THE RELATIONSHIPS BETWEEN IN-HAND MANIPULATION SKILLS AND SOMATOSENSORY IN PRESCHOOLERS

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ABSTRACT

In-hand manipulation skill is the ability to move objects within the hand. This is an important skill for daily activities such as manipulating coins, buttoning and handwriting. Somatosensory feedback is an essential component for guiding movement. The purpose of this study is to examine the relationships between the in-hand manipulation skills and somatosensory functions in the typically developing preschoolers. Nineteen boys and twenty girls aged from 3 to 5 years (Mean= 4.01, SD=0.6) were recruited from the Ohio State University Childcare Center and Children's Hospital Childcare Center. Each child was given the Test of In-Hand Manipulation (TIHM) and tests of somatosensory functions including the Kinaesthetic Acuity Test (KAT), Stereognosis and Graphesthesia in the Pediatric Examination of Educational Readiness (PEER), Weinstein Enhanced Sensory Test (WEST). The results showed that time scores on the TIHM has moderate correlation with graphesthesia and stereognosis, with $r = -.384$, $p = .008$ and $r = -.371$, $p = .010$ respectively. The scores of drops/stabilization and quality on the TIHM are

related to the KAT scores. There is no significant correlation between scores on TIHM and tactile sensitivity (WEST). The Time scores on the TIHM seem to relate to the child's cognitive processing whereas the drops/stabilizations and quality appear to relate to the proprioceptive feedback. These results can provide a guide for occupational therapy intervention for children with fine motor delay. TIHM might provide information whether the therapist should focus on enhancing sensory functions, particularly proprioceptive, or cognitive processing such as motor planning, sequencing and integrating sensory information.

Dedicated to my parents

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CHAPTER 1

INTRODUCTION

1.1 Background Information

In hand manipulation is the ability to move objects within the hand. It is categorized as rotation of the object within the fingers and translation of objects in and out of the hand (Case-Smith & Weintraub, 2002). The purpose of these adjustments is to allow more efficient placement of the object in the hand for use. The daily activities include handwriting, buttoning, manipulating coins and keys. Somatosensory information is important for the development of manipulation skills (Haron & Henderson, 1985). Researchers and studies have shown the positive relationships between somatosensory functions, particularly kinesthesia, and motor skills (Exner, 2001; Haron & Henderson, 1985; Livesey & Parker, 1995). Case-Smith (1991) studied the relationship between both tactile defensiveness and tactile discrimination and in-hand manipulation skills in 50 children between 4 and 6 year-old. The results showed that only those children who had both tactile discrimination problems and tactile defensiveness had difficulties with performance of the in-hand manipulation skills. Poor discrimination or tactile defensiveness alone did not relate to poor in-hand manipulation. Replicated study is needed to validate the relationships between somatosensory functions and fine motor skills.

1.2 Significance of the Problem

The ability to rapidly sequence the movements of the fingers and the strength of the grip force are important motor components in the manipulation of an object in the fingers (Pehoski, 1995). Vision can guide the hand to reach the target but tactile information such as discriminative touch and proprioception appears to guide movement of objects in the fingers or the hand (Case-Smith & Weintraub, 2002; Pehoski, 1995). Exner (2000) stated that the role of somatosensory information and feedback are critical to the development of children's hand skills, especially when the task involves isolated finger movement. Somatosensory problems can produce significant problems with hand function, even when muscle tone and strength are good (Pehoski, 1995). Poor hand skills can contribute to the children obtaining a limited amount of somatosensory information (Exner, 2001). The purpose of this study is to investigate in-hand manipulation skills and their relationship to somatosensory perception, including, tactile sensibility, kinesthesia/proprioception and haptic perception in typically developing children. This study will investigate which sensory perceptual function can predict the motor skills. The results of this investigation can be the basis for further investigation on children who have developmental disorders.

1.3 Research Questions

1. What are the relationships between sensory-perceptual functions and in-hand manipulation skills in typically developing children?
2. Which of the sensory-perceptual functions predicts the children's in-hand manipulation skills?

1.4 Definition of Terms

1. In-hand manipulation

In-hand manipulation skills are the ability to move objects within the hand. Exner (2001) defines translation as moving objects in and out of the palm, and rotation as rotating an object around its axis using the fingertips.

2. Somatosensory system

Somatosensory system refers to the sensory information from the skin and musculoskeletal systems. Sensory information from the skin is called superficial or cutaneous superficial sensory information includes touch (including pressure and vibration), pain, and temperature. Sensory information from the musculoskeletal system includes proprioception and pain (Lundy-Ekman, 2002). In this study, only touch and proprioception will be discussed.

3. Tactile system

The tactile system is usually divided into the cutaneous (or tactile) and haptic subsystems (Loomis & Lederman, 1986). The cutaneous system uses sensory inputs obtained from receptors embedded in the skin. The perceptual system uses not only cutaneous information but also kinesthetic information from receptors in muscles, tendons and joints (Lederman & Klatsky, 1998).

4.Touch/Pressure sensibility

Touch/pressure sensibility is the ability to feel or perceive minimal force or pressure. In this study, we use the Weinstein Enhanced Sensory Test to determine the touch/deep pressure thresholds.

5. Haptic perception

Haptic perception is to use the hand as a perceptual or information-seeking organ through active touch. Haptic perception deals with the retrieval, analysis and interpretation of the tactile properties (such as size, shape, and texture) and identity of objects through manual and in-hand manipulation (Stilwell & Cermak, 1995).

6. Proprioception/Kinesthesia

The term kinesthesia (or kinesthesis) means a sense of movement. The other term, proprioception referred to sensations produced by action of the body as well as static limb position. Proprioceptive functions include the kinesthetic and position senses (Hendry, Hsiao & Bushnell, 1999). Proprioception will be used in this study except for referring the assessment tool.

CHAPTER 2

LITERATURE REVIEW

This chapter presents a review of development of in-hand manipulation skills and related daily activities. Motor components of in-hand manipulation skills including individual finger movements and force regulation, and sensory components, including tactile system, proprioceptive and haptic perception will be discussed. Finally, the neural development and network related to individual finger movements will be addressed.

2.1 In-Hand Manipulation

2.1.1 Categories and Terminology

In-hand manipulation skills are used to allow more efficient placement of objects in the hand for use. In-hand manipulation is categorized as rotation of the objects within the fingers and translation of objects in and out of the hand (Case-Smith & Weintraub, 2002). Translation movement refers to moving objects from the fingers to the palm, or the palm to the fingers, such as picking up a coin and placing it in the hand and then moving the coin from the hand to the fingers for placement in a bank or purse. Exner (1992) indicated that the amount of individual finger movements required for a task may make one task more difficult than the other. For example, the ability to move an object from the fingers to the palm is relatively easier than from the palm to the fingers because fingers work as a unit in finger-to-palm translation.

Rotation movement refers to the ability to rotate the object in the pads of the fingers such that the object is rolled or turned in the fingers. In complex rotation, the object is rotated at least 180 degrees and the movement requires independent action of the fingers and thumb (Pehoski, 1995).

2.1.2 Development of In-Hand Manipulation

Exner (1990) reported that simplest in-hand manipulation skills, simple rotation such as turn the lid of a jar, can be accomplished by at least half of 18 month-old to 2 year-old children. By 3 and 4 years, the child presents sequential and isolated finger movement and is able to execute more complex in-hand manipulation tasks. The most complex in-hand manipulation can be performed by 4 and 5-year old children.

Pehoski, Henderson and Tickle-Degnen (1997a, 1997b) investigated the time and movement pattern of complex rotation and translation in children aged from 3 years to 6 years 11 months. The author asked 153 children and 13 adult subjects to rotate 10 small pegs in a pegboard using only one hand in the rotation task. The task of translation is to pick up two to five pegs, one at a time; move them into the palm and then move from the palm to place them in the pegboard. The results showed that there are no significant differences between boys and girls in both rotation and translation tasks. Children in the 6-year-old group accomplish the task faster than any other age group but still slower than adults. In the rotation task, children in different age groups use various methods, whereas adults rotated the pegs by using a series of individual finger movements of the two radial fingers and the thumb. Approximately half the time, children at 3 years old rotate the peg using two other immature approaches. One was to use an external surface, such as holding the peg against the chest or the other hand while he/she is rotating. The other common method is to pronate the forearm before picking up the peg so that the peg can be rotated without using individual finger movements. Pehoski et al.(1997a) suggested that children needed to an use external surface to readjust the peg position because it tended to slip out of optimal position in the radial fingers. In the translation task, the major differences between children and adults are the methods they used to assist the movement. Adults used gravity to assist moving pegs to and from the palm, whereas children commonly raked the pegs from the palm to the finger surface by using all the fingers together. To use gravity, the hand must maintain loose contact with the object. Translation from the palm to the fingers requires a loose palmar grip on the objects but not so loose that the objects are dropped. The authors suggested that the child tends to grip tightly and to maintain contact with the peg during the translation movements because a loose grip felt insecure or the children were unable to modulate the pressure of their grip.

2.1.3 Relationship of In-Hand Manipulation and Functional Activities

Manipulating an object, such as a peg in the fingers, rotating a pencil so the tip is in the correct position to write, and turning a small bead in the fingers to orient the hole for stringing all require a grip that is sufficient to keep the object from being dropped but also light enough to allow the object to be moved. Manipulating coins and keys requires the translation movement, which used radial fingers to retrieve small objects from palm or push small objects from fingers to palm. Children with poor in-hand manipulation skills often show awkward and clumsy movement patterns or drop small objects easily in the daily activities such as feeding, buttoning, handwriting, constructive play and tabletop games and avoid manipulative activities.

Cornhill and Case-Smith (1996) examined the factors that could predict good and poor handwriting. Motor Accuracy Test (MAT), Visual-Motor Integration(VMI) and in-hand manipulation task were administered to the 49 typically developing first grade children. In their findings, in-hand manipulation was the greatest predictor of poor handwriting performance. The correlations between in-hand manipulation and handwriting scores were moderate to high and both items of in-hand manipulation, translation and rotation, predicted handwriting performance.

Early object manipulative experience is related to the later development on functional activities. Readdick (1994) investigated the relationships of drawing and early home manipulative experiences such as coloring/drawing, cutting with scissors, pasting and buttoning in toddlers and preschoolers aged 24-59 months. The author found that children who have more frequent manipulative experiences at home, as reported by parents, were produced more mature drawing products.

2.2 Motor Components of In-Hand Manipulation

2.2.1 Individual Finger Movement

The ability to rapidly sequence the movements of the fingers and the strength of the grip force are important motor components in the manipulation of an object in the fingers or the hand. Individual finger movement is required for manipulating objects within the hand. For example, rotating a pen in the fingers for use requires the sequencing of individual movements among the radial fingers and the thumb. Although 12-month-old child has the ability to isolate the index finger from radial fingers to pick up a small object with thumb, isolated finger movement for the child under three is still difficult(Pehoski, 1995).

Stutsman (1948, as cited in the Pehoski, 1995) looked at the ability of young children to make a fist and wiggle the thumb without moving the fingers. She states that this task appears rather suddenly at 33 months. She further asked children to oppose each finger to the thumb. The results showed that 35% of the children by 36 to 41 months could accomplish the task, but it was not until 42 to 47 months that 50% of the children were successful. This indicated that isolated movements of individual fingers are difficult for children 3 years of age and under, and may be a major deterrent to the ability to accomplish deft manipulatory patterns with objects in the fingers.

2.2.2 Force Regulation

The force of the grip used to hold an object may hinder the in-hand manipulation skills. Stable grip force can prevent slips and accidental loss of object when one moves or manipulates the object. Excessive grip forces will cause unnecessary fatigue and may crush fragile objects or injure the hand. The coordination of forces is regulated by the tactile system feedback information. Forssberg, Eliasson, Kinoshita, Johansson & Westling (1991) compared the grip force in children and adults when picking up a small object between thumb and index finger. The results showed that young children used greater grip force than adults. In addition, the young children showed irregular force rate profile instead of mature bell-shape force rate profile. The author suggested that children of one year can already use sensory feedback to adjust the forces during the static phase (before lift-off), but the regulation of fingertip force is still immature. This manipulative force rapidly develops until age two and matures until the teenage years.

The developmental trend of force regulation can be observed in functional activities. For example, one-year old children usually crush an ice cream cone, whereas children of two years manage quite well. At 4 years old, children have more coordinated and adjusted movements when they carry a kitten or efficiently play with building blocks (Eliasson, 1995).

2.3 Sensory Components of In-Hand Manipulation

Vision can guide the hand to reach the target but tactile information such as touch and proprioception appears to guide the objects in the fingers or the hand, especially with visual occlusion (Case-Smith & Weintraub, 2002; Pehoski, 1995). In addition, the haptic perception system, which can identify and distinguish material properties such as texture, temperature and shapes, also provides sensory input to the CNS to regulate the force of the muscles during grasping and holding of objects (Connolly, 1998; Eliasson, 1995).

Discriminative touch and proprioception are regarded as two major sensory components contributing to the in-hand manipulation skills (Case-Smith & Weintraub, 2002). Exner (2001) stated that the role of somatosensory information and feedback is critical to the development of children's hand skills, especially when the task involves isolated finger movement. Somatosensory problems can produce significant problems with hand function even when motor tone and strength are good (Pehoski, 1995). Poor hand skills can contribute to children obtaining a limited amount of somatosensory information (Exner, 2001). Case-Smith (1991) studied the relationship between both tactile defensiveness and tactile discrimination and in-hand manipulation skills in 50 children between 4 and 6 year-old. The results showed that those children who had both tactile discrimination problems and tactile defensiveness had difficulty with performance of the in-hand manipulation skills. Poor discrimination or tactile defensiveness alone did not relate to poor in-hand manipulation.

2.3.1 Tactile System

The tactile system is used to discriminate between different surfaces and shapes and providing sensory input to regulate the force of the muscles during grasping. The receptors mediating tactile sensation can be classified on the basis of their receptive fields and morphology. Meissner, which have small, sharply delineated sensory fields, and Pacini corpuscles, which have large and diffuse sensory fields, are fast adapting receptors. Two other types of receptors that are slow-adapting units are Merkel disks, with small and sharply delineated sensory fields, and Ruffini disks, with large and diffuse fields (Eliasson, 1995). The hand is innervated primarily (70%) by receptors with small receptive fields which implies that the tactile system of the hand is highly developed to detect small movements and discriminate between different surfaces (Johansson & Vallbo, 1983).

The different types of receptors respond differently during the object-lifting task. Fast-adapting receptors are activated when the hand first touches an object and silent during the static phase (holding position), whereas slow-adapting receptors fire continuously during the static phase. These complementary receptor characteristics make it possible to handle small fragile objects without crushing them.

2.3.2 Proprioception/Kinesthesia

Proprioception referred to sensations produced by action of the body as well as static limb position. Proprioceptive functions include the kinesthetic senses of position and movement (Hendry, Hsiao & Bushnell, 1999). The word "proprioception" was introduced by the English physiologist Charles Sherrington referring to the sensory process involved in the conscious appreciation of posture and movement (Sherrington,1900 as cited in Clark & Horch, 1986). The proprioceptive system derives information from receptors in muscles, skin, and joints and uses these inputs to determine where limbs are in space and the amplitude and velocity of limb movements.

Researchers suggested that muscle receptors appear to be the predominant source of this proprioceptive information (Clark & Horch, 1986; Jones, 1999), but receptors in the skins and joints also contribute to these perceptual processes. Absence of sensory information from the skin of the hand can lead to the deficiencies in proprioceptive abilities, especially of the hands (Jones, 1999).

Bairstow and Laszlo (1981) believed that kinesthesia is essential to the learning and performance of all skilled motor acts. They further stated that efficiency of motor performance depends on both well-controlled muscles and the integration of information generated by proprioceptive receptor. Proprioception is considered as the sensory component most related to in-hand manipulation skills. Proprioception provides immediate feedback to adjust force and accuracy of movement pattern for error correction. In-hand manipulation appears to use this feedback system to adjust force and motor pattern when one manipulates objects within the hand (Case-Smith & Weintraub, 2002).

The proprioception is important to motor control because duplicate information is carried over two tracts, one to the cerebellum (spinocerebellar tract) and one to the primary somatosensory cortex (dorsal column lemniscal pathway). The proprioceptive information carried via the spinocerebellar tract is called unconscious proprioception, which contributes to automatic movements and postural adjustments. Damage to the spinocerebellar tracts cannot be differentiated from the dorsal column lemniscal pathway during clinical testing (Zucker-Levin, 2003). The information in the spinocerebellar tracts is from proprioceptors, spinal interneurons and descending motor pathways. The cerebellum compares the intended motor output with the actual movement output and uses this information to make corrections to the motor outputs via its connections with other brain areas. The detailed neural networks and central process will be discussed in the section 2.4.

2.3.3 Haptic Perception of the Hand.

The haptic system is a perceptual system that uses both cutaneous and kinesthetic inputs to derive information about the world of surfaces and objects (Lederman & Klatsky, 1998). Haptic perception involves the retrieval, analysis and interpretation of the tactile properties (e.g. size, shape and texture) and identity of objects through manual and in-hand manipulation. Manipulation of objects facilitates the learning of the characteristics of the objects (Ruff, 1980, 1989). Haron and Henderson (1985) found that the use of active touch, which is to actively manipulate an object in the hand, contributes accuracy in matching shapes with visual image more than passive touch, which refers to passively applying stimuli to the hand.

Chapman (1994) explained why the active touch contributes more to the tactile perception than passive touch. This is because the cutaneous mechanoreceptors are specialized to signal transient, and not static, events. Furthermore, the slowly adapting mechanoreceptive afferents discharge much more intensely during dynamic as opposed to static stimulation. Finally, neurons in the somatosensory cortex are rapidly adapting in nature. Therefore, the stimuli that are applied passively to the body surface often elicit incomplete perception of the surround.

Studies have shown that children can correctly recognize common objects but were unable to identify geometric shapes by 2.5 to 3.5 years. The ability to recognize the geometric figures emerges at 4 and 4.5 years. Children at this age can differentiate curvilinear (circle and ellipse) from rectilinear (square and rectangle) shapes. By 7 years old, children are able to match forms/shapes having more complex distinctive features (Stilwell & Cermak, 1995).

Haptic discrimination of texture and size has been shown to improve with increasing age in 4- to 9-year-old children (Gliner, as cited in Stilwell & Cermak, 1995; Miller, 1986). Gilner found third grade subjects showed a lower threshold (greater sensitivity) to the texture stimuli than the kindergarden children. Gilner further found that young children (4 to 5 years old) prefer to use texture over shape while Seigel and Vance (1970 as cited in Stilwell & Cermak) found that third-grade children preferred to use the shape over texture and size in object identification during intramodal (haptic-haptic) matching tasks. Miller (1986) suggested that younger children (4 years old) tend to ignore shape cues when texture is available for use in object discrimination. Therefore, during tasks requiring haptic discrimination, children may choose to use the sensory property that produces the strongest distinctive features. As the ability to recognize shapes improves with age, there may be increased preference for the use of shape over other properties for object identification because shape yields distinctive features that are more useful in object recognition than texture or size (Stilwell & Cermak, 1995).

2.4 Neural Development and Networks of Individual Finger Movement

2.4.1 Dorsal Column-Medial Lemniscal Pathway

The dorsal column pathway is important to mediate discriminative touch. The mechanoreceptors described above in the skin and joint capsules receive innocuous touch to the skin and carry information to the dorsal column nuclei (cuneate nucleus and gracile nucleus) in the medulla without synapsing in the spinal cord. The dorsal columm/medial lemniscal pathway crosses over at the medulla and continues on to the thalamus and terminates in the somatosensory cortex. The duplicate proprioceptive information (unconscious proprioception) is further projected ipsilaterally from cuneate nucleus and gracile nucleus to the cerebellum via the Spinocerebellar tract. The sensory inputs from somatosensory area project to the basal ganglia and cerebellum, then via the thalamus to the primary motor cortex, the origin of the corticospinal tract (Lundy-Ekman, 2002). The dorsal column pathways are associated with the functions of tactile discrimination or perception such as detection of size, form, texture and movement. Researchers have hypothesized that poor tactile perception may be related to difficulties in manipulative hand skills (Haron & Henderson, 1985).

Diminution of sensory feedback to the motor cortex can result in poor manual skills (Juliano & McLauchlin, 1999).

2.4.2 Development of Corticospinal Tract

Successful skilled hand movement depends on several factors as described above. If the maturation of individual finger movements corresponds to the development of the central nervous system, any discussion related to the maturation of finger movement must include the corticospinal tract, since it is a necessary system for individual finger movements.

Transcranial magnetic stimulation (TMS) is a noninvasive measurement of current flow underlying neural tissue by creating a strong localized transient magnetic field near the scalp. It is commonly used with eletromyogram (EMG) to investigate the development of corticospinal tract. The central motor conduction time was estimated by subtracting, from the latency of EMG response to TMS recorded in a given muscle, the latency of the responses excited by magnetic stimulation over the cervical spines. The latter is thought to excite the peripheral motor axons as they leave the vertebral column and thus gives an estimate of the peripheral conduction time. Subtraction of this value allows the central motor conduction time to be calculated. Dividing this value by the electrode distance will obtain the conduction velocity, which scientists assumed relates to functional maturation of motor system (Armand, Olivier, Edgley & Lemon, 1996).

Eyre, Miller and Ramesh (1991) used TMS to measure the motor conduction time in over 450 subjects, aged from 32 weeks gestation to 55 years. They found that the adult value of central motor conduction time was reached by 3 and 4 years. Since the conduction distance between the cortex and cervical spines (C7) increases linearly between 2 and 16 years, their finding implies that the conduction velocity of corticospinal neurons increased proportionally over this period of time. Therefore, the author concluded that the maturation of the corticospinal system (axon growth and myelination), as estimated by the conduction velocity of the fastest corticospinal neurons, is not reached before about 16 years of age. In addition, they believe that the constant central conduction time would help to provide stability of timing in movement command signals throughout the developmental period. Muller and Homberg (1992) investigated if the increase in movement speed with age among children aged 2 to 13 years old is determined by a structural change in the central nervous or neuromuscular system or dependent on training or motor learning by using TMS. The authors found that there were significant relationships between the central motor conduction time and the speed of finger tapping and aiming movements and the time to complete a peg-transportation test. They did not find significant effects of repetitive training on speed of the movement. They concluded that development of central conduction times determines the speed of repetitive movements in children and the development of fastest voluntary movements is a structure-bound phenomenon, being independent from learning.

2.4.3 The Development and Organization of Somatosensory Cortex

The somatosensory cortex is an important area for tactile integration and provides sensory feedback for motor control. Researchers used evoked potential recordings to investigate the maturation and changes of central nervous system throughout the life span. Fagan, Taylor and Logan (1987) described the somatosensory system as the most immature sensory system at birth and found variation in the sensory evoked potential rate of maturation until 3 to 8 years of age. The authors also found that the sensory evoked potential remains constant between 10 and 49 years of age with slowing after 49 years of age. Somatosensory cortex comprises four distinct cytoarchitectural regions, designated areas 1, 2, 3a and 3b. Most of the thalamic fiber terminates in area 3, which further projects to areas 1 and 2. Area 3a receives input from muscle spindle and Golgi tendon organ receptors, as well as joint receptors, whereas area 3b processes information from cutaneous receptors. The input from muscle and joint receptors appears to overlap in area 3a, but project to area 2 separately. Thus, area 2 is characterized by the presence of neurons with complex response properties that can represent the results of cortical integration of sensory inputs such as receiving convergent tactile and proprioceptive inputs. For example, neurons in area 2 are insensitive to passively applied stimuli but in react to active manipulation of specifically shaped objects (Chapman, et al., 1996).

2.5 Conclusion

Sensory information appears to be crucial for precise finger movements. Tactile information is important for discrete finger movements, whereas proprioception is more important for reaching in different directions and handling objects of different weights. A child can button his own shirt, even without the aid of visual feedback. This is one of many examples of the importance of tactile information in a daily task. Sensory information, which can correct and adjust the movement and update the motor program, is also important for learning movements. When sensory processing is less functional, the anticipation is disturbed and children have a problem in building internal representations and thus in executing precise movements. Children with less functional sensory processing may be still able to handle objects but they often show clumsy or immature motor pattern because they are relying on immediate sensory feedback rather than learned motor programs (Eliasson, 1995). Coordination in the motor task is dependent on anticipatory control that links different movement phases based on previous experience.

CHAPTER 3

METHODOLOGY

This study examined the relationships between the in-hand manipulation skills and the sensory-perceptual functions in the preschoolers. The Test of In-hand Manipulation (TIHM) and four sensory perceptual measures including Kinaesthetic Acuity Test (KAT), Weinstein Enhanced Sensory Test (WEST), stereogonosis and graphesthesia in the Pediatric Examination of Educational Readiness (PEER) were employed in this study. In this chapter, the research questions, research procedures, data collection and assessment tools employed in this study are described.

3.1 Research questions

1. What are the relationships between sensory-perceptual functions and in-hand manipulation skills in typically developing children?

2. Which of the sensory-perceptual functions predicts the children's in-hand manipulation skills?

3.2 Subject Selection

This study recruited 39 typically developing preschoolers, 20 girls and 19 boys, between the ages of three to five from Ohio State University Child Care Center and Columbus Children's Hospital Childcare Center. With 39 subjects, we have power of .69 to .98 to detect a medium to large effect with $p = .05$. The age range was considered to be appropriate for the study because other research has found that children around four years of age demonstrate the ability to manipulate objects within the hand (Pehoski, 1995). For purpose of this study, typically developing is defined as the child who has no medical diagnosis and does not receive special education services.

Letters briefly describing the purpose and procedures of this study were distributed to parents in the child care centers to ask if they were interested in participating in this study and whether or not their child had a medical diagnosis or received special education service. The child care center administrators were asked to distribute the letters. Parents who indicated interest and willingness were sent an informed consent which were returned using a self addressed stamped envelope. Children who receive parental permission were scheduled for testing after consultation with the child care center administrator.

Approval from the Behavioral and Social Sciences Institutional Review Board at The Ohio State University was obtained prior to data collection of this study (Appendix A). Only subjects with written parental consent (Appendix B) were tested for the study.

3.3 Instrumentation

3.3.1 Test of In-Hand Manipulation (TIHM)

Case-Smith (1991, 1993) is developing the TIHM using a 9-hole pegboard (12.5 cm square) to measure in-hand manipulation in preschool and school age children. The child is required to rotate and translate 5 pegs (3.7 cm in height, 0.65 cm in diameter) in both hands. Children were asked to draw a smiley face to identify the preferred hand before the test. The child was tested with both right and left hand in translation and rotation tasks. The translation task required finger-to-palm and palm-to-finger translation with stabilization. Detail information about testing procedure and scoring criteria is in the Appendix C.

The average of time, drops/stabilization and quality from prefer and non-preferred hand were used in data analysis separately. The performance for the preferred hand was used to investigate the relationships between motor skills and the performance from the sensory perceptual tests.

The in-hand manipulation test has demonstrated construct validity (Case-Smith, 2002). The TIHM can distinguish children with fine motor delays from typical children. The children with fine motor delays performed slower and dropped the pegs more frequently (Case-Smith, 1993). The concurrent validity has demonstrated by correlating the TIHM with motor tests such as the Peabody Developmental Motor Scales (Case-Smith et al., 1998) and with handwriting (Cornhill & Case-Smith, 1996).

3.3.2 *Pediatric Examination of Educational Readiness (PEER)*

The graphesthesia is the ability to identify the sensory stimuli on the skin. On the PEER, graphesthesia test requires the child to associate a shape that is drawn on his skin with one that he sees on a page from the Stimulus Booklet. This test is assessed in such a way as to minimize any linguistic input. During the test, the examiner places the page with four configurations (a circle, a straight line, a square, and a cross) in front of the child. The examiner then took the child's preferred hand and with a blunt pencil gently drew the shapes one at a time in the following sequence: line, cross (plus sign), circle, square. The child was asked to point to the shape on the booklet that is the same with shape that the examiner drew on his/her hand. A child at the school age should be expected to offer a correct response on at least three of the four items.

Stereognosis on the PEER tests the ability to perceive and recognize a shape without manipulating objects. The difference between the Graphesthesia and Stereognosis on the PEER is that the former ability needs to perceive the stimulus over time (the period it takes to draw a configuration on the skin). Stereognosis is the ability of simultaneous detection of the parts that constitute a whole three-dimensional configuration. The PEER Kit contains two sets of solid wooden shapes for this task. In each set are two rectangular solids and three cylinders of various sizes. The examiners then put the objects in the child's hand and asked the child do not move his fingers. The child was asked to point to the object on the desk, which is the same with the object in his/her hand. The detailed information about instructions and scoring criteria is in the Appendix D.

3.3.3 Kinaesthetic Acuity Test (KAT)

Various methods have been used in clinical settings to evaluate the proprioceptive sense including detection and discrimination of imposed movements, detection of movement and weight discrimination. It has been argued that the "total proprioceptive sensitivity" is evaluated by awareness of both movement and position rather than position alone (Carey et al., 1996; McCloskey, 1978). Active movements were believed to have greater functional values than passive movement when evaluating proprioceptive sense.

Kinaesthetic Acuity Test (KAT) was developed by Livesey and Parkes (1995) for the measurement of proprioceptive sense in young children. With vision occluded, the child will be told to visit a zoo and to find the animal he/she is visiting when occluded vision. The test is easily understood and sufficiently interesting to maintain children's attention (Livesey & Parkes, 1995). Task performance relies on passive hand/arm movement without demand on memory or motor planning. The apparatus consists of two rectangular boards with 16 familiar animal motifs on the top boards. The child's task is to grasp the stylus, which is moved by the examiner, and to report its position when asked "which animal are we visiting now?" Ten trials are randomly given with equal numbers of trials occurring in each quadrant. The accuracy score is the number of correct responses and the error score is the cumulative numbers of animal positions different from the correct responses (See Appendix E).

3.3.4 *Weinstein Enhanced Sensory Test (WEST)*

Tests such as monofilament, two-point discrimination and location of touch are commonly used in the clinical settings to evaluate the sensitivity of discriminative touch system. However, Weinstein (1993) argued that the monofilament , two-point discrimination and point location reflect different processing between the central and peripheral nervous system. He compared the performance of pressure sensitivity and two-point discrimination while a neurosurgeon applied the weak current to a seizure patient' hand area during a craniotomies. He found that pressure sensitivity remained unchanged on both ipsilateral and contralateral hands during application of the current. However, two-point discrimination threshold changed on the contralateral hand but not ipsilateral hand. These findings suggested that pressure sensitivity is subsumed with subcortical structure and Area 3b whereas spatial ability depends much more on cortical integration.

In another experiment, Weinstein compared the pressure sensitivity and spatial measures, two-point discrimination and point location, in 24 young women and 24 young men. He found that there was a high correlation (0.92) between these two spatial measures but pressure sensitivity correlated only 0.17 and 0.28 with two-point discrimination and point location. In addition, for the pressure sensitivity, the most sensitive part was face, followed by the trunk, then the fingers and upper extremities. For both two-point discrimination and point localization, the most sensitive parts were the fingers followed by the face and the feet. These results indicated that the ability to detect pressure was not essentially related to the ability to detect spatial measures.

WEST was employed to measure the touch/pressure sensibility, as defined by the minimal force that one can feel or perceive. Adults are able to feel the 0.076 gm anywhere on the face and upper limbs. Inability to sense filaments at 0.209 gm indicates diminished light touch (Lundy-Ekman, 2002). Women have lower sensation thresholds and are more sensitive than men for all body regions. Testing results have not been documented for children. The examiner touched a monofilament to the child's skin at the fingertips and began testing with filament marked 2.83 (0.076gm). The monofilament was applied perpendicular to the skin with the filament bent for 1.5

seconds. The examiner repeatedly applied the filament three times at each testing site, including the thumb, index and little fingers, palm and used thicker filaments if the child did not perceive thin ones.

The test forms supplied with the WEST indicate the usual sites for testing. At each test site there are five circles within a square that are used to record results. Circles are filled to indicate particular threshold levels (See Appendix E). In the data analysis, one point indicates the child can detect 0.07 gram. Two points indicate the child can detect 0.2 grams. The sensibility is the average of the score from 6 tested sites for each hand.

3.4 Procedures

The 39 children were tested individually by the researcher during one 20-25 minute session. Two typically developing preschool children were tested prior to data collection. The purpose of the pilot study was to improve the researcher's skill in administering the tests and adjust the assessment tools. The subjects were from the Ohio State University Child Care Center and were reported by their parents to be typically developing children. All subjects were tested in a quiet room with minimal distractions. Each child sat in a child-sized chair at a table of appropriate height during the test administration. The tests were presented to all children in the same order a) Kinesthetic Acuity Test b) Weinstein Enhanced Sensory Test c) graphesthesia and stereognosis from Pediatric Examination of Educational Readiness d) Test of In-Hand Manipulation.

3.5 Data Analysis

In order to investigate the association among tactile system and in-hand manipulation performance in the samples, Pearson correlation coefficients were used to determine the correlations between the time, drops/stabilization and quality of the TIHM and scores of PEER, WEST, tactile sensibility using SPSS. Multiple linear regressions were used to determine which sensory-perceptual tests predict the TIHM scores. Significance is accepted at $p = .05$.

CHAPTER 4

RESULTs

This chapter presents the results of the data analysis. The first section presents a description of the sample. The next sections provide a comparison of performance measures between boys and girls, including means, standard deviation and ranges. The final section presents descriptive data regarding the relationships and regression analysis among scores on all items.

4.1 Description of the Sample

Nineteen male and twenty female typically developing children aged from 3 to 5 years (Mean= 4.01, SD=0.6) were recruited from the Ohio State University Childcare Center (n=23) and Children's Hospital Childcare Center (n=16). A t-test was used to compare the age between male and female. There was no significant difference for age between male and female. Table 1 provides descriptive data of the subjects.

	Male (n=19)	Female (n=20)	t	p
Age (Mean)	4.2	3.9	t(37) = 1.78	0.083
Age (SD)	0.7	0.5		
Range (months)	40 - 66	40 - 59		
Right handedness	15	20		
Left handedness	4	0		

Table 1: Descriptive data of the subjects.

4.2 Comparisons of Performance Measures for Genders and Preferred Hand

Descriptive data for each of the TIHM are provided to compare scores between preferred and non-preferred hand in both girls and boys. A t-test was used to compare the scores on the TIHM and sensory perceptual functions in different gender groups.

4.2.1. Test of In-Hand Manipulation (TIHM)

The TIHM includes two-trial rotation and four-trial translation (two pegs, three pegs, four pegs and five pegs) tasks on each hand. Time, drops/stabilizations and quality were recorded in each trial. The total scores of time, drops/stabilization and quality were calculated separately on both hands as the sum from averages of the translation and rotation tasks.

First preferred and non-preferred hands were compared in different gender groups. As shown in Table 2, there are no significant differences in time, drops/stabilizations and quality between preferred hand and non-preferred hand on boys. For girls, there are significant differences in drops/stabilization and quality but not time between preferred and non-preferred hand. There is a moderate correlation, with $r = -.304$ and $p = .03$ between genders and time scores of TIHM. Boys showed more movement time on the performance of preferred hand.

	Preferred Hand (Mean & SD)	Non-Preferred Hand (Mean & SD)	t	p
Boys (n=19)				
Time (SD)	37.13 (8.15)	37.01 (8.89)	t(18)= 0.091	0.928
Drops/Stabilizations	3.20 (2.64)	3.46 (2.36)	t(18) = -.604	0.553
Quality	1.24 (0.43)	1.15 (0.35)	t(18)= 1.344	0.196
Girls (n=20)				
Time (SD)	32.15 (7.89)	34.08 (7.92)	t(19)=-1.571	0.133
Drops/Stabilizations	2.68 (1.59)	4.51 (3.07)	t(19)= -3.52	0.002**
Quality	1.29 (0.42)	1.11 (0.47)	t(19)= 2.964	0.008**

* $p < .05$

* * $p < .01$

Table 2: Means, standard deviations and differences between preferred and non-preferred hand for the TIHM

The combined scores of preferred and non-preferred hands were used to compare the performance of TIHM between boys and girls. As shown in Table 3, there is no significant difference and correlations between boys and girls on the overall TIHM performance.

	Boys (Mean & SD)	Girls (Mean & SD)	t	p
Time (SD)	37.07 (7.98)	33.12 (7.41)	t(37)= 1.603	.117
Drops/Stabilizations	3.33 (2.32)	3.6 (2.15)	t(37)= -.379	.717
Quality	1.19 (.36)	1.2 (.43)	t(37)= -.040	.968

* $p < .05$
* * $p < .01$

Table 3: Means, standard deviations and differences between boys and girls for the TIHM

4.2.2 Sensory Perceptual Tests

A t-test was computed to compare the performance of four sensory tests between genders. Table 4 showed the comparisons of four sensory tests between genders. There is a significant difference between genders on the graphesthesia but not on the stereognosis, KAT and sensitivity. There is a significant correlation, with r = -.353 and p= .014 between genders and graphesthesia.

	Boys (Mean & SD)	Girls (Mean & SD)	Range	t	Sig.
Graphesthesia	1.95 (1.18)	1.2 (0.83)	0-3	5.279	.027*
Stereognosis	2.37 (0.76)	2.10 (0.89)	0-3	1.441	.238
KAT					
Correct	5.89 (2.02)	5.95 (19.5)	2-9	.008	.931
Error	4.53 (2.63)	4.3 (2.27)	0-11	.083	.775
Sensitivity					
Right	1.12 (0.41)	1.15 (0.28)	1-2.5	.730	.398
Left	1.18 (0.42)	1.07 (0.16)	1-2.83	1.148	.291

* p< .05

* * p< .01

Table 4: Comparisons of sensory tests between boys and girls

4.3 Correlations among Variables and Summary of Regression Analysis

4.3.1 Correlations Between the TIHM and Sensory-Perceptual Tests

In order to investigate the relationships between in-hand manipulation skills and sensory functions, Pearson correlation coefficients were computed. The 39 subjects' scores of in-hand manipulation on the preferred hand were used to compute the correlation with scores of the sensory tests on the preferred hand. The scores of the preferred hand were used because the combined scores of preferred and non-preferred hand on the TIHM may diminish the correlations with sensory tests, which tested only on the preferred hand.

Table 5 presented the correlation among all variables. Time on the TIHM has moderate and negative correlation with graphesthesia and stereognosis. The total drops and stabilizations are positively correlated with KAT error scores but not correct scores. The quality of in-hand manipulation skills has moderate correlation with KAT correct and error score. The correlation between drops/stabilization and Quality is stronger than the correlation between drops/stabilization and time. The direction of the correlation coefficients was expected based on how each test was scored.

	TIHM (Time)	TIHM (Drops)	TIHM (Quality)	Graph	Stereo	KAT (correct)	KAT (error)
TIHM (Drops)	.367*						
TIHM (Quality)	-.318*	-.565*					
Graph	-.384**	-.129	.163				
Stereo	-.371**	-.224	.225	.221			
KAT (correct)	.202	-.214	.487**	.246	.058		
KAT (error)	-.218	.291*	-.471**	-.173	-.030	-.932**	
Sensitivity	.088	-.173	.007	-.023	-.052	-.311*	.260

* $p< .05$

* * $p< .01$

Graph: Graphesthesia

Stereo: Stereognosis

Table 5. Pearson correlation coefficients between scores for sensory tests and TIHM

4.3.2 Predictors of time on the TIHM

A stepwise multiple linear regression analysis was performed separately to identify which variables predict a child's time, drops/stabilizations and quality on the in-hand manipulation tasks. Time, drops/stabilizations and quality of the preferred hand from the Test of In-Hand manipulation were used to be the criterion variables and gender, age, sensory tests including graphesthesia, stereognosis, KAT correct, KAT error and sensitivity were used to be the predictors.

Results presented in Table 6 indicate that scores of graphesthesia, which entered first and accounted for 12.5% of the variance, is the best predictor of time on the TIHM. Gender and stereognosis accounted for additional 20.8% and 11.9% of the variance. These results indicate that graphesthesia, gender and stereognosis together predict 45% of variance in Time scores on the TIHM. Results presented in Table 7 indicate that KAT error score, which account for 8.5% variance, is the only predictor of the Drop and Stabilization scores on the TIHM. Results presented in Table 8 indicate the KAT correct score, which accounts for 23.7% variance is the only predictor of the quality on the TIHM.

Step	Variables	R*	R-square*	F*
1	Graphesthesia	.384	.125	6.414
2	Gender	.607	.333	10.502
3	Stereognosis	.704	.452	11.447

* Values reported are cumulative for each step

Table 6: Results of step-wise multiple regression analysis: explained variance of time scores on the TIHM

Step	Variables	R*	R-square*	F*
1	KAT (error)	.291	.085	3.433

Table 7: Results of step-wise multiple regression analysis: explained variance of drops/stabilizations on the TIHM

Step	Variables	R*	R-square*	F*
1	KAT (correct)	.487	.237	11.514

Table 8: Results of step-wise multiple regression analysis: explained variance of quality on the TIHM

4.4 Summary

The first research question of this study is to investigate the relationships between in-hand manipulation skills and sensory-perceptual functions. Results showed that the Time scores on the TIHM have moderate and negative correlations with graphesthesia and stereognosis. The total drops and stabilizations are positively correlated with KAT error scores but not correct scores. The quality of in-hand manipulation skills has moderate correlation with KAT correct and error score. The correlation between drops/stabilization and Quality is stronger than the correlation between drops/stabilization and time.

The second research question is to investigate which sensory-perceptual function predicts the children's in-hand manipulation skills. Graphesthesia is the best predictor of time on the TIHM. Graphesthesia, gender and stereognosis together predict 45% of variance in Time scores on the TIHM. KAT error score is the only predictor of the Drop and Stabilization scores on the TIHM. KAT correct score is the only predictor of the quality on the TIHM.

Chapter 5

DISCUSSION, RECOMMENDATIONS, CONCLUSION

This chapter presents a discussion of the results of the current study, including implication for occupational therapists providing intervention to preschoolers with special needs. Limitations of the study are discussed and recommendations for further research are suggested.

5.1 Discussion of Results

5.1.1.Gender Differences on the Test of In-Hand Manipulation(TIHM)

The purpose of this study is to investigate the relationship between sensory-perceptual function and in-hand manipulation skill in typically developing preschoolers. However, some studies showed that there is a significant difference on the degree of lateralization such as degree of hand preference, degree of asymmetry in hand skills and tactile lateralization between boys and girls (Maharaj, Mandar, & Georges, 2001). The combined scores of preferred and non-preferred hand on the TIHM may diminish the correlations with sensory tests, which tested only on the preferred hand.

In the present study, no significant differences were found between boys and girls on time, drops/stabilization and quality for TIHM. Children at this age did not use the mature method to perform these in-hand manipulation tasks. They tend to use forearm rotation or rake method to manipulate pegs. Pehoski et al. (1997a, 1997b) investigated the time and movement pattern of complex rotation and translation in children aged from 3 years to 6 years 11 months. Their results showed that there are no significant differences between boys and girls in both rotation and translation tasks. The author also found that in the translation tasks, adults used gravity to assist moving pegs to and from the palm whereas children commonly raked the pegs from the palm to the finger surface by using all the fingers together. In the rotation task, the children often used an external surface such as body or pegboard or rotate the arm to adjust the pegs and prevent the drops.

Simple effect analysis reveal significant differences in drops/stabilization and quality but not time between preferred and non-preferred hand on girls, however, these differences did not show on the boys. This result corresponds to previous studies regarding gender differences in the degree of lateralization (De Agostini , Pare, Goudot & Dellatolas 1992). De Agostini et al. (1992) investigated the manual preference and skill development in preschool children by using a peg-moving test and graphic test on both hands. In the graphic test, the child was asked to put a dot in small circles which were drawn in a certain pattern. The examiner recorded how many dots the child made in the circles in 20 seconds. In the manual preference test, the child was asked to perform some daily activities such as draw a line with a pencil, use an eraser. They found that between boys and girls, each hand performance is not significantly different at the peg-moving task, but significantly higher in girls than boys at the graphic task. The graphic tack task was more closely related to handedness than the peg-moving task. The author suggested that pronounced ambidextrous tendencies and a weaker lateralization appear in boys more than in girls which corresponds with statement of early maturity in girls by Maehara, Negishi and Tsai (1988).

5.1.2. Correlation between TIHM and Sensory-Perceptual Tests

Time. In the present study, different measures on the in-hand manipulation tasks showed correlations with different sensory tests. Time on the in hand manipulation tasks have moderate correlation with graphesthesia and stereognosis, with r = -.384, p = .008 and r=-.371, p = .010 respectively. There is no significant correlation between in-hand manipulation and tactile sensitivity. These results correspond to the research of Case-Smith (1991). Case-Smith (1991) studied the relationship between both tactile defensiveness and tactile discrimination and in-hand manipulation skills in 50 children between 4 and 6 year-old. In this study, the author showed the correlations between scores of in-hand manipulation and items of discrimitive touch from Southern California Sensory Integration Tests (SCSIT) including finger identification, graphesthesia and localization of tactile stimulation. There is a moderate correlation between graphesthesia and in-hand manipulation skills but no significant correlation between in-hand manipulation skills and finger identification as well as localization of tactile stimulation. The author explained that graphesthesia requires a precise motor response that involves motor planning, whereas the other two tactile subtests rely less on motor planning.

The other possibility that time of the TIHM has stronger correlations with graphesthesia and stereognosis than proprioception in this present study is because graphesthesia and stereognosis as well as time scores of the TIHM involve higher-order cognitive process. In the in-hand manipulation tasks, children needed to observe the examiner's demonstrations and followed the sequence of the tasks. This process involved sequencing and motor planning. Graphesthesia and Stereognosis tests are intermodal sensation tasks (haptic-visual matching) and require more complicated cognitive process. The graphesthesia and stereognosis tasks when compared to touch detection required not only the ability to discriminate objects based on cutaneous information but also to use higher-order integration of the primary sensory information into an internal object representation (Deibert, Kraut, Kremen & Hart, 1999; Kalaska, 1994).

Deibert et al.(1999) investigated the neural pathway in a stereognosis task using functional MRI. Subjects are required to identify an ordinary object such as a button without manipulation. The results showed the brain regions involved in this task include calcarine and extrastriatal cortex, inferior parietal lobule, inferior frontal gyrus, and superior frontal gyrus. The authors concluded that this task may utilize visual systems to access an internal object representation. The parietal cortices and inferior frontal regions may be involved in a concomitant lexical strategy of naming the object being examined. Frontal polar activation likely serves a role in visuospatial working memory or in recognizing unusual representations of objects. This study confirms that the tasks such as stereognosis and graphesthesia involved higher-order and complex cognitive process.

The correlation between drops/stabilization and quality, with r = -.565, p = .0001 is stronger than the correlation between drops/stabilization and time, with r = .367, p= .011. This result may further confirm that time as well as drops/stabilization and quality involve different central processing. The time of the performance may involve cognitive process such as sequencing or motor planning whereas drops/stabilization and quality involve on the feedback of the tactile system. The relationship between sensory-perceptual tests and drops/stabilization as well as quality will be discussed in the following section.

Drops/Stabilization & Quality. The total drops and stabilizations are positively correlated with KAT error scores but not KAT correct scores, with r = .291, p = .036. The KAT error scores have stronger correlation with drops of in-hand manipulation than KAT correct scores might be due to the weighted error scores. The KAT error score is the cumulative numbers of animal positions different from the correct responses whereas the accuracy score on the KAT is only the number of correct responses. The quality of in-hand manipulation skills has moderate correlation with KAT correct and KAT error score, with r = .487, p = .001 and r = -.471, p = .003 respectively. These results support the previous statement that proprioception contributes most to the quality of motor performance (Zucker-Levin, 2003). The author states that proprioception provides more feedback than other tactile systems to motor control because duplicate information is carried over two tracts, one to the cerebellum (spinocerebellar tract) and one to the primary somatosensory cortex (dorsal column lemniscal pathway).

In this study, children showed immature movement patterns on the TIHM. They tend to grip pegs tightly and to maintain contact with the peg during the movement which correspond to the research of Pehoski (1997a, 1997b) and Forssberg et al. (1991). The greater grip force and readjustment of pegs may be due to the insufficient tactile and kinesthetic feedback among the children. Pehoski et al. (1997a, 1997b) suggested that most children under age of six did not use mature method to manipulate subjects because they tend not to modulate grip force in the same efficient manner as adults. Forssberg et al.(1991) compared the grip force in children and adults when picking up a small object between thumb and index finger. The results showed that young children used greater grip force than adults. The author suggested that children of one year can already use tactile and proprioceptive to adjust the forces during the static phase (before lift-off), but the regulation of fingertip force remain immature. This manipulative force rapidly develops until age two and matures until the teenage years.

Documents comparing whether cutaneous information or proprioception contributes most to force regulation among normal preschoolers have not been found. In the present study, there is no significant correlation between tactile sensitivity and the TIHM measures. It seems that proprioception contributes more than cutaneous information to the motor performance. However, occlusion of the contribution from the cutaneous information on the motor performance might be due to ceiling effect on detecting touch among this age or insensitive device.

Fess (1990) has described a hierarchy of sensory functioning. Detection, defined as the ability to distinguish a single point stimulus from background stimulation, is the lowest level of the hierarchy. Discrimination, the ability to distinguish the difference between stimulus a and stimulus b, is next. Quantification, the ability to organize tactile stimuli according to degree, such as roughness or weight, is the next level. Finally, the recognition, the ability to recognize objects by touch, is at the highest level. Fess's hierarchy suggests that it may not be necessary to test every sensory modality in every patient. For example, if the patient is able to discriminate stimuli, sensory detection tests need not be performed. The WEST requires subjects to detect the touch on the hand, which belong to the lowest level of the hierarchy. Most children in this study can detect 0.7 grams, indicating normal tactile sensation (scored as one point) on both hands.

The stimulus levels of WEST used in this study are from .07 to 300 grams which can only discriminate normal and impaired sensation. The spectrum of tactile sensibility between subjects and between different tested sites cannot be determinined by using this instrument. With a more sophisticated device, tactile sensibility can be differentiated in the normal population. Schulz, Bohannon and Morgan (1998) investigated the normal digit tip values for the WEST among subjects aged from 21 to 86 without peripheral neuropathy. The stimulus levels of the instrument range from .004g to 1.68g. Their results showed that aging affects the performance of normal subjects on sensibility tests, with a reduction of sensibility along with increased age. In addition, the sensibility differences can be seen within individual digits. A more sophisticated instrument is necessary for further research to investigate the relationships between tactile sensitivity and fine motor skills among children.

In the present study, only one subject correctly responded on 10 trials on the Kinesthetic Acuity Test. The average accuracy score and error score are 4.42 and 5.92 in ten trials. Most errors in each trial are within one position of the correct position, which support the research of Livesey and Intili (1995). The authors suggested that majority of the errors made are closer to the correct position indicating the child could sense the approximate location of the hand even if this lacked precision. The target positions on the KAT were 22.5 degrees separation around the circumference of the circle. Bairstow & Laszlo (1981) suggested that a child who cannot reliably discriminate between movements that differ in angle by 20 degree would find it very difficult to perceive errors in his movement which are of smaller amplitude. This might be one reason why children prefer to draw large pictures because large movements allow great changes in kinaesthetic information, thus aiding in the detection and correction of errors.

5.1.3. Predictors of the TIHM

The second research question examines which sensory-perceptual functions can predict in-hand manipulation skills. In order to identify the strongest predictors of the in-hand manipulation skills, a step-wise regression analysis was completed. Graphesthesia is the best predictor of Time scores on the TIHM. Graphesthesia, gender and stereognosis accounted for 45.2% of the variance. These results indicated that graphesthesia, genders and stereognosis were good predictors of Time score for the TIHM. KAT error, which accounts for 8.5% variance, is the only predictor of the drops and stabilizations on the TIHM. KAT correct, which accounts for 23.7% variance, is the only predictor of the quality on the TIHM.

Time. It is interesting that different performance measures of in-hand manipulation skills are predicted from the different sensory perceptual tasks. Graphesthesia, genders and stereognosis can predict scores on Time of the TIHM and account for near 50% of the variance. Manipulative skills, require interaction of cognitive and motor ability. Object manipulation that requires a sequence of movements for successful performance particularly depends on higher-level cognitive skills.

Movement time provides an indication of an individual's speed in preparing a response, which may involve analyzing a situation followed by selecting and organizing a movement response (Exner & Henderson, 1995). The movement time on the TIHM seems to reflect cognitive processing.

In addition, the continuity between perception and cognition in these relationships, perception is the process of acquiring information about objects, places and events. One perceives what is specified through one's senses and selectively attends to particular perceptions. Mental representations of our perceptions are stored in our memory and perceptions form the basis for our knowledge about our environment. On the graphesthesia and stereognosis task, the child needs to perceive the stimulus over time, introspectively construct a mental image of the geometric shape and ultimately recognize its overall form. This perceptual-cognitive processing helps people to understand the physical characteristics of objects, such as the shaping of the hand to fit the size and orientation of an object and further plan actions to accomplish the manipulative tasks. These same processes may be used in the TIHM.

Exner (1995) found that all basic in-hand manipulation skills were present in normal children before the age of 7 years, but that many of the children were inconsistent in their performance. She proposed that children's increase in consistency of use of these skills during the preschool years is, in part, a result of their cognitive development.

Drops/Stabilizations & Quality. The drops/stabilization and quality can be predicted from the score of kinesthetic acuity tests. Accuracy in perception of movement relates to the quality of motor performance. Kinesthetic training has been viewed as an important method to improve the motor performance such as handwriting and typing (Benbow, 1995).

5.2 Implication for Practice

The results of the investigation of the correlations between in-hand manipulation sills and sensory-perceptual functions have implications for therapists' focus on the development of in-manipulation skills. The Time scores on the TIHM seems to relate to the child's cognitive processing whereas the drops/stabilizations and quality appear to relate to proprioceptive feedback. The Test of In-Hand Manipulation can provide a guide on the occupational therapy intervention for children with fine motor delay. It might provide information whether the therapist should focus on enhancing sensory functions, particularly proprioceptive, or cognitive processing such as motor planning, sequencing and integrating sensory information.

Insufficient proprioceptive feedback will affect motor control and development of motor skills such as handwriting and typing. Efficient writing depends on the kinesthetic inputs without visually monitoring the pencil point. Research investigating the effect of kinesthetic training on first-grade students (Sudsawad, Trombly, & Henderson, 2002) did not support for the use of kinesthetic to improve motor performance. However, some methodological deficits need to be discussed. Subjects in this study showed the effect of regression and practice effects on the Kinesthetic Sensitivity Test (KST). The KST measures the relative sensitivity of the upper limbs to passive movement. The participant's hand are placed around two pegs, which were guided passively by the experimenter up two inclined runways. The range of angles for two runways is from 0 degrees to 22 degrees to the horizontal. All subjects showed extremely low scores on the pre-test, and both experimental and control groups showed improvement on post-test. Livesey and Parks (1995) argued that the KST might not be an appropriate instrument because distinguishing the differences between 3 degree and 5 degree angles seems to be too difficult for the younger child.

Recent research has shown how training and experiences affect the neural changes on the monkeys. Jenkins, Merzenich, Ochs & Allard (1990) performed an experiment in which monkeys were able to reach for food by using a strategy that involved use of their middle fingers only. After considerable experience with this task, the monkeys' cortical map showed an area for the middle fingers that was significantly larger than normal. Nudo, Milliken, Jenkins & Merzenich (1996) tested if the motor cortex, like sensory cortex, was altered by behavioral experience. They found that as the skills were acquired, the representation of digit and wrist-forearm were redistributed within primary motor cortex, with expansion of finger representations for the digit task. In addition, although the behavior dropped to pretraining levels, the reversibility was not complete after an extinction phase. These results demonstrate that clinical training and experience are important for neural changes. Once the skills were learned, central mapping changes persist for long periods.

Children who demonstrated fine motor difficulties may avoid fine motor activities and get less practice than their peers. The fine motor difficulties of these children need to be identified and functional activities providing either proprioceptive feedbacks or motor planning training that are appropriate to their level of skill and interest need to be introduced.

5.3 Limitations of Study

The limitations of this research have been identified as the following:

1. The Weinstein Enhanced Sensory Test (WEST) use in present study is insensitive to differentiate the different levels of tactile sensitivity between subjects or between tested sites of the hand. This lack of sensitivity may cause the threats to the internal validity.
2. Only four sensory tests were used in this study. Other sensory perceptual tests of texture, position sense, and weight discrimination should be explored to thoroughly understanding the relationships between the fine motor skills and sensory functions.
3. The method used for recording observations during the testing tasks was limited. It was difficult to document children's performance when they used a variety of methods to manipulate the pegs during translation and rotation tasks while the researcher was timing and counting at the same time.
4. In-hand manipulation skills were tested on both hands while some of the sensory tests were only test on preferred hand. The results may not be able to generalize to non-preferred hand due to different degree of lateralization and maturation among three to five year old boys and girls.

5.4 Recommendations for Further Study

1. A replication of this study with more sophisticated instrument for testing tactile sensitivity is needed to increase the validity.
2. A study examining the relationship between performance scores using other sensory tests or kinesthetic tests including movement sense, position sense and weight discrimination is recommended.
3. Videotaping the in-hand manipulation test to confirm the scores during the testing could decrease the examiner's measurement errors.
4. All sensory perceptual tests should be tested on both hands to consolidate the consistent relationships between motor skills and sensory functions between preferred and non-preferred hands.
5. Further research is needed to examine if the time scores on the Test of In-Hand Manipulation are related to cognitive functions, such as sequencing and motor planning.

5.5 Conclusion

The purpose of this study is to investigate the relationship between in-hand manipulation and sensory perceptual functions including graphesthesia, stereognosis, kinesthesia and tactile sensitivity among three to five year old typically developing children. The Time scores on the TIHM seems to relate to the child's cognitive processing whereas the drops/stabilizations and quality appears to relate to the proprioceptive feedbacks. The Test of In-Hand Manipulation can provide a guide on the occupational therapy intervention for children with fine motor delay. It might provide information whether the therapist should focus on enhancing sensory functions, particularly proprioceptive, or cognitive processing such as motor planning, sequencing and integrating sensory information.

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APPENDIX A

HUMAN SUBJECT APPROVAL

THE OHIO STATE UNIVERSITY

BEHAVIORAL AND SOCIAL SCIENCES
INSTITUTIONAL REVIEW BOARD (IRB)
The Ohio State University

Office of Responsible Research Practices
1960 Kenny Rd., Columbus, Ohio 43210-1063
Phone: 614-292-6950 FAX: 614-688-0366

Research Involving Human Subjects

ACTION OF THE INSTITUTIONAL REVIEW BOARD

X	Full Committee Review	X	Original Review
____	Expedited Review	____	Continuing Review
		____	Amendment

With regard to the employment of human subjects in the proposed research protocol:

2003B0021 THE RELATIONSHIPS BETWEEN IN-HAND MANIPULATION AND TACTILE/KINESTHESIA PERCEPTION IN PRESCHOOLERS, Jane D. Case-Smith, Yun-Ju Chen, Allied Medical Professions/Occupational Therapy

THE BEHAVIORAL AND SOCIAL SCIENCES HUMAN SUBJECTS IRB HAS TAKEN THE FOLLOWING ACTION:

____	**APPROVED**	____	**DISAPPROVED**
X	**APPROVED WITH CONDITIONS** *	____	**WAIVER OF WRITTEN CONSENT GRANTED**

* Conditions stated by the IRB have been met by the Investigator and, therefore, the protocol is **APPROVED**.

- **No procedural changes may be made without prior review and approval from the IRB.**
- **You are reminded that you must promptly report any problems to the IRB.**
- **You are also reminded that the identity of the research particip[illegible] ust be kept confidential.**
- **It is the responsibility of the principal investigator to retain a co[illegible] ch signed consent form for at least three (3) years beyond the termination [illegible] participation in the proposed activity. Should the principal invest[illegible] University, signed consent forms are to be transferred to the Hum[illegible] RB for the required retention period.**

Date: January 24, 2003

Signed: ____________________

Thomas E. Nygren, Chair

APPENDIX B

PARENT CONSENT FORM

February 10, 2002

Dear Parent,

Faculty in the School of Allied Health Professions of The Ohio State University is investigating the relationship between fine motor skills and sensory-perceptual function. Your child will be given four brief tests measuring his or her ability to perceive touch and movement of his/her fingers and hands and one test of manipulation. In the tests light touch is administered and your child is asked to locate the place in which he/she is touched. In addition he/she is asked to detect movement at the wrist and to identify small objects from touch alone.

We would like to test your child. The testing requires about 30 minutes and will take place at a small table and chair just outside your child's classroom. Children report that the tasks are fun and they pose no risks to your child. The evaluators are faculty and graduate students of Ohio State University. If your child has poor performance in these tests, we will recommend further evaluation.

If you are willing to allow your child to be tested, please sign below and return this form to your child's teacher. We will schedule a time to test your child with his/her teacher and send you an informed consent form to be returned to us via a self addressed stamped envelope. If your child have any medical diagnosis or receive any special education services, he/she may not be eligible in this study.

Thank you for considering our request.

Sincerely,

Jane Case-Smith, Ed.D., OTR/L
Professor

_________ Yes, I permit my child, _________________ to be scheduled for testing and would like you to send me the informed consent. If yes, please provide your name and address
_________ No, I am not interested in my child participating in this study.

Please return this form to your child's teacher by February 20, 2002. Thank you.

APPENDIX C

TEST OF IN-HAND MANIPULATION PROTOCOL

Test of In-Hand Manipulation
Protocol

Equipment: 9 hole peg board, 7-10 pegs, stop watch, child sized table and chair

Set-up: The pegboard is placed a child's midline, 4-5 inches from the edge of the table. Determine the child's preferred hand by asking him/her to draw a smiley face.

Rotation

Place five pegs in the pegboard holes, with one in each corner and one in the middle. Point to the child's preferred hand. Say "we will use this hand first." Hold the child's non-preferred hand or ask the child to place it in his/her lap. Say:

We're going to play the Little Man game. I'm going to turn each man on his head. Turn each peg over, using in-hand rotation. Say: **You turn the men over so they are standing on their feet.**
A second trial with the same hand is initiated, by saying:
Now turn the men back onto their heads

If the child drops the peg on the table, the child is encouraged to make a rapid recovery by saying, **Its OK, keep going.** If the peg drops onto the floor or out of reach, the trial is stopped and then repeated. If the child stabilizes the peg on his body, the table or another surface, timing continues. With younger children, discourage the possible use of two hands by holding one in his/her lap.

Repeat the procedure with the child's non-preferred hand.

Scoring

Record the **time** in seconds beginning when the child first touches a peg until the fifth peg is rotated and placed into the board. Record instances when the child **drops** a peg or **stabilizes** a peg on the table or on his body. The **quality** of the performance was recorded by a three-level scale categorized as none, partial and full (scored as 0, 1, 2 respectively). **Zero point** was given when the child use external surface or other hand to rotate the pegs. **One point** was given when the child pronate his/her arm to pick up the peg and supinate to neutral position to replace the peg. By using this method, the peg was partially turned and minimal finger movements were needed to position the peg correctly into the board. **Two points** was given when the child use mature method. The child

picked up the peg between the thumb and finger and then pulled it with the middle finger to begin the 180° rotation. He/She then transferred the peg to the thumb and middle finger, and the rotation was completed by a push movement of the index finger.
For each hand average the two time, drop/stabilization and quality scores.

Translation with Stabilization

Instructions

Place two pegs in opposite corners of the front row of the pegboard. Indicate again that the child is to use his or her preferred hand. Place your hand over his non-preferred hand or ask him to put that hand in his lap. Say:

Now you will play a hide and seek game. Watch me. I will pick up one man and hide him in my hand. Pick up one peg and move it to the palm. **Then I pick up the other man and hide him in my hand**. Pick up the other peg. **Out comes one man.** Replace one peg. **Out comes the other.** Replace the second peg. **Now you play the hide and seek game. Pick up one man, pick up the other, now out comes the first man, out comes the other**. The time score recorded begins when the child touches the first peg and ends when he places the second peg in a hole. The number of times that he/she drops the peg(s) and stabilizes one on another surface are recorded.

Now place a third peg in the center of the pegboard. Say: **Pick up one man, pick up another, pick up the last man. Now bring them back out. Out comes one, out comes two, and out comes three**. Keep the child moving, with your verbal cueing, i.e., give continuous cueing. Continue timing if the child drops the peg on the table, and encourage rapid recovery. If the peg falls on the floor or is out of reach, begin the trial again.

Scoring

Record **time** from the moment the child touches the first peg, until all of the pegs are replaced. Record the number of **drops and stabilizations**. The **quality** of movement was recorded by a three-level scale categorized as none, partial and full (scored as 0, 1, 2 respectively). **Zero points** was given when the child showed no attempt to move the peg under the fingers for storage. The child picked up the peg between the thumb and the side of the index finger or between the fingers and the palm without any attempt to move the peg under the ulnar fingers. Usually, the child did not show palm-to-finger translation or use an external surface or the other hand when he replaced the peg into the hole. **One point** was given when the child use “supination thumb push” or” pronation thumb push” to pick up pegs and replace the pegs by using “Rake” method. By using the supination thumb push and pronation thumb push, the child partially supinated the arm or maintain pronation after the peg was picked but the peg was pushed under the partially flexed ulnar fingers by the thumb. Contact with the peg was maintained for the entire sequence. Rake method is identified when the child's hand was partially supinated and the pegs were raked or awkwardly moved by the thumb working against the fingers until they were near the base of the fingers. One of the pegs was then shifted by the thumb into the distal radial fingers. **Two points** was given when the child partially use gravity to let the peg drop or roll into the palm and retrieve the pegs from the palm. The important process was to raise the ulnar border of the hand, flex the little finger, and partially flex the ring and middle fingers. This hand shape allows pegs to be stored and retrieved more efficiently. The fingers then closed over the pegs, allowing the hand to be pronated to pick up a peg or replace a peg. This is the method that the majority of adult participants used to facilitate the task.

Repeat the same instructions with 4 and then 5 pegs, placing them in the corners of the row furthest away from the child. It does not matter what holes the child uses to place the pegs.

Repeat 2, 3, 4, and 5 pegs with the non-preferred hand.

Scoring

Sum the times for the 4 tasks with each hand. Average each sum. Average the total number of drops and stabilizations for all 4 tasks. Average the quality of movement scores for all 4 tasks.

IN-HAND MANIPULATION TEST
SCORE SHEET

Name ______________________ Birthdate _________________

Date ______________________ Location __________________

Evaluated by ________________ Preferred hand _________

ROTATION

Trial		Time	Drops	Stabilizations	Quality
R L	1	_____	_____	_______	_____
	2	_____	_____	_______	_____
R L	1	_____	_____	_______	_____
	2	_____	_____	_______	_____

TRANSLATION

R L	Trial	Time	Drops	Stabilizations	Quality
	2 pgs	_____	_____	_______	_____
	3 pgs	_____	_____	_______	_____
	4 pgs	_____	_____	_______	_____
	5 pgs	_____	_____	_______	_____

R L	Trial	Times	Drops	Stabilizations	Quality
	2 pgs	_____	_____	_______	_____
	3 pgs	_____	_____	_______	_____
	4 pgs	_____	_____	_______	_____
	5 pgs	_____	_____	_______	_____

Quality of Performance: Use of In-Hand Manipulation
0: None 1: Partial 2: Full

APPENDIX D

GRAPHESTHESIA AND STEREOGNOSIS FROM PEER

Graphethesia

The graphesthesia is the ability to identify the sensory stimuli on the skin. On the PEER, graphesthesia test requires the child to associate a shape that is drawn on his skin with one that he sees on a page from the Stimulus Booklet. The examiner places the page with four configurations (a circle, a straight line, a square, and a cross) in front of the child. The instruction is " **I am going to take this pencil and pretend to draw one of these things on your hand. While I do it you must keep your eyes closed. When I am finished you should open your eyes and then point to the thing on the page that is the same as the one I drew on your hand. Are you ready? Now close your eyes.**" The examiner then took the child's preferred hand and with a blunt pencil gently drew the shapes one at a time in the following sequence: line, cross (plus sign), circle, square. After each shape was drawn, the examiner says: "**now open your eyes and point to the one that I just drew**". A child at the school age should be expected to offer a correct response on at least three of the four items.

The children who identified three out of four shapes correctly were given a Level Three rating. Those with fewer than three should be considered on Level One.

Stereognosis

Stereognosis on the PEER tests the ability to perceive and recognize a shape without manipulating objects. The difference between the Graphesthesia and Stereognosis on the PEER is that the former ability needs to perceive the stimulus over time (the period it takes to draw a configuration on the skin). Stereognosis is the ability of simultaneous detection of the parts that constitute a whole three-dimensional configuration. The PEER Kit contains two sets of solid wooden shapes for this task. In each set are two rectangular solids and three cylinders of various sizes. One set of shapes is placed in front of the child on the table (Approximately on inch apart). The short, wide cylinder was placed on the extreme left; then the examiner said: "**Can you see these five things on the table? I have exactly the same things here in my hand. I will ask you to close your eyes, and then I will put one of these in your hand. I want you to hold it very tight and don't move it around. Then without looking in your hand, you can open your eyes and show which one on the table is just the same as the one you have in your hand. Are you ready?**" The examiners then put the objects in the child's hand and asked the child do not move his fingers. The child should maintain a fist-like grip with the object in his palm.

The children who identified three out of four objects correctly were given a Level Three rating. Those with fewer than three should be considered on Level One.

Scoring sheet for graphesthesia and stereognosis

Task	Below Levels	Level One	Level Two	Level Three	Refuse Task	Other Minor Neurological sign
Graphesthesia	☐	1-2 ☐	3 ☐	4 ☐		AGRAPH ☐☐☐
Matching	○ | ☐ +					
Stereognosis	☐	1-2 ☐	3 ☐	4 ☐		ASTEREO ☐☐ ☐
Matching						

APPENDIX E

SCORING SHEET FOR KAT AND WEST

Kinaesthetic Acuity Test (KAT)

Name:________________________________ Date: ____________________________

Trial	Correct	Error	Trial	Correct	Error
1			6		
2			7		
3			8		
4			9		
5			10		

Weinstein Enhanced Sensory Test (WEST)