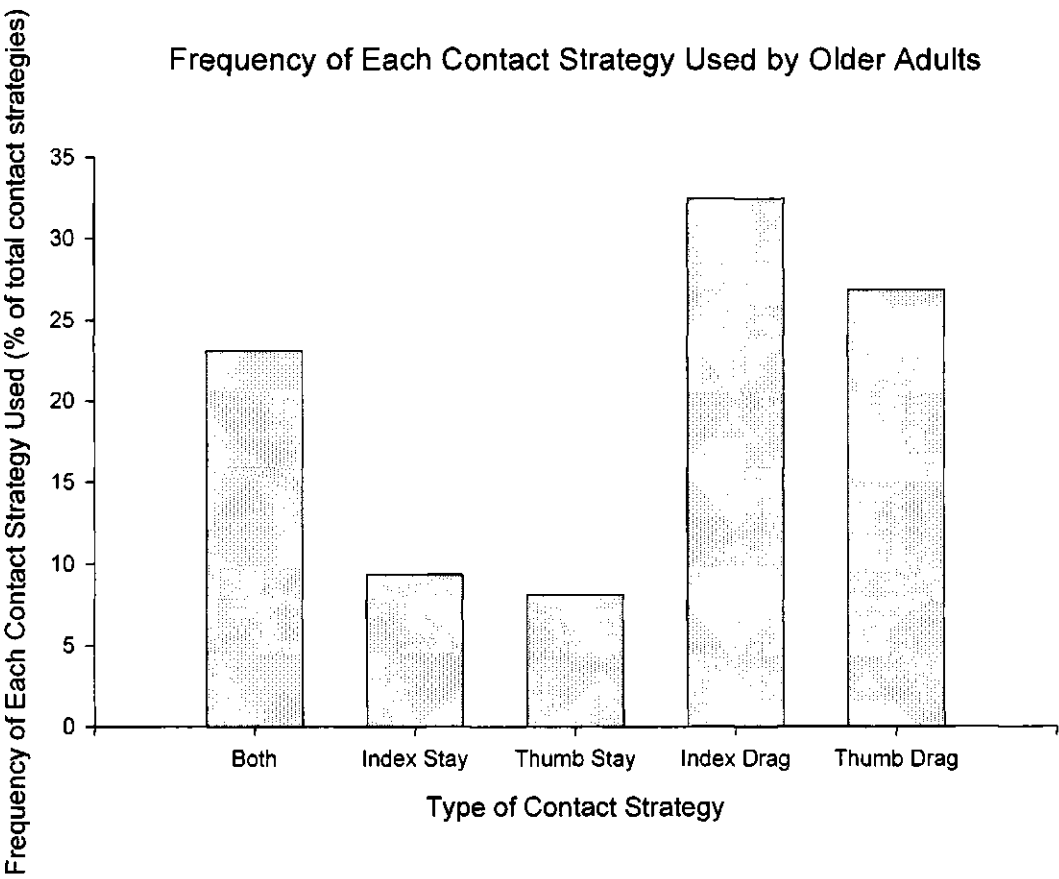


Figure 4.4. Total Frequency Distribution (percent of total grasping) of Contact Strategies for Older Adults.

least common (0.5%). The distribution of purchase patterns was relatively similar across all the bead sizes except for the smallest bead size. There was a significant interaction between grasp type and bead size ($F_{(4, 68)} = 46.038$, $P = 0.000$). As is illustrated in Figure 4.6, this appeared to be due mainly to a decrease in the probability of using Type 1, the *proper pincer* type, for the larger bead sizes. There was no effect of hand use or handedness, as subjects used almost identical purchase patterns with left and right hands. There was an effect of sex ($F_{(1, 73)} = 59.016$, $P = 0.000$) due mainly to the use of more multiple digit purchase patterns by females than by males (See Figure 4.7 A). Hand size had a significant linear effect on the grasping complexity of the purchase patterns (determined by the number of fingers recruited to grasp the object) of the larger bead sizes compared to the two smallest bead sizes. Digit size was significant in determining purchase patterns for the larger beads using the left hand, but not the right (10mm to 16 mm diameter). For the largest bead size (16mm diameter), the effect was that as hand size increased, the grasping complexity noticeably decreased for both the left hand ($F_{(1, 73)} = 13.929$, $P = 0.0004$), and for the right hand ($F_{(1, 73)} = 6.240$, $P = 0.0147$). For the smallest bead size (3mm diameter) the grasping complexity was not significantly affected by hand size ($F_{(1, 73)} = 0.128$, $P = 0.721$) for the left hand and ($F_{(1, 73)} = 0.539$, $P = 0.465$) for the right hand.

Children

Figure 4.8 shows the probability of occurrence for each purchase pattern. A Chi-square analysis ($\chi^2 = 664.088$, d.f.= 8) indicated there was significant purchase pattern preference. This appeared to be due to the preference of the *proper pincer grasp* (Type 1, at 42.3%) and the *supported pincer grasp* (Type 3, at 24.9%) compared to the other types of purchase patterns. Figure 4.9 shows the distribution of purchase patterns for children separated according to bead size. When compared with

Table 2: Purchase Patterns

Purchase Patterns	Digits Used
1) Proper Pincer	Only digits 1 and 2 are used to contact the object.
2) Improper Pincer	Only digits 1 and 3 are used to contact the object.
3) Supported Pincer	Digits 1, 2 and 3 are used to contact the object, but either digit 2 or digit 3 is only used for support.
4) Triangular Grasp	Digits 1, 2 and 3 are used to contact the object, shared contact and equal support from digits 2 and 3.
5) Improper Triangular Grasp	Digits 1, 3 and 4 are used to contact the object.
6) 4-digit (flower) Grasp	Digits 1,2, 3 and 4 are used to contact the object, with most support from digits 1 and 3.
7) 5-digit (flower) Grasp	Digits 1, 2, 3, 4 and 5 are used to contact the object, with most support from digits 1 and 3.

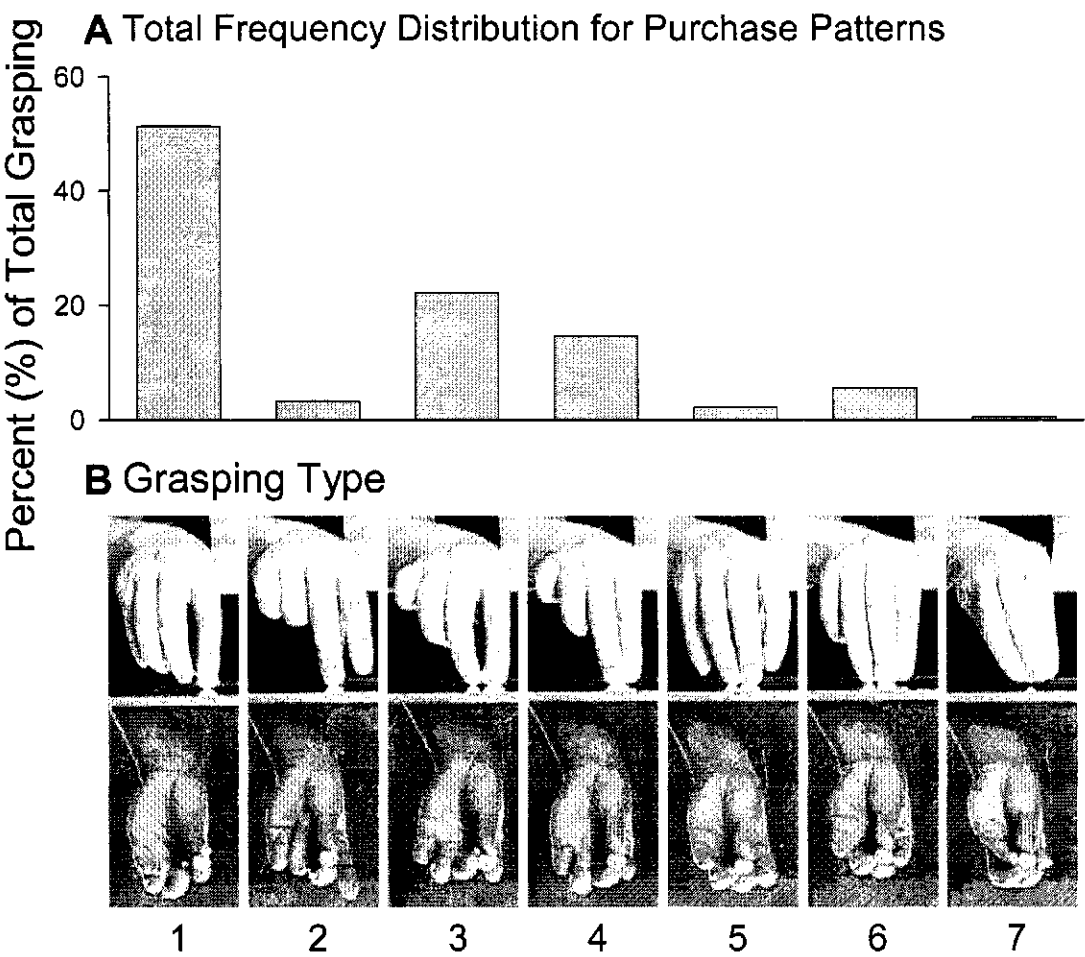


Figure 4.5. Frequency of 7 different precision grasps (Purchase Patterns) for Normal Adults. A) Percentage of grasping for each recorded type of grasp (shown below in figure 1 B). Note: the digits used, and the number of digits contacting the bead define grasp types.

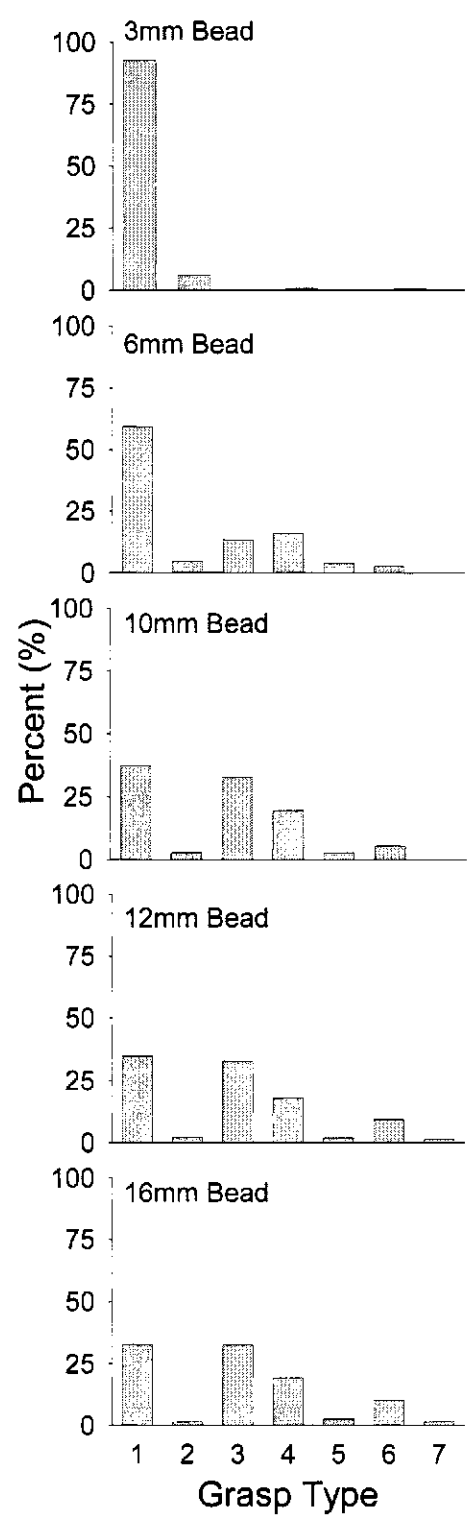


Figure 4.6. Percentage of purchase patterns as a function of different bead sizes for Normal Adults. Note: as the bead diameter increases more variations in the type of grasps occur.

the adult distribution, the distributions of child purchase patterns across the five bead sizes are almost identical. In addition to the seven purchase patterns as seen in the adults, there was a category of “Fail” and an extra pattern “D1 & D4” that children used, where only the thumb and the ring finger are used to grasp the beads. There were no gender or hand size differences on the purchase pattern as seen in children, but there was a significant effect of bead size on purchase pattern ($F_{(4,32)} = 4.60$, $P = 0.005$). There was no significant effect of gender or the dexterity index on any of the purchase patterns, but there was a significant effect of age on the purchase pattern “D1 & D4” ($F_{(7, 47)} = 3.108$, $P = 0.010$). This was due to this pattern being used only by the younger children, aged 6 to 7 years.

Older Adults

Figure 4.10 shows the probability of occurrence for each purchase pattern used by elderly people. A Chi-squared analysis ($\chi^2 = 320.112$, d.f. = 6) shows that there was a significant purchase pattern preference. This was due to the greater use of the *proper pincer grasp* (Type 1, at 61.9% of the total frequency) over all other grasp patterns. Figure 4.11 shows the distribution of purchase patterns across the separated by bead sizes. There was no significant effect of the hand used, gender, age, dexterity index or presence of medical conditions on any of the purchase patterns ($P < 0.05$). A curve fit regression analysis showed that there was no significant effect of hand size on the purchase pattern for any of the bead sizes ($F > 1.0$, $P > 0.05$). There was a significant effect of bead size on purchase pattern ($F_{(1, 4)} = 221.914$, $P = 0.043$) due to the greater use of the *proper pincer grasp* for the smallest bead size.

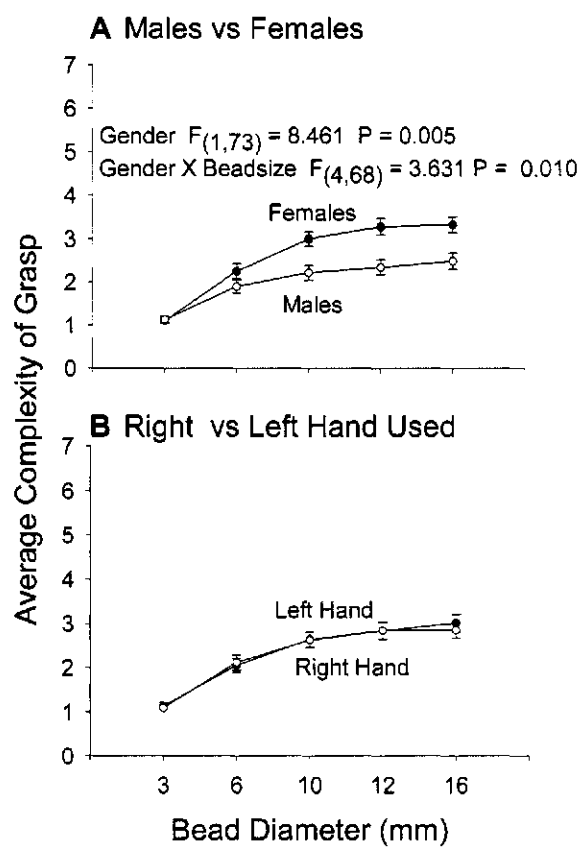


Figure 4.7. Purchase pattern as a function of sex and handedness for Normal Adults:

A) Purchase pattern as a function of sexes. B) Purchase pattern as a function of handedness.

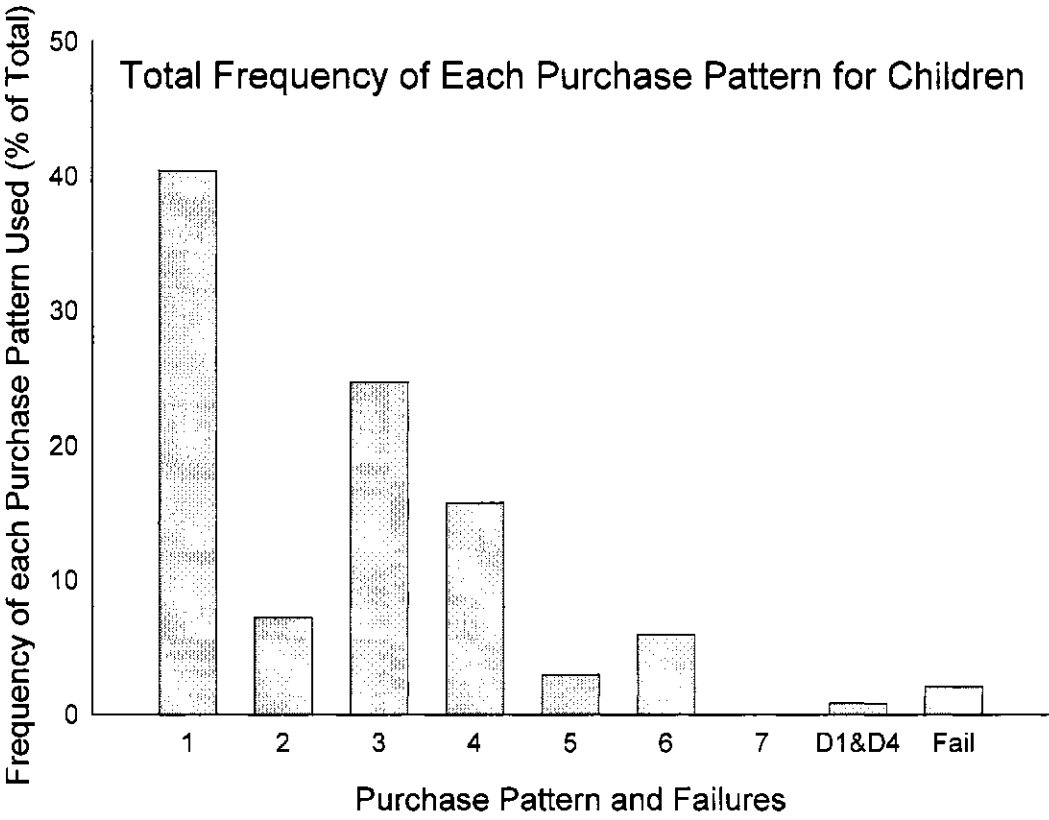


Figure 4.8. Frequency of 7 different precision grasps (Purchase Patterns) for Children.

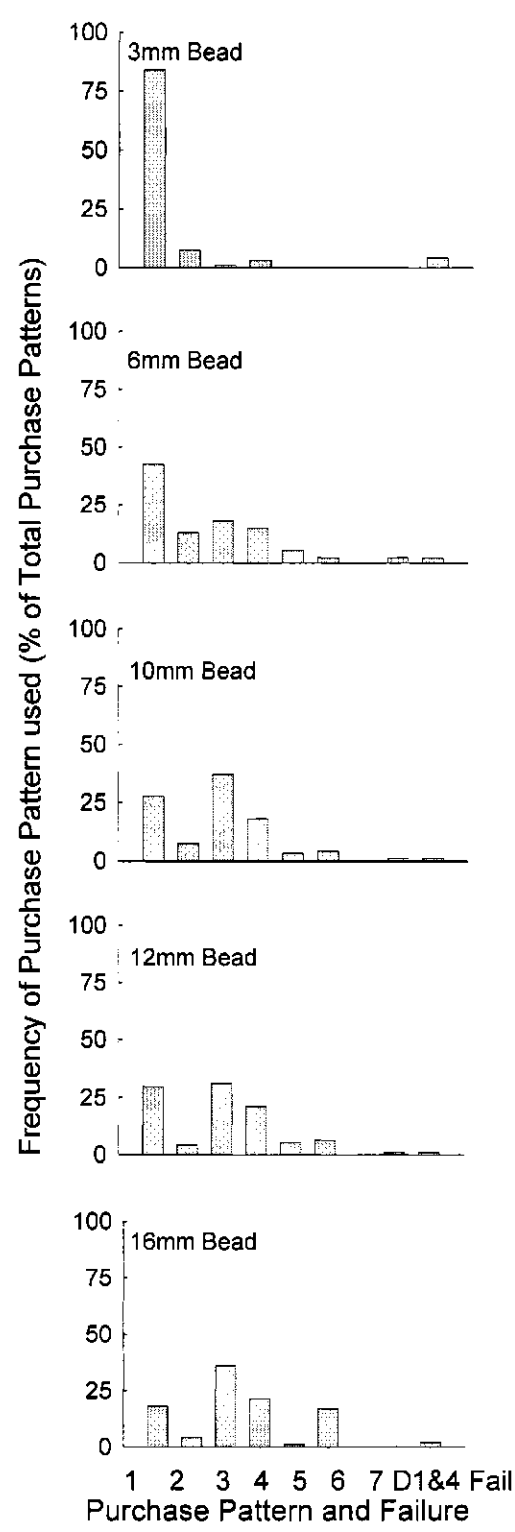


Figure 4.9. Percentage of purchase patterns as a function of different bead sizes for children. Note the similarity of distribution compared to normal adults.

Postures of Non-grasping Digits

There were 4 variations in the posture of the digits not used in bead retrieval, based on whether the digits were abducted (open), adducted (closed), flexed or extended (See Table 3):

- (1) *Open-flex Posture*– Abducted (open) and flexed digits.
- (2) *Close-flex Posture* – Adducted (closed) and flexed digits.
- (3) *Open-extend Posture* – Abducted (open) and extended digits.
- (4) *Close-extend Posture* – Adducted (closed) and extended.

Normal Adults

Figure 4.12 shows the probability of occurrence for each posture in normal adults and their respective illustrations. A Chi-square analysis ($\chi^2 = 955.968$ d.f. = 6) indicated that there was a significant preference of posture 2 (90.9%), the adducted and flexed position, over postures *open-flex* (5.6%), the abducted and flexed position, *open-extend* (2.8%), the abducted and extended position, and *close-extend* (0.7%), the adducted and extended position. Bead size had a significant effect on the posture ($F(4,68) = 3.827$, $P = 0.007$) due to the decreasing use of posture 4 with the smaller bead sizes. There was no significant effect of gender, handedness, or hand use ($F > 1$, $P > 0.05$) on the preferred postures. Hand size also had a significant effect on three out of four postures ($F_{(3,74)} = 3.949$, $P = 0.000$ for Posture 1; $F_{(3,74)} = 3.505$, $P = 0.000$ for Posture 2; $F_{(3,74)} = 7.103$, $P = 0.000$ for Posture 4). Only Posture 4, where the digits were closed and extended, was not significantly affected by hand size.

Children

Figure 4.13 shows the probability of occurrence of each posture for children. A Chi-square analysis ($\chi^2 = 1049.979$ d.f. = 4) indicated that there was a significant strategy

Table 3: Postures of non-grasping digits

Subtype	Description
a)	Digits are abducted (open) and flexed
b)	Digits are adducted (closed) and flexed
c)	Digits are abducted (open) and extended
d)	Digits are adducted (closed) and extended

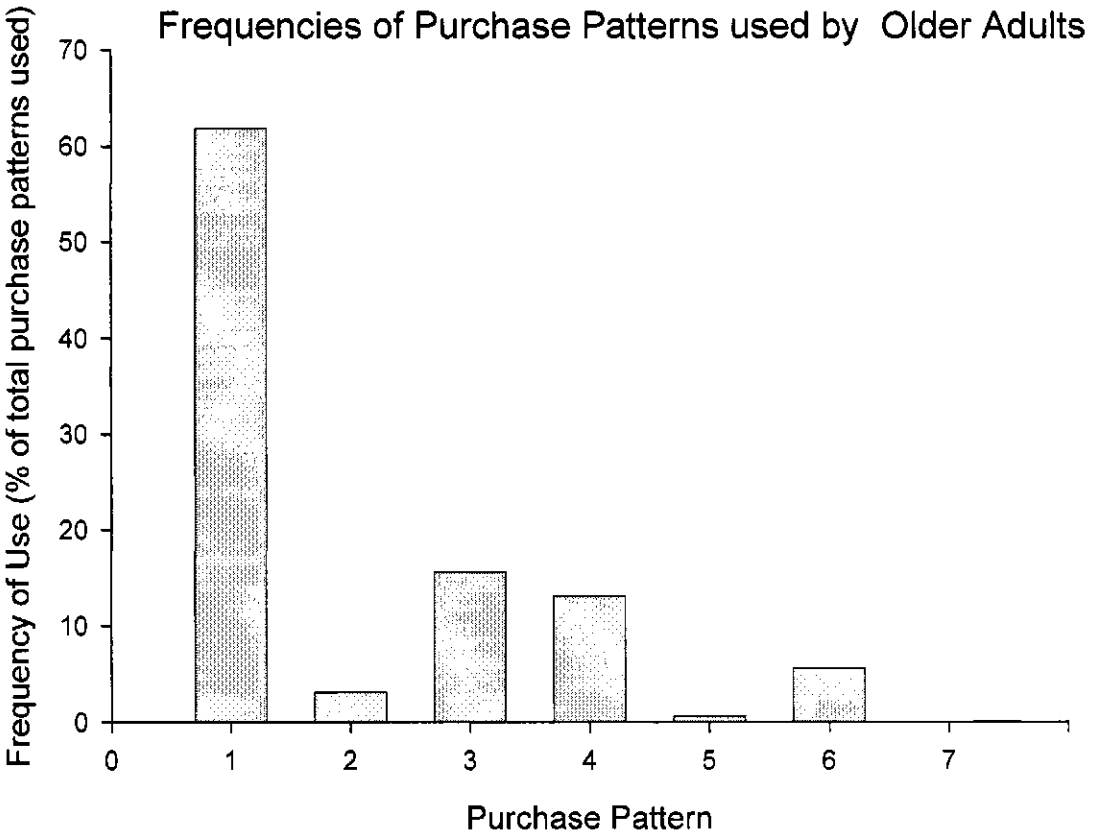


Figure 4.10. Frequency of 7 different precision grasps (Purchase Patterns) for older adults.

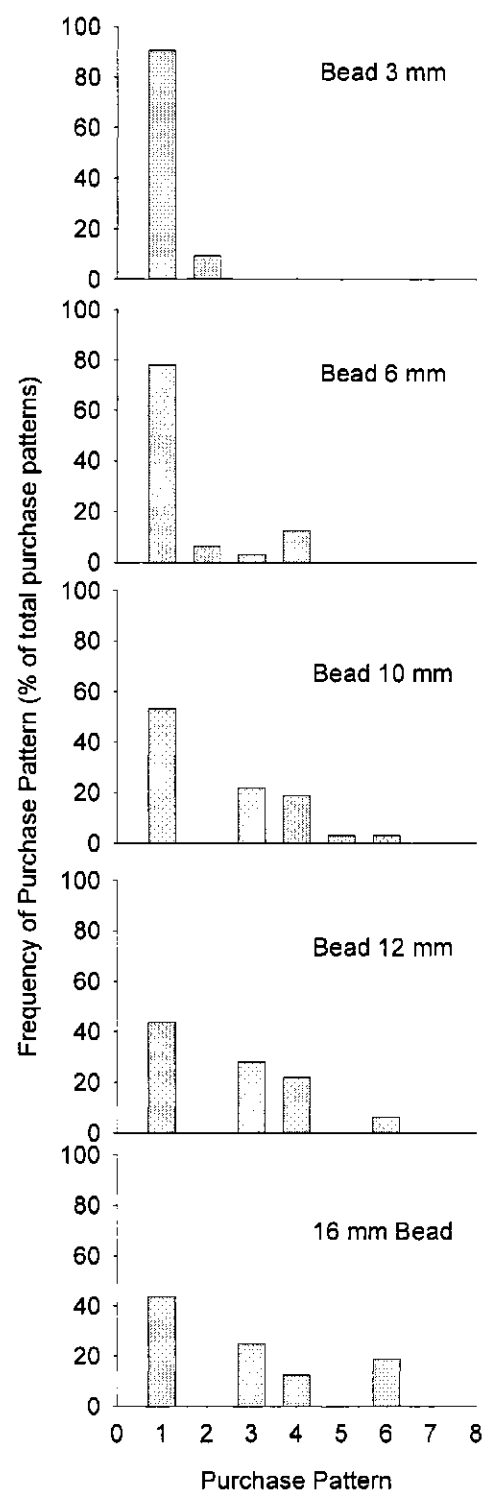


Figure 4.11. Percentage of grasp types as a function of different bead sizes for older adults.

preference of posture 2 *closed-flexed* (79.1%), over postures *open-flexed* (19.6%), *open-extend* (0.2%), and *close extend* (2.1%). For the children, 1% of the grasps were “Failed” or incomplete, as compared to 0% for the elderly and normal adults. Age, gender and dexterity index had no significant effect on any of the postures of the non-grasping digits ($P < 0.05$).

Older Adults

Figure 4.14 shows the probability of occurrence of each posture for older adults. A Chi-square analysis ($\chi^2 = 354.850$ d.f. = 3) indicates that there was a significant preference of the *close-flex* posture (87.4%) over the *open-flex* posture (5.6%), *open-extend* posture (5%), and the *close-extend* posture (0%). There was no effect of presence of medical conditions, age or gender on any of the postures ($P < 0.05$). However, the dexterity index had a significant effect on the *open-flex* posture ($F(5, 15) = 10.969$, $P = 0.001$). This was due to greater use of this posture by most of the subjects with higher dexterity indexes.

Individual Differences

A partial correlation was performed on the purchase patterns for the mid-sized beads (6mm, 10mm, and 12mm in diameter) across the left and the right hands (See Table 4). Six out of nine possible combinations for the left versus right were significantly correlated (Left hand 12 mm bead versus Right hand 12 mm bead Coefficient($C_{(37)}$)=0.5377, $P = 0.000$; Left 10 mm versus right 10 mm $C_{(37)}$ =0.5251, $P=0.001$; Left 10 mm versus Right 10 mm, $C_{(37)}$ =0.5972, $P=0.000$; Left 6 mm versus Right 10 mm $C_{(37)}$ =0.4429, $P=0.005$; Left 12 mm versus Right 6 mm $C_{(37)}$ =0.4063, $P=0.01$; Left 10 mm versus Right 6 mm $C_{(37)}$ =0.4552, $P=0.004$). As well, partial correlations (again controlling for subject) were performed for the left versus left and right versus right hands (See Table 4). Two out of three possible combinations for the

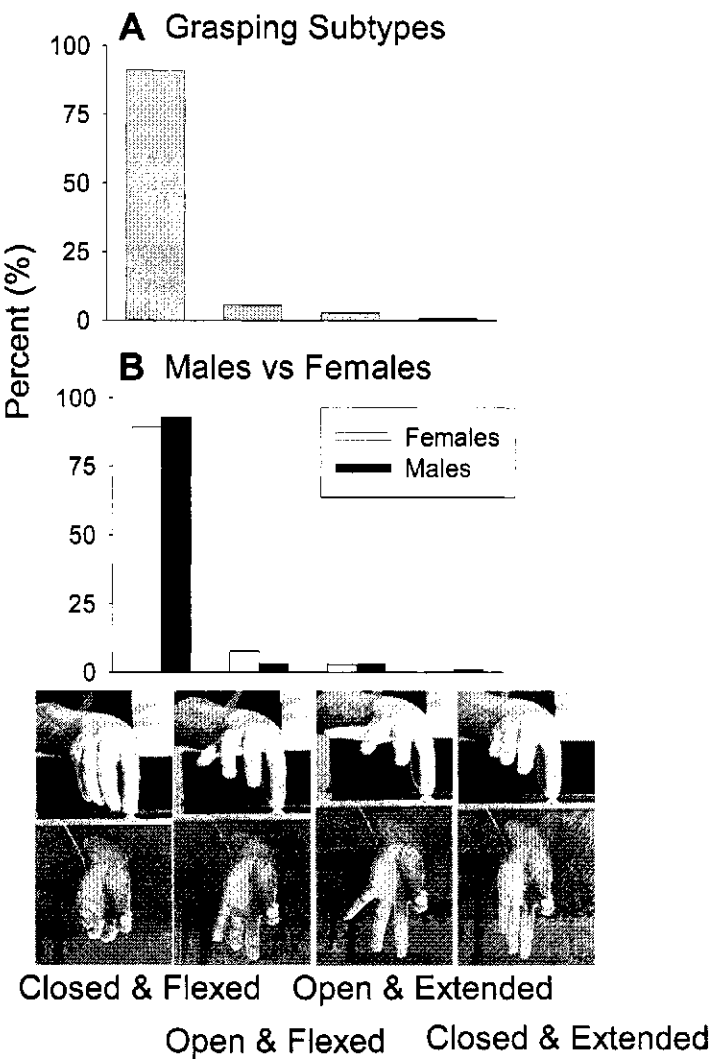


Figure 4.12. Distribution of digit postures for normal adults: A) Postures of non-grasping digits, percent. B) Percent of total grasping for males and females. Postures of non-grasping digits in which digits are closed, opened, flexed or extended (shown below).

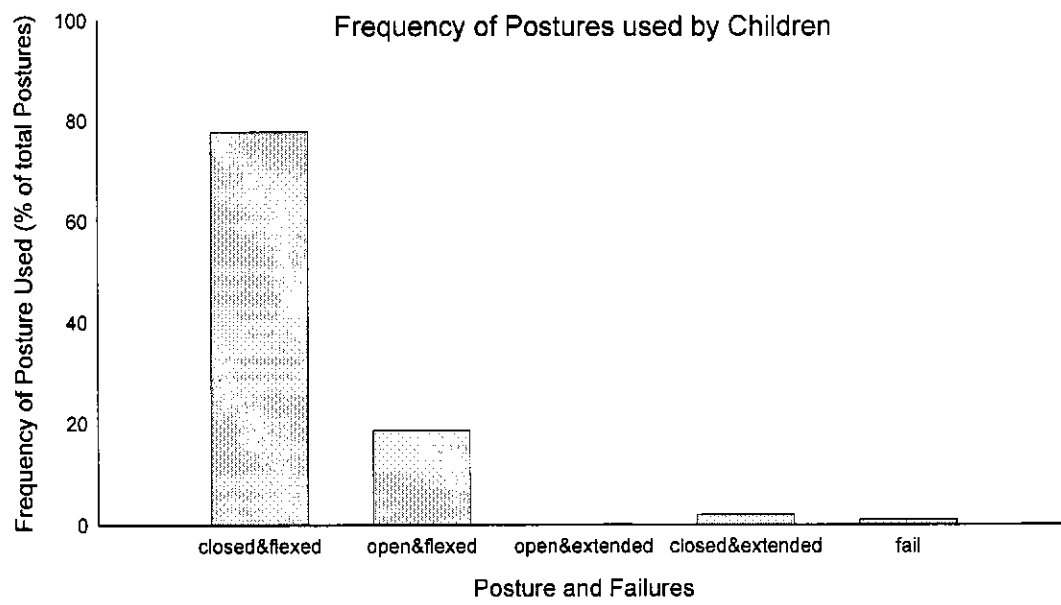


Figure 4.13. Postures of non-grasping digits, percent (children).

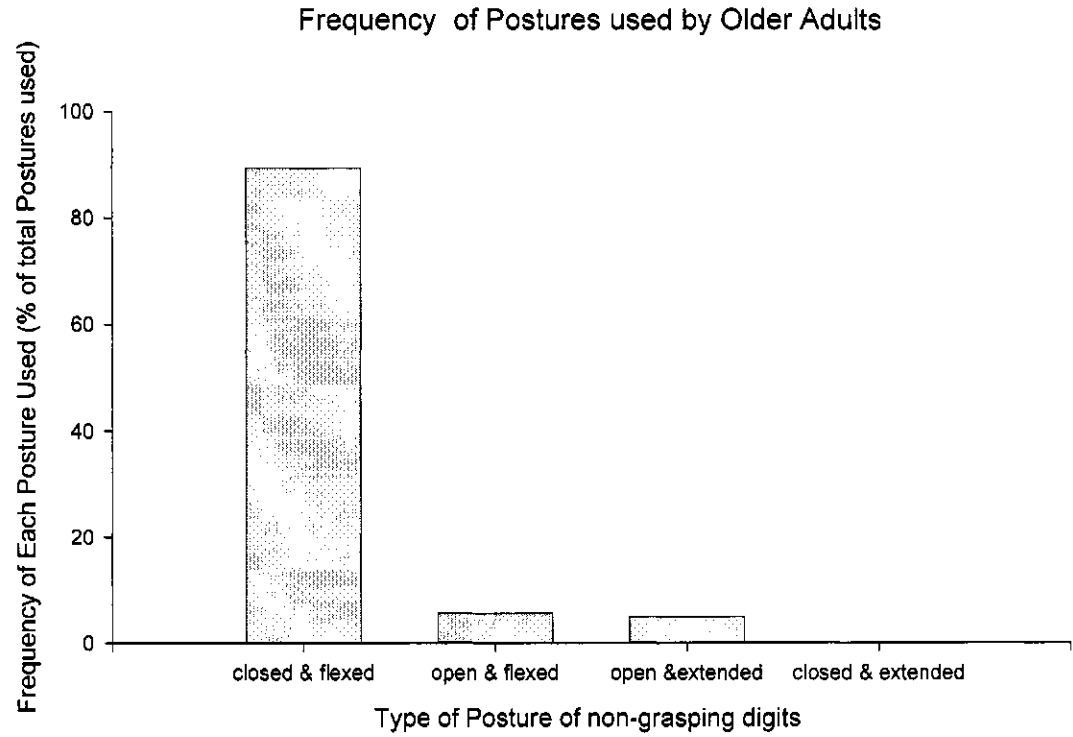


Figure 4.14. Postures of non-grasping digits, percent (older adults).

left versus left correlation (Left 10 mm versus Left 12 mm $C_{(37)}=0.4756$, $P=.002$; Left 6 mm versus Left 10 mm $C_{(37)}=0.4740$, $P=0.002$), and all three possible combinations for the right versus right hand correlation were significantly correlated (Right 10 mm versus Right 12 mm $C_{(37)}=0.5342$ $P=0.000$; Right 6 mm versus Right 12 mm $C_{(37)}=0.5032$, $P=0.001$; Right 6 mm versus Right 10 mm $C_{(37)}=0.4661$, $P=0.003$). The results for both hands and individuals show that purchase pattern preference was based significantly on individual preferences, as opposed to random choice patterns.

The choice of purchase patterns was not related to posture choice. A partial correlation was run on the choice of purchase pattern and the contact strategy (See Table 5). Only 4 out of 36 possible pairs were significantly correlated, all four pairs containing the right contact strategy for the 10 mm diameter bead (Left purchase pattern for the 12 mm bead versus the Right contact strategy for 10 mm bead $C_{(37)}=-0.3441$, $P=0.032$; Left purchase pattern for 10 mm versus Right contact strategy for 10 mm bead $C_{(37)}=-0.3589$, $P=0.025$; Right purchase pattern for 12 mm bead versus Left contact strategy for 10 mm bead $C_{(37)}=-0.3923$, $P=0.013$; Right purchase pattern for 6 mm bead versus Left contact strategy for 10 mm bead $C_{(37)}=-0.3853$, $P=0.015$). The lack of many significant correlations between the contact strategies and purchase patterns shows that preference for certain purchase patterns were not related to choice or certain contact strategies.

Discussion

Normal Adults

There was evidence that external factors did influence grasp pattern even with the limited variability of the target objects. Napier (1956) proposes that grasp patterns will vary depending upon the need to stabilize a target object (Napier 1956).

Table 4. Partial correlations for 6, 10 and 12-millimeter beads for both left and right hands, controlling for subject.*

		Purchase Pattern Left Hand			Purchase Pattern Right Hand		
		6 mm	10 mm	12 mm	6 mm	10 mm	12 mm
Purchase Pattern Left Hand	6 mm	X (37) P=0.002	0.4740 (37) P=0.002	0.01431 (37) P=0.385	0.2658 (37) P=0.102	0.4429 (37) P=0.005	0.0479 (37) P=0.772
	10 mm	0.4740 (37) P=0.002	X (37) P=0.002	0.4756 (37) P=0.002	0.4552 (37) P=0.004	0.5972 (37) P=0.000	0.5251 (37) P=0.001
	12 mm	0.01431 (37) P=0.385	0.4756 (37) P=0.002	X (37) P=0.010	0.4063 (37) P=0.073	0.2903 (37) P=0.000	0.5377 (37) P=0.000
Purchase Pattern Right Hand	6 mm	0.2658 (37) P=0.102	0.4552 (37) P=0.004	0.4063 (37) P=0.010	X (37) P=0.003	0.4661 (37) P=0.000	0.5032 (37) P=0.001
	10 mm	0.4429 (37) P=0.005	0.5972 (37) P=0.000	0.2903 (37) P=0.073	0.4661 (37) P=0.003	X (37) P=0.000	0.5342 (37) P=0.000
	12 mm	0.0479 (37) P=0.772	0.5251 (37) P=0.001	0.5377 (37) P=0.000	0.5032 (37) P=0.001	0.5342 (37) P=0.000	X

*Reported in format (Coefficient/(Degrees of Freedom)/2-tailed significance). “X” is printed if significance could not be computed.

Table 5. A partial correlation table of contact strategies and purchase patterns for bead sizes 6, 10 and 12 millimeters in diameter for both left and right hands.*

		Purchase Pattern Left Hand			Purchase Pattern Right Hand		
		6 mm	10 mm	12 mm	6 mm	10 mm	12 mm
Contact Strategy Left Hand	6 mm	-0.1064 (37) P=0.519	-0.1892 (37) P=0.249	-0.1072 (37) P=0.516	-0.1933 (37) P=0.238	-0.1493 (37) P=0.364	-0.0202 (37) P=0.903
	10 mm	-0.2024 (37) P=0.216	-0.1193 (37) P=0.469	-0.0176 (37) P=0.915	-0.2248 (37) P=0.169	0.0044 (37) P=0.979	0.2209 (37) P=0.177
	12 mm	0.0529 (37) P=0.749	-0.0390 (37) P=0.813	-0.0300 (37) P=0.856	-0.1755 (37) P=0.285	-0.2198 (37) P=0.179	-0.1751 (37) P=0.286
Contact Strategy Right Hand	6 mm	-0.0311 (37) P=0.851	-0.0532 (37) P=0.748	-0.0744 (37) P=0.653	-0.0232 (37) P=0.889	-0.2786 (37) P=0.086	-0.0944 (37) P=0.567
	10 mm	-0.3441 (37) P=0.032	-0.3589 (37) P=0.025	-0.1990 (37) P=0.225	-0.3853 (37) P=0.015	-0.2638 (37) P=0.015	-0.3923 (37) P=0.013
	12 mm	-0.1327 (37) P=0.421	0.0520 (37) P=0.753	0.0435 (37) P=0.793	0.0267 (37) P=0.872	0.0267 (37) P=0.872	0.1267 (37) P=0.443

*Reported in format (Coefficient/(Degrees of Freedom)/2-tailed significance). “X” is printed if significance could not be computed.

Therefore, the more digits recruited, the more stable the grip. A Type I (*proper pincer*) grasp appeared most appropriate for the smallest object because contact space was limited. In addition, there was more use of Type 4 and Type 5 patterns, in which more than two digits contacted the bead, with beads of the largest diameters that provided more contact space. Finally, there was a small but significant relation between digit size and grasping pattern, again suggesting that subjects with smaller digits are able to recruit more digits to assist in obtaining a stable grasp.

Despite the influence of the external properties of the objects and subject hand size, there was still a remarkably wide range of intersubject grasp types used for every object. Even though two different experiments were performed (random ordered versus sequentially ordered), there were no significant difference between the results, and so ordering of the bead sizes did not dictate the results. Different subjects used the five contact strategies and almost any of the 28 grasp types. For example, some subjects grasped all objects with a Type 1 grasp whereas other subjects preferentially used a Type 2 or Type 3 grasp, in which one of the other digits was substituted for the second digit of the Type 1 grasp. As well, the results show that there are a strong correlations strategies used by the left and right hands, indicating that for each subject, individual preference determined purchase patterns, as opposed to random choice. Some subjects used grasp patterns in which all digits were flexed while others used grasp patterns in which the nongrasping digits were extended and still other subjects had the nongrasping digits flexed and open, flexed and closed, extended and open, or extended and closed. Finally, contact strategy did not determine grasp pattern. Thus, there are individual differences that strongly suggest that central factors play a strong role in the type of grasp pattern used.

Although there was no sex difference in the grasp subtype used, there was a significant difference between females and males in the complexity of grasp-patterns used. Females used more complex grasp patterns involving recruitment of more digits compared to males. One possible explanation is that females have smaller hands and thinner digits than males, as shown in the results, and hence are able to use more digits on the surface area of a bead. This idea is supported by a study by Peters et al. (1990), who found that sex differences on fine motor tasks disappear when finger size is considered. It has also been proposed that testicular hormones contribute to the intrinsic variability between sexes. Kimura and Vanderwolf (1970) report that females are more flexible in digit use than males (Kimura and Vanderwolf 1970). Similarly, females tend to show similar advantages in performing finger tapping sequences and touching each finger in succession against the thumb, than do males (Kimura and Vanderwolf 1970; Matano and Nakano 1998; Highley, Esiri et al. 1999; Kimura 1999). Although hand size and sex were significant factors in influencing grasp patterns, it is uncertain that the relationship is casual.

It is interesting that grasping variability has not received much study in humans as it has in apes. Butterworth and Itakura (1998) show that older chimpanzees mostly used a pincer grip on the smallest sizes of apple cubes and a power grip position on the largest sizes, and that there are 4 variations of grasp patterns by chimpanzees. The chimpanzees' preference noticeably accounts for the varying patterns of precision, imprecise, power and middle-index grips used for apple cubes in intermediate sizes. It would be interesting to further explore the evolution of the proper pincer grip, as the present study predicts that it likely originated for grasping extremely small objects.

The variability in grasping patterns used by different subjects could have a number of explanations. Variation may be related to genetic heterogeneity, variations in nervous system anatomical structure, or to learning. It is known that the motor cortex has multiple digit representations, and because the motor cortex encodes a large number of synergies (Schieber 1999; Hager-Ross and Schieber 2000; Schieber 2001; Schieber, Gardinier et al. 2001; Graziano, Taylor et al. 2002) variations in this encoding may underlie variation. With respect to the learning hypothesis, during developmental and beginning within the first two months of life, human infants display prolonged practice exemplified by spontaneously generated hand and digit movements, followed by self-grasping, and finally reaching (Wallace and Whishaw 2003). Smeets and Brenner (2001) have suggested adult grasping is the result of learned control of individual digits, and this developmental practice may thus underlie subsequent variation (Smeets and Brenner 2001). Future research could explore both the inheritance of grasping strategies and their development in childhood.

An interesting finding of the present study was that the grasping patterns used by the two hands of individual subjects were almost identical. This could have resulted from the object familiarity gained after using the first hand, allowing the other hand to use the vicariously obtained visual and tactile information. This seems unlikely, however, because varying the sequence of bead size or varying the starting hand did not affect interhand patterns. Thus, similar movements in the two hands likely have central origins. It is unlikely that there is a hand command center in the hand region of one hemisphere that underlies interhand similarities, because there are few or no direct interhemispheric connections between the hand regions of the motor cortex (Andres, Mima et al. 1999). Possibly the command region for the selection of grasping movements is in the parietal cortex (Mountcastle 1995; Connolly, Andersen

et al. 2003). Haaxma and Kuypers (1974) have demonstrated using a disconnection paradigm that visual control of grasping depends upon interhemispheric connections originating in the parietal neocortex. For humans, it is likely that it is the left parietal cortex that encodes individual preferences (Mountcastle 1995).

Children

Children, who have smaller hand size and were pre-pubertal, displayed a similar distribution of grasp patterns and similar individual differences to adults. Children were also similar to adults in preference of the *index drag* strategy, as well the extensive use of the *proper pincer* and *supported pincer* grasping types over other purchase patterns. Children, especially the younger ones, did tend to fail at retrieval more often than the adults, and also exhibited an extra purchase pattern that adults did not exhibit, the *D1 & D4* pattern. This supports the theory that learning precision grasp patterns involves experimenting with different grasping types and narrowing the selection to the more efficient grasp patterns. Siddiqui (1995) cites that children tend to use grasps involving the radial digits (the thumb, index and middle fingers) more often as they grow older, and that is due to the better establishment of cortico-motor neuronal connections in older infants. Unlike the adults, there was no effect of gender on the purchase pattern preferences in the children. The average difference of hand size between boys and girls is a smaller discrepancy than the adult gender hand size differences. Kuhtz-Buschbeck et al. (1998), state that the dependence on visual control of movement declines during motor development, and suggest that the development of prehensile skills during childhood lasts until the end of the first decade of life, which may explain the increased rate of failing at bead retrieval for children under the age of 12 (Kuhtz-Buschbeck, Stolze et al. 1998).

Older Adults

For the contact strategies, the older adults tend to use a combination of the most popular strategies used by adults and children, that is, the *index drag*, *both*, and *thumb drag* strategies. There was no effect of sex or dexterity on any of the contact strategies. However, there was an effect of age only on the most common contact strategy, *index drag*. The distribution of contact strategies were more pronounced in the elderly, in that the preferred strategies were significantly used more than the *thumb stay* or the *index stay* strategies.

As well, the purchase pattern distribution across the different bead sizes was quite different compared to the adults and children. There was less variation used in the mid sized beads, and more use of *proper pincer* and the *supported pincer* compared to the other purchase patterns. The *5-digit grasp* and the *improper triangular grasp* were not present in older adults, and there was minimal use of the *improper pincer*, unlike in normal adults and children. This loss of variation may be due to the use of grasps that can apply greater grip force because of the decrease of sensory feedback that occurs with age (Cole, Rotella et al. 1999; Ranganathan, Siemionow et al. 2001; Gilles and Wing 2003). The grasps that recruit more digits may provide more stability with less force. It would be interesting to determine grip force of other variations of precisions grasps, aside from the pincer grasp.

The older adults also exhibit less variation in the presence of different postures for the non-grasping digits. There was no use of the *close-extended* posture, compared to normal adults and children. As well, the *open-flexed* posture was used more by adults with higher dexterity indices.

The lack of variation in the purchase patterns and postures older adults supports the hypothesis that aging may play a factor in the selection of the most

efficient grasp patterns. Normal deterioration of hand function, due to local structural changes as well as a more distant loss of neural control, may attribute to the loss of variation within normal older adults (Carmeli, Patish et al. 2003).

CHAPTER FIVE

GENERAL DISCUSSION

Nature-Nurture Dichotomy

The nature-nurture dichotomy is a long-standing problem addressed by biologists and psychologists alike. Behaviors can be attributed to either “biology” or genetic inheritance (nature) or learning from experiences (nurture). Genetic inheritance of behaviors would predict that there are similar brain structures that are responsible for similar behaviors across all individuals. This would be because similar genetics (from the human genome) in people dictate the formation of the cortex, and hence its underlying behavior. Another prediction suggests that learning from experience would imply that people raised in different environments have different experiences, and in turn exhibit different and variable behaviors across all individuals. Therefore, we would expect variable brain structure (from incorporating learned aspects into the cortex) and variable behaviors. A third prediction also arises, in which a combination of both biology and environmental factors attribute to behaviors in individuals. This would mean that there would be some variation of a certain behavior because the experiences of each individual is different, but that variation would be minimal, as similar biology across all humans would constrict the amount of variation that is possible. In this thesis, precision grasping is examined in terms of this central problem.

Early Studies

Early literature first noted that infants developed grasping abilities in distinct phases. (Myers 1915; Halverson 1931; Castner 1932) confirmed the phases of grasping, starting with the kinaesthetic grasping reflex that was present within the first few days of birth. Infants then learn to inhibit that reflex and begin to start actively

reaching for objects after visual acknowledgement after a couple of months after birth. At around ten months after birth, infants are able to use “volar” or precision grasping. (Wallace and Whishaw 2003) have also noted that before targeted grasping movements, infants 1 to 5 months of age progressed, in order, from closed fists to vacuous (empty) hand movements, and finally to self directed grasping. Wallace and Whishaw suggest that this “hand babbling” in infancy is to prepare and practice for targeted reaching later in life. The function of “hand babbling” is comparable to the function of babbling in the development of language (Werker and Tees 1983). Since all human infants follow the same phases for the development of grasping, this implies that nature (biology) determines the development of grasping. Wallace and Whishaw suggest that the development of these complex hand and digit movements may be mediated by the development of the pyramidal tract, including the pruning of exuberant axons and connection of the remaining axon terminals to spinal cord and motor neurons.

Early literature examining the effects of brain damage on grasping also implies that nature (genetics) affects grasping in adults. (Adie and Critchley 1927; Walshe and Robertson 1933) have examined patients that exhibited “forced grasping and groping”, in which the patients grabbed and held onto objects placed in their palm without being able to control the reflex. After examining the patients’ cortices after they died, Adie and Critchley and Walshe and Robertson found that an area in the frontal lobe was damaged in each patient. This area is later defined as the supplementary motor area (SMA) (Smith, Frysinger et al. 1983). Smith et al. found similar damage in the SMA in primates resulted in forced grasping. Damage to the SMA leads to forced grasping and groping behavior in people and in monkeys,

supporting the “nature” aspect of the nature-nurture dichotomy, in which the SMA has similar function and location in humans and primates.

Subsequent studies on grasping have focused on taxonomy and grasping components of humans (Napier 1956; Elliott and Connolly 1984; Cutkosky 1989; Siddiqui 1995). Napier (1956) was the first to provide a classification of grasping in adults by describing two types of grasping: power grasps and precision grasps. Elliot and Connolly (1984) distinguished between intrinsic movements, coordination of the hand to grasp an object, and extrinsic movements, the total movement of the hand and the object grasped. Cutkosky (1989) classified grasping into 9 types of power grasps and 7 types of precision grasps for use in robot arms. Finally Siddiqui (1995) studied prehension in children and developed a 6 part classification system based on the number of digits children use to pick up objects. The similarity across all the studies mentioned above is that grasping is not limited to one pattern. The variations that exist for grasping support the notion that experience (nurture) plays an important role in determining what is the most efficient grasp type to use, leading to differences in grasp preferences.

Present Studies

Present studies use quantifiable variables, such as displacements, trajectories, velocities, neuron firing and reactions to neuron stimulation, to measure grasping. These studies include kinematic analysis, dynamic analysis, and electrical stimulation and recording.

In particular, kinematic analysis examines the reach-to-grasp trajectories and velocities of limb segments while grasping. These reach to grasp trajectories are well defined in normal people, and are often compared to patients with movement disorders, such as Parkinson’s patients and those with other neurological disorders

(Edin, Westling et al. 1992; Johansson and Cole 1994; Johansson, Backlin et al. 1999; Hosseini, Hejdukova et al. 2000). Visual, mass and density variables can also be manipulated in order to examine the effects of vision on grasping trajectory (Servos, Goodale et al. 1992; Castiello 2001; Milner, Dijkerman et al. 2001; Gentilucci 2002; Jackson, Newport et al. 2002; Smeets, Brenner et al. 2002). The results of these studies, show that trajectories are well defined and similar in most individuals, support the notion that biology and genetics determine grasping.

Studies that examine the response of neurons to behaviors exhibited by an animal are called electrical recording studies. A good example of a grasping study is (Iwamura and Tanaka 1996), in which researchers recorded from 109 neurons in the somatosensory area in 4 monkeys while they reached for objects. They found that neurons in the medial digit region fired to power grasping and scratching or touching behaviors and neurons in the lateral region fire to precision grasping behaviors. This supports (Schieber 2001) reviews of multiple complex maps in the cortex that represent the hand and digit area.

These representations are plastic and can change with damage and rehabilitation after damage (Nudo and Milliken 1996; Nudo, Wise et al. 1996; Friel and Nudo 1998). Nudo et al. trained the monkeys to retrieve food pellets and mapped the hand and digit representation areas in the primary motor cortex (M1) using intracortical microstimulation (ICMS), after which they lesioned the hand area in M1. They showed that after damage and no rehabilitation, the hand and digit representations in the brain shrank. With rehabilitative training the hand and digit region representations were spared (See Figure 5.1). This evidence supports that notion that experience (nurture) plays a large role in the behavior and brain structure of an animal.

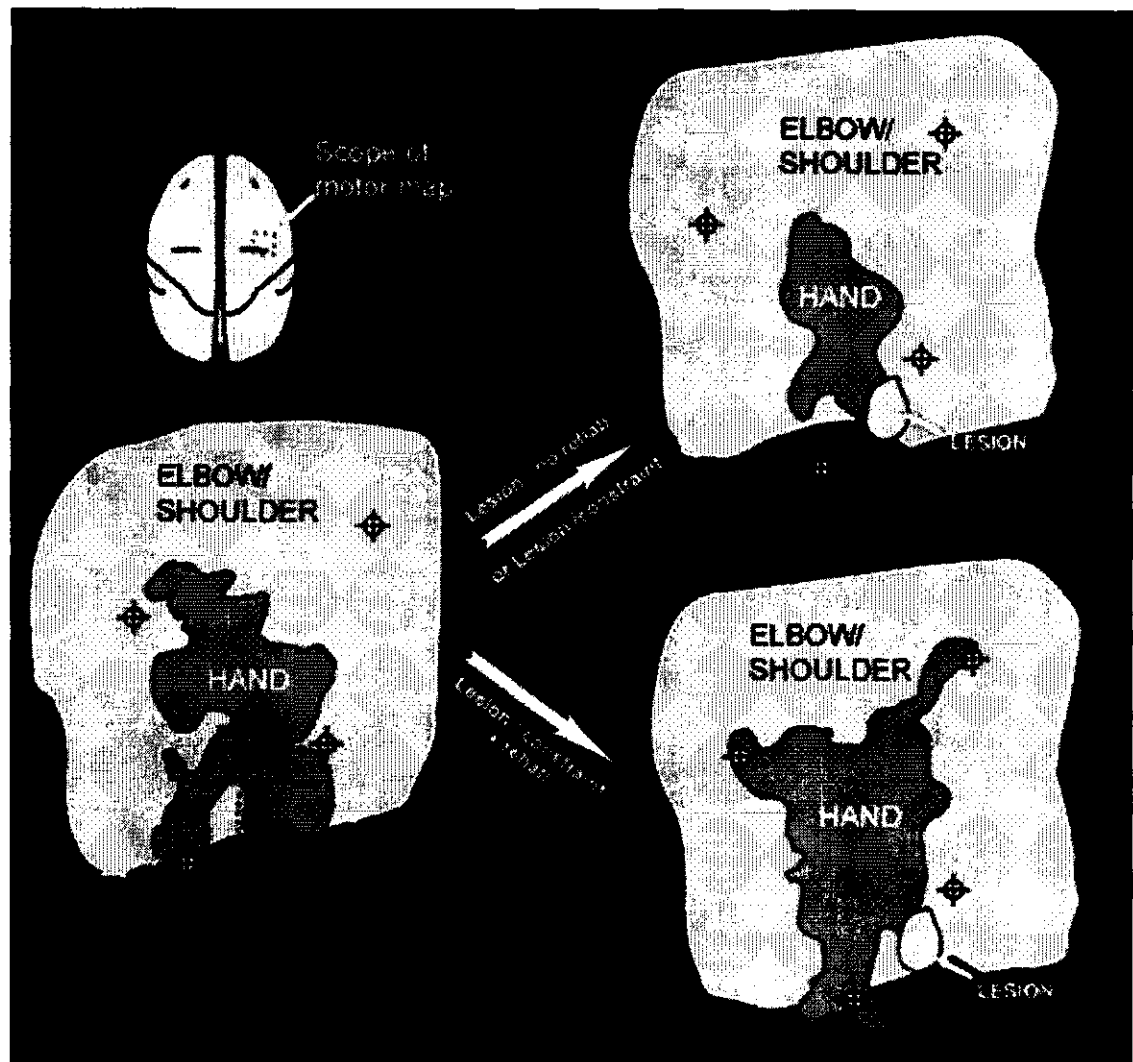


Figure 5.1 Hand and digit representations in the primary motor cortex pre and post ischemic infarct. Note the larger hand representation after constraint and rehabilitation.

(Figure acquired online from Nudo et al. 1998)

Eshkol-Wachmann Movement Notation

In order to examine similarities of behaviors across individuals, the use of Eshkol-Wachmann Movement Notation (EWMN) to distinguish behavior is needed. Former studies have used EWMN to characterize distinguishable attributes of grasping behaviors that can be quantifiably analyzed (Whishaw and Pellis 1990; Whishaw, Suchowersky et al. 2002).

The use of EWMN in this thesis was no exception. By analyzing in detail the most common precision grasp, the pincer grasp, a strategy for object retrieval can be isolated, and the movements separated into other possible combinations. EWMN analysis of the pincer grasp teased out the contact strategy “thumb drag”, in which the thumb first contacts the object and drag it towards the index finger. From that result, four other possible combinations were interpolated: 1) “index drag” contact strategy, in which the index drags the object toward the thumb; 2) “thumb stay” contact strategy in which the thumb contacts the object and stabilizes it for the index finger to contact; 3) “index stay” contact strategy, in which the index finger stabilized the object for the thumb; and 4) “both” contact strategy, in which both the index finger and the thumb contact the object at the same time. These five variations in turn have there own intrinsic properties for the thumb and index finger, and are addressed below.

Kinematic Analysis of Precision grasping

The kinematic analysis of the five contact strategies not only determined the thumb and index properties velocities during reach, but also confirmed the existence of these strategies. The ideal properties for each strategy is as follows: 1) The “index drag” and “thumb stay” contact strategies consist of the index finger velocity peaking sooner and having a higher peak velocity than the thumb; 2) the “both” contact strategy have relatively similar index finger and thumb peak velocities, and similar

times to reach peak velocity; and finally 3) in the “thumb drag” and “index stay” contact strategies, the thumb has a higher peak velocity and reaches peak velocity sooner than the index finger. These findings lead to the question, what other variations of precision grasping are there?

Variations of Precision Grasping

Previous work has examined the effects of external factors, such as the size and shape of objects, in determining grasp patterns used by humans. Here, by using a limited range of objects of similar shape but slightly different sizes, the possible contribution of central factors (individual preferences) to grasping patterns was examined. The subjects were filmed reaching for small beads, having the same texture but differing in size, and grasp patterns were analyzed using frame-by-frame video analysis. There were five contact strategies based on whether the index or the thumb stabilized or dragged the object towards the opposing digit, seven purchase (or grasping) patterns based on the number of digits used to grasp the object, and four subtypes (based on the posture of the non-grasping digits) each, based on the digits and the number of digits used to contact the bead. Some, but not all, variance was accounted for by object size, hand size, and sex. Thus the main findings are that there is substantial variation in human grasping and so central factors are influential in use of grasp type.

Previous research has demonstrated that external factors (shape and size of the object) influence hand-grasping patterns. The objective of the present experiment was to examine whether central factors are also influential in determining grasp preference; that is, whether there is intersubject variation in grasping. In the design of the experiment, round small beads were selected for two reasons. First, their shape would limit the variability in digit contacts with the object. It was presumed that

subjects would be most likely to contact the object with digit pads placed tangential to the horizontal and vertical midline of the objects (Goodale and Milner 1992). Second, small objects were used because it was hypothesized that a pincer grasp would be appropriate for all of the objects (Napier 1956). For example, the largest object was smaller than a jelly bean, an object that Napier (1980, p. 59) uses as an exemplar object for directing the pincer grasp. Thus, by reducing the variability of the objects, intrinsic factors could be identified more easily. In this respect, the experiment was successful, in that with the exception of the smallest object, for which most subjects used a Type I (conventional pincer grasp), there was considerable interindividual variation in the way that subjects contacted the beads, grasped the beads, and in the posture of the non-grasping digits.

Normal Adults

There was evidence that external factors did influence grasp pattern even with the limited variability of the target objects. Napier (1956) proposes that grasp patterns will vary depending upon the need to stabilize a target object. Therefore, the more digits recruited, the more stable the grip. A Type I (*proper pincer*) grasp appeared most appropriate for the smallest object because contact space was limited. In addition, there was more use of Type 4 and Type 5 patterns, in which more than two digits contacted the bead, with beads of the largest diameters that provided more contact space. Finally, there was a small but significant relation between digit size and grasping pattern, again suggesting that subjects with smaller digits are able to recruit more digits to assist in obtaining a stable grasp.

Despite the influence of the external properties of the objects and subject hand size, there was still a remarkably wide range of intersubject grasp types used for every object. Even though two different experiments were performed (random ordered

versus sequentially ordered), there were no significant difference between the results, and so ordering of the bead sizes did not dictate the results. Different subjects used the five contact strategies and almost any of the 28 grasp types. For example, some subjects grasped all objects with a with a Type 1 grasp while other subjects preferentially used a Type 2 or Type 3 grasp, in which one of the other digits was substituted for the second digit of the Type 1 grasp. As well, the results show that there are a strong correlations strategies used by the left and right hands, indicating that for each subject, individual preference determined purchase patterns, as opposed to random choice. Some subjects used grasp patterns in which all digits were flexed while others used grasp patterns in which the nongrasping digits were extended and still other subjects had the nongrasping digits flexed and open, flexed and closed, extended and open, or extended and closed. Finally, contact strategy did not determine grasp pattern. Thus, there are individual differences that strongly suggest that central factors play a strong role in the type of grasp pattern used.

Although there was no sex difference in the grasp subtype used, there was a significant difference between females and males in the complexity of grasp-patterns used. Females used more complex grasp patterns involving recruitment of more digits compared to males. One possible explanation is that females have smaller hands and thinner digits than males, and hence are able to use more digits on the surface area of a bead. This idea is supported by a study by Peters et al. (1990), who found that sex differences on fine motor tasks disappear when finger size is considered. It has also been proposed that testicular hormones contribute to the intrinsic variability between sexes. Kimura and Vanderwolf (1970) report that females are more flexible in digit use than males. Similarly, females tend to show similar advantages in performing finger tapping sequences and touching each finger in succession against

the thumb, than do males (Kimura and Vanderwolf 1970; Matano and Nakano 1998; Highley, Esiri et al. 1999; Kimura 1999). Although hand size and sex were significant factors in influencing grasp patterns, it is uncertain that the relationship is casual.

It is interesting that grasping variability has not received much study in humans, whereas it has received extensive study in apes. Butterworth and Itakura (1998) show that older chimpanzees mostly used a pincer grip on the smallest sizes of apple cubes and a power grip position on the largest sizes, and that there are 4 variations of grasp patterns by chimpanzees. The chimpanzees' preference noticeably accounts for the varying patterns of precision, imprecise, power and middle-index grips used for apple cubes in intermediate sizes (Butterworth and Itakura 1998). It would be interesting to further explore the evolution of the proper pincer grip, as the present study predicts that it likely originated for grasping extremely small objects.

The variability in grasping patterns used by different subjects could have a number of explanations. Variation may be related to genetic heterogeneity, variations in nervous system anatomical structure, or to learning. It is known that the motor cortex has multiple digit representations, and because the motor cortex encodes a large number of synergies (Schieber 1999; Hager-Ross and Schieber 2000; Schieber 2001; Schieber, Gardinier et al. 2001; Graziano, Taylor et al. 2002) variations in this encoding may underlie variation. With respect to the learning hypothesis, during developmental and beginning within the first two months of life, human infants display prolonged practice exemplified by spontaneously generated hand and digit movements, followed by self-grasping, and finally reaching (Wallace and Whishaw 2003). Smeets and Brenner (2001) have suggested adult grasping is the result of learned control of individual digits, and this developmental practice may thus underlie

subsequent variation. Future research could explore both the inheritance of grasping strategies and their development in childhood.

An interesting finding of the present study was that the grasping patterns used by the two hands of individual subjects were almost identical. This could have resulted from the object familiarity gained after using the first hand, allowing the other hand to use the vicariously obtained visual and tactile information. This seems unlikely, however, because varying the sequence of bead size or varying the starting hand did not affect interhand patterns. Thus, similar movements in the two hands likely have central origins. It is unlikely that there is a hand command center in the hand region of one hemisphere that underlies interhand similarities, because there are few or no direct interhemispheric connections between the hand regions of the motor cortex (Andres, Mima et al. 1999). Possibly the command region for the selection of grasping movements is in the parietal cortex (Mountcastle 1995; Connolly, Andersen et al. 2003). Haaxma and Kuypers (1974) have demonstrated using a disconnection paradigm that visual control of grasping depends upon interhemispheric connections originating in the parietal neocortex. For humans, it is likely that it is the left parietal cortex that encodes individual preferences [15,23].

Children

Children, who have smaller hand sizes and were pre-pubertal, displayed a similar distribution of grasp patterns and similar individual differences to adults. Children were also similar to adults in preference of the *index drag* strategy, as well the extensive use of the *proper pincer* and *supported pincer* grasping types over other purchase patterns. However, the children, especially the younger ones, did tend to fail at retrieval more often than the adults, and also exhibited an extra purchase pattern that adults did not exhibit, the *D1 & D4* pattern. This supports the theory that

learning precision grasp patterns involves experimenting with different grasping types and narrowing the selection to the more efficient grasp patterns. Siddiqui (1995) cites that children tend to use grasps involving the radial digits (the thumb, index and middle fingers) more often as they grow older, and that is due to the better establishment of cortico-motor neuronal connections in older infants (Siddiqui 1995). Unlike the adults, there was no effect of gender on the purchase pattern preferences in the children. The average hand size for the girls was less than the boys, and the discrepancy is smaller than the adult gender differences. Kuhtz-Bushbeck et al. (1998), state that the dependence on visual control of movement declines during motor development, and suggest that the development of prehensile skills during childhood lasts until the end of the first decade of life, which may explain the increased rate of failing at bead retrieval for children under the age of 12 (Kuhtz-Buschbeck, Stolze et al. 1998).

Conclusion

In summary, kinematic analysis into the contact strategies shows that conventional measures of kinematic analysis must be supplemented with video and behavioural analysis in order to obtain a better understanding of the strategies involved with fine prehension. It is suggested that the classification presented here may be a useful tool in evaluating brain organization of hand movements as well as providing a standard against which to compare deficits in skilled movements. There were three patterns of variation that were classified in the present experiment: 1) the digit contact strategy, 2) the purchase pattern, and 3) the posture of the non-grasping digits. Each of these components presents several variations that are not obviously related to external factors such as object size, hand size, sex, and handedness.

This variability in grasping strongly suggests that individual preference is

determined by central factors, possibly related to learning or to central organization. The similarity of the purchase patterns across both hands suggests that these patterns may be encoded within a hand control area of one hemisphere. The similarity between the distribution of purchase patterns across bead sizes for normal adults and children, and the extra purchase pattern exhibited by children, indicate that there is some neural hard-wiring for purchase pattern preference followed by corticomotor refinement in the later ages of development. As well, the loss of variation in the grasp patterns and postures of the elderly indicate that the normal deterioration of hand function may be a factor in the loss of fine motor skills with age. This loss may be similar to those exhibited in those with motor afflictions, such as Parkinson's disease, and a comparison study into the differences between normal deterioration of fine motor skills and those afflicted with motor disorders may provide insight into rehabilitative and prophylactic therapies. These biological factors constrain the amount variance for precision grasping, however, variance still exists.

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Appendix 1: Consent forms for Parents and Guardians of Children and for Older Adults.

Dear Parents and Guardians:

I am requesting your child’s participation in a study relating to object handling abilities. This study will involve a short series of trials during which the child will be required to reach for and pick up different objects. In addition, the child will be required to answer some basic questions regarding activities of interest. The experiment will take approximately 10 to 20 minutes. Once your child has completed the experiment, I will provide a complete debriefing. The information from this study will be reported in general terms without reference to your child’s particular results. The complete results of the study will be available in about six months. If you wish to obtain a copy of these results, you may contact me.

I hope you will allow your child’s participation in this study, but if for any reason you decide to withdraw your child from the experiment, you are free to do so. If you have any questions about the study, please call me at the University of Lethbridge [Phone: (403)394-3928]. Questions of a more general nature may be addressed to the Office of Research Services, University of Lethbridge [Phone: (403)329-2747].

Yvonne Wong
Canadian Centre for Behavioural Neuroscience
Department of Psychology and Neuroscience
University of Lethbridge

-----Detach and Return Signed-----

I consent to allow my child to participate in the study entitled, “Investigations into the development of the human pincer grasp in childhood” as described in the letter dated January 13, 2003.

Printed Name and Signature	Date
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August 15, 2003

Dear <name>:

I am requesting your participation in a study relating to object handling abilities. This study will involve a short series of trials during which you will be required to pick up different sized marbles/beads and place them in a box. These trials will be filmed, with a video-camera recording your hand posture while you pick up these beads. The experiment will take approximately 5 to 15 minutes, and there will be a complete debriefing upon completion of the experiment. The information from this study will be reported in general terms without reference to your particular results. The complete results of this study will be available in about six months. If you wish to obtain a copy of these results, you may contact me.

I hope you will participate in this study, but if for any reason you decide to withdraw from the experiment, you are free to do so. If you have any questions about the study, please call me at the University of Lethbridge [Phone: (403) 394-3928] or email me at yvonne.wong@uleth.ca. Questions of a more general nature may be addressed to the Office of Research Services, University of Lethbridge [Phone: (403) 329-2747].

Yvonne Wong
Canadian Centre for Behavioural Neuroscience
Department of Psychology and Neuroscience
University of Lethbridge.

I < name > consent to participating in the study entitled "Investigations into precision grasps of healthy elderly" as described in the letter dated August 15, 2003.

Signature Date

Appendix 2: Questionnaires and Surveys for Children and Older Adults

Investigation into the Development of the Human Pincer Grasp in Childhood

Subject # _____
Handedness _____
Age _____
Sex _____
Grade _____

1. Can you write the alphabet?
2. How long have you known this?
3. What hobbies do you have (e.g., sewing, needle work, sports)? How many times a week do you do each?
4. Do you like to do arts and crafts? How many times a week?
5. Do you enjoy building with lego or building blocks or working with tools?
6. Do you play video games? What kind (RPG, fighting, adventure, puzzle)? How many times a week?

Older Children:

7. Do you draw/paint/do calligraphy?
8. Play sports?
9. Dance?
10. Play any instruments?

Investigation into the aging of precision grasping in elderly people

Name: _____
Subject #: _____
Age: _____
Sex: _____
Handedness: _____

	Right Hand		Left Hand	
	Length	Width	Length	Width
Thumb				
Index				
Middle				
Ring				
Pinky				

1. Do you do needle-work, knitting, etc...? How often do you knit/sew/etc?
2. Do you like to do arts and crafts (eg. painting, sculpting, macramé)? If so, what type? How often?
3. Do you play any instruments? Which instrument(s)? How many times a week?
4. Do you type on the computer? How often? How many words a minute do you type?
5. Do you play video games such as X-Box, Playstation, Gamecube, PC, etc? If so, what kind of games (fighting, puzzle, RPG)? How often do you play?
6. Do play sports or dance? If so, which sports/dance? How often do you practice/play?
7. Do you have any other hobbies that require finger movements (eg. Jigsaw Puzzles, Woodwork)? If so, what are they and how often do you do them?
8. Do you have any medical motor conditions (such as Parkinson’s, Alzheimers, arthritis or previous strokes)? If so, are you on medication at this time?

Thank you for your time and patience in completing this questionnaire.