DIFFERENCES IN PERCEPTUAL-MOTOR FUNCTIONING BETWEEN BLIND AND SIGHTED ADULTS: A NEUROPSYCHOLOGICAL PERSPECTIVE

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Joyce, Arthur Differences in perceptual-motor functioning between blind and sighted adults: A neuropsychological perspective. Doctor of Philosophy (Health Psychology and Behavioral Medicine), August 2002, 73 pp., 7 tables, 61 reference titles.

The purpose of the study was to explore perceptual-motor differences between blind and sighted adults from a neuropsychological perspective, and to analyze differences within the blind group. Perceptual-motor abilities were examined using the Comprehensive Vocational Evaluation System (CVES), a vocational rehabilitation and neuropsychological battery designed for use with blind populations. The data were processed using Analysis of Covariance. Results showed that sighted persons had better motor abilities, while persons with blindness were more skilled at haptic identification of shape and texture. Analysis within the blind group showed that texture identification skills are better when blindness occurs earlier in life and to the extent that the blindness is total. Later onset blindness and the retention of some functional vision may not lead to a refocusing of attentional states necessary to develop haptic images. New neural connections may develop in persons with congenital/total blindness, a hypothesis in line with recent neuroradiological findings that occipital lobe activation occurs when congenitally blind individuals engage in tactile processing tasks. One implication of the findings is that teaching individuals who retain some functional vision to read Braille is probably counterproductive. These individuals would be better served by learning to use a CCTV and large print books. Future researchers should examine blindness from a multivariate perspective, examining subsets of blind groups based on age at onset, visual status, and other pertinent variables. Other implications are discussed and recommendations for future research are provided.

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Boehm Test of Basic Concepts ®. The Psychological Corporation: 555 Academic Court, , San Antonio, Texas 78204-2498

Halstead-Reitan Neuropsychological Battery ®. Reitan Neuropsychology Laboratory: 2920 South 4th Ave., Tucson, AZ 85713-4819

McCarron-Dial System ®. McCarron-Dial Systems, Inc.: P.O. Box 45628, Dallas, TX 75245

Wechsler Adult Intelligence Scale – Revised ®. The Psychological Corporation, 19500 Bulverde Road, San Antonio, Texas 78259

Wechsler Intelligence Scale for Children-Revised ®. The Psychological Corporation, 19500 Bulverde Road, San Antonio, Texas 78259

CHAPTER 1

INTRODUCTION

The abilities of persons who are blind have been studied for centuries, with philosophers citing the performance of individuals who were blind to defend their theories about the development of ideas (Heller, 1991). It was not until the mid 20th century that researchers began studying the characteristics of visually impaired/blind (VI/B) populations to gain practical information about real world ability levels. Revesz (1950) and Worchel (1951) both conducted research on haptic (the ability to sense objects through active sensory manipulation of those objects) and spatial abilities of individuals who were blind and came to several conclusions that were highly influential at the time. For example, Revesz hypothesized that tactile sensation was inferior to vision, and that visual imagery was necessary to obtain information about shapes. This, for Revesz, left the congenitally blind at a distinct disadvantage for processing information.

Worchel (1951), like Revesz, found haptic and spatial deficits in congenitally blind individuals. These deficits, according to Worchel, were caused by reliance of the congenitally blind subjects on the haptic sense alone to assimilate spatial information. Worchel argued that the haptic sense was an inferior means of incorporating spatial information compared to the use of visual imagery. Both Revesz (1950) and Worchel (1951) concluded, based on their findings, that blind persons had inferior sensory processing and spatial abilities compared to the sighted population.

Other thinkers, most notably Piaget (Piaget & Inhelder, 1969) and Luria (1973), postulated that haptic and motor functions were important to the development of higher order cognitive abilities. Piaget suggested that the slower development of blind individuals could be understood as being caused by a lack of *experience* with the environment. Luria's theory surmised that complex multisensory integration was necessary for cognitive development and that interaction with the environment was necessary for this integration to occur. The implication of Luria's ideas was that cognitive development would be delayed if the necessary experiences were lacking. Juurmaa (1973) and others have argued that perceptual-motor differences between blind and sighted children are caused in part by slower (but not less efficient) development of the haptic sense in contrast to the visual sense. The implication of this argument is that differences may disappear as children grow into adults.

A strong link exists between perceptual and motor abilities in persons who are blind. For example, haptic perception involves manipulation of objects with the hand in such a way that an accurate mental representation of the object and its characteristics (e.g., size; shape; texture; configuration) can be formed. By this definition, motor functioning is inseparable from haptic perceptual ability; movement is involved in all haptic sensing. Therefore, perceptual and motor functioning should ideally be examined together.

Our current understanding of individuals who are blind is complicated by the fact that research has yielded equivocal findings. Some studies comparing the perceptual-motor functioning of VI/B and sighted subjects found advantages for the sighted groups; others found advantages for the VI/B groups; still others found no significant differences.

The topic has both theoretical and practical importance. From a theoretical standpoint, data could increase our understanding of compensatory brain mechanisms following loss of vision. For example, recent research using brain-imaging tools suggests that the occipital lobes of totally blind individuals are actively involved in the processing of information (Roder, Rosler, Hennighausen, & Nacker, 1996; Roder, Rosler, & Hennighausen, 1997; Rosler, Roder, Heil & Hennighausen, 1993). In practical terms, VI/B children lag behind sighted peers about one year in reading achievement (Rankin & Caton, 1976), oral reading skill and mathematics (Daugherty, 1977). Haptic discrimination skills may develop at a slower rate than comparable visual skills (Easton & Benzen, 1987; Juurmaa, 1973), so some differences between blind and sighted children may disappear in adults. New data comparing the perceptual motor functioning of VI/B and sighted adults could aid in the development of more effective interventions for the visually impaired population.

Overview of Research

Research on the perceptual-motor functioning of blind and sighted individuals has led to inconclusive findings. The most common research design compares a sighted control group with congenitally and adventitiously blind subjects. Those persons with congenital blindness (a minority of the blind population) have never seen and therefore, cannot use vision to assist them in perception. The performance of sighted groups compared to congenitally blind subjects may increase understanding of perceptual-motor abilities with and without the assistance of visual imagery.

An extensive review of the literature examining differences in perceptual motor functioning of VI/B and sighted individuals reveals mixed findings. Some studies have indicated an advantage in haptic ability for congenitally blind persons, specifically in recall of textures and in shape and tactile pattern recognition of unfamiliar objects (Heller, 1989a; Heller, 1989b; Heller & Kennedy, 1990). Many more studies have found haptic, spatial and motor advantages for the sighted population. Sighted groups performed better than congenitally blind groups in tactile pattern recognition of familiar objects (Shimizu, Saida, & Shimura, 1993); formation of a cognitive map (Fletcher, 1980); spatial form synthesis (Garry & Ascarelli, 1969; Groenveld & Jan, 1992); concept development (Caton, 1977); and fine and gross motor functioning (Daughtery & Moran, 1982).

A consideration of factors that may influence the perceptual-motor functioning of individuals with blindness may increase understanding of the differences between blind and sighted groups. The impact of developmental factors and life experiences on emerging perceptual-motor functions is important to consider. A review of Piaget’s developmental theories is useful in this regard, particularly from the perspective of the limited exploratory experience of blind children during the sensorimotor stage (Piaget & Inhelder, 1969). The limitations of experience secondary to blindness probably contribute to differences in sensory and motor processing between congenitally blind and sighted individuals.

A second important factor to consider involves differences in sensory-perceptual developmental processes between blind and sighted persons. Juurmaa (1973) contends that haptic differences between persons with blindness and sighted individuals disappear as the haptic sense develops over time. Developmental processes also appear to influence performance on mental rotation tasks and the use of mental imagery (Hollins, 1985).

Neuropsychological and neuroradiological findings are a third factor that may improve understanding of perceptual motor abilities of blind populations. In studies of individuals who are totally blind, occipital lobe activation is observed during somatosensory and auditory processing tasks. This occipital activation does not occur in sighted persons, suggesting that different processing mechanisms are at work in blind subjects (McCallum & Curry, 1993; Roder et al., 1997; Rosler et al., 1993). Finally, a consideration of research design issues may lead to a better understanding of the methodological problems found in studies using VI/B populations. A summary and justification for the importance of examining perceptual and motor functioning in blind and sighted adults is set forth.

Differences in Perceptual-Motor Functioning of Blind and Sighted Individuals

The following section reviews the evidence comparing performance of congenitally blind, adventitiously blind, and sighted individuals on perceptual-motor tasks. The goals of the literature review are to examine these sometimes contradictory findings, then to present some possible explanations for the results.

Advantages of blind over sighted persons

Contrary to myths that persons with blindness have enhanced perceptual abilities, few studies have shown an advantage in sensory functioning for VI/B individuals. The advantages that have been found are in the areas of texture recall and pattern recognition. Research has shown that blind persons have equal or superior texture recall compared to sighted subjects (Heller, 1982; Heller, 1989a; Walker & Moylan, 1994). In one study, blind and sighted individuals were given verbal descriptions of simple objects using color or texture descriptors (i.e., yellow square, rough triangle). After a distracter task, subjects felt a geometric shape cue and were asked to recall the color or texture of the objects. VI/B and sighted groups performed similarly when recalling the shape's color, but the VI/B group was significantly better at recalling surface texture (Walker & Moylan, 1994).

One explanation for the finding involves haptic imagery. Research has shown that haptic imagery gradually replaces visual imagery in adventitiously blind individuals (Hollins, 1985), while congenitally blind individuals appear to use haptic imagery exclusively. The superior texture recall ability of VI/B subjects emerged gradually based on length of time spent without sight, suggesting that enhanced haptic imagery in blind individuals may assist them in identifying textures (Walker & Moylan, 1994).

Persons with blindness also perform better than sighted persons in shape and pattern recognition tasks that have no recognizable visual component (Heller, 1989b; Heller & Kennedy, 1990). Heller (1989b) used raised line drawings to communicate picture information to groups of congenitally and adventitiously blind and sighted individuals. Both blind and sighted subjects correctly identified most raised line drawings of common objects. Interestingly, a clear advantage was found for the adventitiously blind subjects over both the congenitally blind and sighted groups. Heller attributed the performance of the adventitiously blind to having more experience with pictures than congenitally blind individuals and better tactile skills than sighted persons. Increased retention of shape information by persons with blindness was also found under conditions of high memory demand (Davidson, Barnes, and Mullen, 1974).

Advantages of sighted over blind persons

As early as 1950 (Revesz, 1950; Worchel, 1951), multiple researchers have found perceptual and motor advantages of sighted in comparison to blind populations. Performance of sighted groups was superior to that of VI/B groups on measures of pattern recognition, spatial synthesis, abstraction ability, mental rotation, recognition of optically familiar shapes, and motor strength and balance. These findings have influenced educational and vocational opportunities of persons who are blind, as well as influencing public policy decisions affecting blind populations. The following section will examine studies that found better performance of sighted persons in comparison to individuals who are blind.

Haptic recognition of familiar objects was examined in congenitally and adventitiously blind and sighted adults. Raised pins were used to simulate two-dimensional (1.5 mm) and three-dimensional (up to 10 mm) stimuli. The task involved haptic exploration of the raised pins and identification of familiar objects from this haptic information. Individuals who were congenitally blind had a significantly lower percentage of correct responses on both two-dimensional and three-dimensional stimuli than did the late blind and sighted subjects. Inferior pattern recognition in persons with congenitally blindness may be a result of decreased environmental experience (Shimizu, Saida, & Shimura, 1993).

Superior spatial abilities have been found in sighted children. Fletcher (1980) compared 34 blind and 34 sighted children matched for age and general intellectual ability as measured by teacher rating. The participants explored a room either freely or by predetermined route, and then were questioned regarding the placement of furniture in the room. Some questions could be answered by a route type serial learning whereas others required formation of a cognitive map. The sighted participants performed significantly better than the participants who were blind. Blind participants performed better on route type questions than on map questions; sighted participants performed equally well on either route or map questions (Fletcher, 1980). The results suggest that individuals with blindness tend to encode spatial information by learning a sequential series of steps rather than by formation of a cognitive map. However, Easton and Bentzer (1987) found that both blind and sighted subjects encode verbal route descriptions into cognitive maps to guide finger tracings.

Many children with blindness learn to verbalize spatial concepts without direct experience of those concepts. As language develops, blind children often apply rote learning to their understanding of spatial concepts, having had limited experiences from which to apply meaning (Hill & Hill, 1980). This lack of practical experience makes conceptualization of abstract symbols a much more challenging task for individuals who are blind (Rubin, 1964).

Groenveld and Jan (1992) found that totally blind persons had significantly lower performance on the Wechsler Intelligence Scale for Children ®-Revised (WISC-R ®, 1974) Similarities subtest, thought to measure abstract reasoning ability. The authors noted that totally blind individuals responded in a concrete manner with information they had overheard or memorized. Some researchers (Garry & Ascarelli, 1969; Groenveld & Jan, 1992) suggest that the abstract reasoning deficits of persons who are blind may be related to deficits in spatial skills. In contrast to sighted persons ability to use vision, individuals with blindness are dependent on the haptic sense to understand space. For example, many children who are blind understand the word “here” only in the temporal sense (i.e. right now), not in the spatial sense of here as opposed to there. Children with blindness also have difficulty understanding of the position of objects (i.e. upright, front, back, right, and left). These deficits in understanding spatial relationships may affect the development of abstract thinking ability.

Conceptual skills may develop more slowly in children who are blind than in sighted children. A test of concept development for sighted children, the Boehm Test of Basic Concepts ®, was adapted for use with blind children as The Tactile Test of Basic Concepts (Caton, 1977). The tactile version was used as a measure of concept development in children with blindness. Results comparing blind and sighted children found no overall differences in concept formation between grades K-2. Interestingly, children with blindness performed slightly better than their same-aged sighted peers in kindergarten, while sighted children performed better than blind peers in first and second grades. This finding suggests that sighted children may learn concepts more quickly than children with blindness (Caton, 1977).

Numerous differences in motor abilities have been found in studies comparing blind and sighted children and adolescents. Daugherty and Moran (1982) examined the motor abilities of visually impaired and sighted children aged 7 to 18, assessing gross and fine motor abilities using the Tactual Performance Test and Finger Oscillation Test, respectively. These tests are part of the Halstead-Reitan Neuropsychological Battery® (Reitan & Wolfson, 1993). Children and adolescents with visual impairments had significantly lower motor abilities than their sighted peers (Daugherty and Moran, 1982).

A group of German researchers (Troster, Hecker, & Brambring, 1994) examined the motor development of 10 children with congenital blindness in a longitudinal study of the first three years of life. The children received early intervention and their parents received counseling on effectively working with children who are blind. Results of the study found only slight developmental delays in posture and balance, compared to sighted peers. Larger delays in self-initiated locomotion were found. Since this group of children and their parents received special interventions, the results may underestimate motor impairments of children with blindness in the general population.

Another study of the motor development of VI/B children (Adelson & Fraiberg, 1994) found that children with blindness had lower muscle tone, poorer posture, and lower motor skills than sighted peers. Studies have also reported that blind children are less physically fit than their sighted peers (George, Patton, & Purdy, 1975; Seelye, 1983). For example, Seelye (1983) used a fitness test to compare levels of physical fitness, finding that 94% of children with normal vision, 84% of children with low vision, and only 46% of legally blind children passed the fitness test. Data also indicate that sighted children are physically stronger than children with blindness. For example, studies have found weakness of the upper body in children who were blind (Jarowski & Evans, 1981) and weak hip extensors compared to children with normal vision (Wyatt, 1997).

Influential Factors

The preceding review of the data showed equivocal results regarding differences in perceptual motor abilities of blind and sighted persons. Several factors probably contribute to the differences in processing and motor functioning. For one, experiential factors influence emerging perceptual motor abilities. Piaget’s developmental theory suggests that limited exploration of their environment may contribute to perceptual-motor deficits of VI/B individuals in comparison to sighted peers.

Second, complex sensory-perceptual abilities may develop at slower speeds in those who are deprived of the visual sense. Juurmaa (1973) has suggested that processing differences between blind and sighted persons disappear as the haptic sense develops over time. Research supporting his claim is reviewed.

A third factor that may explain perceptual-motor processing differences comes from neuroradiology. Neuroradiological findings show differences in cortical activation patterns between blind and sighted individuals during encoding and transforming of haptic images. Specifically, activation in the occipital lobes of blind but not sighted persons during tactile and auditory processing tasks has led some researchers to argue that different processing mechanisms are at work in blind individuals. Each of these factors is examined in the following section.

Environmental exploration.

Piaget, in his theory of cognitive development, stressed the importance of experience in the learning process. The sensorimotor stage in particular is related to learning through active exploration of the immediate environment. (Piaget & Inhelder, 1969). According to Piaget, children construct two types of knowledge from experience; physical knowledge occurs from observing the effect of one’s actions on objects, while logical-mathematical knowledge occurs when logical relationships between objects are formed. The visually impaired infant or toddler has more limited ability to explore his or her surroundings, thus is handicapped in the ability to form logical relationships based upon experience (Piaget & Inhelder, 1969). Several studies indicate that children with blindness pass through Piaget’s developmental stages much more slowly than do sighted children (Gottesman, 1973; Simpkins and Stevens, 1974; Tobin, 1972).

From the framework of Piaget’s sensorimotor stage, the motor development of individuals who are blind may be inferior to that of sighted persons for several reasons. Blind infants must rely on auditory cues to stimulate active movements. The ability to process auditory information does not occur until the eighth month, so delays in self-initiated locomotion occur. Second, fine motor tasks such as grasping are also negatively affected by a lack of vision. Third, parents are limited in their ability to interact with their blind infants or toddlers. Parents are often unsure where the infants’ attention is directed because of the limited reactions towards their caregivers of infants with blindness. The blind infants, in turn, are unsure of when their parents are attending to them, making it more difficult for the parents to “react contingently” (Troster, Hecker, & Brambring, p. 63, 1994). Thus, infants who are blind receive little reinforcement for exploratory behaviors. Finally, parents of VI/B children frequently overprotect them due to fears of injury.

As children who are blind grow older, they may explore less than their sighted peers due to anxiety about self-initiated locomotion. Difficulty evaluating the safety of the environment leads many blind children to avoid exploring their surroundings. This avoidance of self-initiated locomotion makes it difficult for children with blindness to decrease their anxiety. As Jones (1975) has argued, this deprives VI/B children of the movement necessary to obtain an understanding of space through the haptic sense. Subsequently, the lack of motor experience makes control of body posture and balance more difficult for individuals with blindness.

Possible effects of this “environmental deprivation” include deficiencies in academic performance. Studies indicate that achievement test score differences exist between visually impaired and sighted children. Academically, blind children tend to lag behind sighted children one to one and one-half years in reading achievement (Rankin and Caton, 1976). For example, Daugherty (1977) found that visually impaired print readers from grades 1 through 12 lagged two years behind their sighted peers in oral reading skill and 0.8 years behind in mathematics. The educational variance between blind and sighted children is probably related in part to differences in haptic functioning; an exploration of the haptic processing of blind and sighted adults may lead to interventions that will assist blind persons in the development of their perceptual-motor abilities.

Developmental variance.

The development of sensorimotor abilities may occur more slowly in persons with blindness. Juurmaa (1973) hypothesized that some of the variance in perceptual-motor functioning between blind and sighted persons could be explained by the relatively slower development of haptic abilities in persons with blindness. He reasoned that haptic ability develops more slowly than visual ability; this gave sighted persons an advantage in comparisons between younger blind and sighted subjects. Juurmaa contended that as individuals age, the haptic frame of reference matures, and differences between blind and sighted individuals disappear (Juurmaa, 1973).

Support for this hypothesis was found in research examining the ways in which congenitally blind and sighted subjects remember route descriptions. A study by Easton & Bentzen (1987) found that both blind and sighted subjects encode verbal route descriptions into cognitive maps to guide finger tracing. This finding is in contrast to a long-standing belief that the imagery abilities of individuals with blindness are deficient or underdeveloped in comparison to sighted individuals (Pick, 1974; Warren, 1970; Warren, 1977). Other studies show that the amount of time since onset of blindness influences visual imagery (Hollins, 1985) and that haptic mental rotation ability is more consistent for adult blind persons in comparison to adult sighted persons (Marmor & Zaback, 1976).

Other research supporting the possibility that perceptual abilities of VI/B develop more slowly than sighted persons includes Hollins' (1985) finding that the use of mental imagery changes based on length of time since blindness. In the study, six blind and four sighted subjects were given two tests of mental imagery, one test using pictorial and the other test using non-pictorial imagery. Results showed that the longer a subject had been blind, the less he or she used pictorial imagery (Hollins, 1985). In persons with adventitious blindness, haptic imagery gradually replaced visual imagery based on length of time since the loss of vision occurred. Persons with congenital blindness appear to use haptic imagery exclusively.

A study by Marmor and Zaback (1976) found differences in mental rotation ability between sighted, adventitiously and congenitally blind subjects. Haptic mental rotation is the ability to formulate a mental image of a design that has been haptically examined, and to manipulate that image in a measurable way. The sighted group had the quickest mental rotation ability, followed by the adventitiously blind group, then the congenitally blind group (Marmor & Zaback, 1976).

Neuroradiological findings.

Differences in perceptual-motor abilities of blind and sighted individuals may be related to different processing pathways in the brain. Researchers have examined processing differences in persons with blindness using brain-imaging tools such as fMRI (functional magnetic resonance imaging), PET (positron emission tomography), and SPECT (single photon emission computed tomography). The findings reveal increased blood flow in the occipital cortex of blind persons during tactile stimulation and Braille reading (Sadato et al., 1996; Uhl, Franzen, Podreka, Steiner, & Deecke, 1993).

Slow event-related potentials (ERPs) of the electroencephalogram are particularly suited to the study of brain changes during processing episodes because ERPs have a faster time resolution than fMRI, PET, or SPECT. ERPs show brain response to discrete stimuli better than other radiological methods. Slow ERPs occur during specific processing episodes in response to a discrete stimulus and last for milliseconds to a few seconds. Moreover, the difficulty of a task is expressed in the amplitude of the negative slow ERP wave; i.e. More difficult tasks show a higher amplitude. The maximum slow ERPs occur over cortical areas that are believed to be essential for processing that particular type of information (McCallum & Curry, 1993). Rosler and Roder examined ERPs in persons with blindness in several studies, which are reviewed below (Roder et al., 1996; Roder et al., 1997; Rosler et al., 1993).

Rosler et al. (1993) examined slow ERPs during a haptic mental rotation task in congenitally and adventitiously blind and sighted adult participants. Subjects initially explored an alpha-numeric tactile stimulus in upright display, then explored the same stimulus in upright or rotated placement. Subjects had to decide if the two stimuli had the same or different rotation. During the task, subjects who were blind showed a significant negative slow ERP shift over the occipital cortex compared to sighted subjects. In addition, the shift increased as the angularity of the two stimuli increased, suggesting that processing effort was highly correlated with occipital lobe activation in the blind participants. The occipital lobe activation did not occur in sighted subjects.

Roder et al. (1997) monitored slow event-related brain potentials in sighted and congenitally blind young adults during processing of haptic images. Both sighted and blind subjects had slow negative shifts over the frontal cortex during initial processing, over the left parietal cortex during encoding of the image from the contra-lateral hand, and over the central parietal cortex during transformation of the image. Differences in haptic processing were found in the occipital lobe, where slow waves were observed only in subjects who were blind. The involvement of the occipital lobe during haptic processing in persons with blindness may indicate the occipital areas are involved in specific non-visual processing. Although significant slow ERP differences were found, no actual differences in performance of the blind and sighted groups were noted.

Two lines of thought have developed to explain these findings. One argument proposes that occipital activation in persons with blindness provides evidence of occipital lobe involvement in specific information processing. Proponents of this argument site research showing enhanced amplitude in the occipital cortex of blind persons during processing of somatosensory tasks (Rosler et al, 1993).

However, occipital activation in subjects with blindness also occurs during processing of non-tactile sensory tasks (i.e. auditory tasks). Roder et al. (1996) examined slow ERPs during processing of simple auditory and somatosensory discrimination tasks and found negative slow ERPs in subjects who were blind regardless of sensory stimulus, suggesting that occipital activation in persons with blindness is not modality specific.

The second explanation of these findings, proposed by Roder et al. (1996), suggests that occipital activation may be the result of decreased efficiency of inhibitory neurons in the occipital cortex. Roder cites several lines of evidence to support this view. First, the occipital activation is not modality specific (Alho, Kujala, Paavilainen, Summala, & Naatanen, 1993; Roder et al, 1996). The occipital lobe seems to activate whenever non-specific attention demanding processing occurs in other sensory modalities (i.e. somatosensory, auditory). Second, inhibitory neurons may not function as effectively in the occipital cortices of blind individuals. Intracortical inhibition is normally mediated by GABA-nergic interneurons. However, Jones (1993) found a reduction of GABA in area 17 of visually deprived primates, suggesting decreased efficiency of inhibitory neurons in the visual cortex of individuals with blindness. A third point supporting the "decreased efficiency" view involves ERP measurement. A negative slow ERP shift during a task indicates activation of excitatory neurons, while a positive slow ERP change is correlated with activation of inhibitory neurons. Subjects with blindness clearly have more negative slow ERP shift in the occipital lobes during haptic and auditory processing tasks, suggesting a higher level of cortical activation in these areas. However, *positive* slow ERP shifts (which indicate activation of inhibitory neurons) are significantly *lower* in the occipital cortices of blind individuals compared to sighted (Roder et al., 1996). The finding suggests that deactivation/inhibition of cortical cells in the occipital lobes is less pronounced in blind persons than in sighted.

Whether occipital activation in the blind during sensory processing tasks is the result of compensatory processing of somatosensory and auditory information or, alternatively, is due to decreased efficiency of inhibitory neurons in occipital cortices is an unanswered question requiring further research. The current study should provide a better understanding of how these differences affect the processing abilities of blind and sighted persons.

Research Design Issues

Research design in studies of persons with blindness has several inherent challenges. In order to understand these challenges, an early influential study (Worchel, 1951) is examined, then general research design problems are outlined. Worchel (1951) was interested in understanding the roles that the visual and haptic senses played in form discrimination. His subjects included 33 congenitally and adventitiously totally blind persons matched by age and sex to a blindfolded sighted control group. Subjects ranged in age from 8 to 21.Worchel gave subjects a series of blocks carved into simple geometric shapes. In the first experiment, the blocks were presented to one hand. In the second experiment, the blocks were larger and subjects were allowed to use both hands to explore. The ability of subjects to identify the blocks was tested by asking subjects to draw and verbally describe each block immediately after each stimulus presentation. The sighted group performed better than the blind group. In addition, adventitiously blind subjects had more accurate drawings and descriptions than the congenitally blind subjects. Worchel interpreted the inferior performance of subjects that were congenitally blind as evidence of spatial deficits in blind individuals. These findings had important implications for the education of individuals with blindness, but there were flaws in Worchel's methodology.

First, his population had a mean age of 14, and many of his subjects were much younger. Recent data suggest that haptic ability develops more slowly in VI/B individuals (Easton and Bentzen, 1987; Juurmaa, 1973), so generalizing findings from child and adolescent subjects to adults is probably not valid. Second, Worchel had subjects draw with pencil and paper, then he drew conclusions about their spatial abilities from the results. Children with blindness have limited experience with pencil and paper, so their inferior performance compared to sighted children may have been based on lack of experience with drawing, not inferior spatial ability. Less biased tests have been developed that use non-visual means to assess spatial ability in both blind and sighted persons (e.g. The Cognitive Test for the Blind; Dial, Mezger, Gray, & Chan, 1988).

The current study was designed to correct several research design problems found in past studies. Many studies have inadequate power to find real differences due to their small number of subjects. These subjects usually were further divided into congenitally and adventitiously blind groups. Due to the resulting lack of power, important differences between blind and sighted persons may have gone undetected. The current study was conducted with a database of 471 VI/B individuals, which should provide the necessary statistical power to detect differences between groups.

A second weakness of some studies was neglecting to correct for possible confounding variables such as age and gender. Correction by age is necessary to account for haptic developmental differences as well as the decline of motor skills in later years of the lifespan. Motor tests should also be corrected for gender to account for strength differences between males and females. The MDS incorporates norms that correct for age and gender, eliminating the need for matched samples. Other potential confounds include age of onset of blindness and level of visual impairment. The current study will examine these variables and account for their influence as necessary.

Typically, studies comparing two groups of subjects match the groups by intellectual ability. However, this variable is confounded in comparisons of blind and sighted groups for several reasons. For example, the educational backgrounds of blind and sighted persons are vastly different and not easily comparable. Reading is a more difficult and less rewarding task for most persons who are blind than for sighted individuals. For visually impaired persons, reading may involve the use of a print enlarger; for totally blind persons, Braille reading is required. In contrast, the experience of reading for sighted persons is often highly reinforcing. Additionally, the sensorimotor development of children with blindness is adversely affected by limited exploration of their environment (Piaget & Inhelder, 1969), which can affect aspects of intellectual development. For example, persons with blindness frequently obtain lower scores on several of the Wechsler Adult Intelligence Scale ® - Revised (WAIS-R ®) subtests in spite of actual ability to solve verbal problems (Kaskel, 1994). Since cognitive and perceptual-motor functions correlate moderately in group data, matching groups on the basis of IQ may actually bias the results in an unintended direction. For these reasons, it is inappropriate to match blind and sighted groups based on measures of intellectual functioning when comparing perceptual-motor functions between the groups.

Many studies of persons with blindness use assessment instruments that were not normed on blind populations. A classic example of this problem was Worchel’s (1951) use of pencil and paper drawings to evaluate the spatial abilities of blind persons. In a more recent example, Daughtery and Moran (1982) studied the motor abilities of blind and sighted persons using motor tests that were not normed on a blind population.

The goal of the current study is to explore differences in perceptual-motor functioning between normal groups of blind and sighted adults. The sample of VI/B individuals in this study is considered to be representative of the normal blind population for two reasons. First, the large number of subjects in this sample (N = 471) makes it much more likely that the sample is representative of the blind population. Second, the exclusion of subjects with a variety of disabling conditions increases the likelihood of a normal sample. The current study employed a battery of tests designed for use with the VI/B persons. The Comprehensive Vocational Evaluation System ® (CVES ®; Dial, Chan, et al., 1991) incorporates cognitive, sensory, and motor tests that have good to excellent reliability for use with VI/B groups.

Summary and Hypotheses

No clear pattern of differences between blind and sighted persons emerges from the current literature. Data comparing perceptual and motor functioning demonstrates that blind persons have an advantage in analysis of texture and optically unfamiliar shape; in contrast, sighted persons perform better on tests of pattern recognition, spatial synthesis, abstraction ability, mental rotation, and the identification of optically familiar shapes. Perceptual-motor abilities may develop more slowly in blind children, and differences found at younger ages may narrow as individuals with visual impairments develop their haptic sense and continue to gain experience in their environment. The haptic and motor abilities of blind adults are, to a large extent, simply unknown. The goal of this study was to better understand perceptual-motor differences between blind and sighted adults. The statistical technique of analysis of covariance (ANCOVA) was used to meet this goal. The study also examined differences within the blind group, based on age at onset of blindness and level of visual impairment. Dependent variables for all of the analyses were obtained from the Comprehensive Vocational Evaluation System (Dial, Chan, et al., 1991), a neuropsychological battery designed for use with blind populations.

CHAPTER 2

METHOD

Subjects

Data for subjects who were blind were obtained from archival records of 471 VI/B consumers of the Texas Commission for the Blind (TCB). These consumers received a standard vocational evaluation that included the Comprehensive Vocational Evaluation System (CVES), a test battery designed specifically for blind individuals. Subject data were obtained from raw data files with identifying information removed. Table 2 (Appendix C) provides the breakdown of etiology of blindness.

The VI/B subjects consisted of 274 males (58.2%) and 197 females (41.8%), with ages ranging from 18 to 65 (M = 31.5, SD = 12.7). The subjects were distributed by race as follows: 232 (49.3%) Caucasian, 85 (18.0%) African American, 146 (31.0%) Hispanic, and 8 (1.7%) other. A right hand preference was reported by 86.6 % of the VI/B subjects, while 13.4 % reported a left hand preference.

Two groups of normal sighted subjects served as a comparison group to the visually impaired/blind group. One group of sighted subjects was obtained from employees of the Texas Commission for the Blind in four Texas cities (Austin, San Antonio, Dallas, and Ft. Worth). TCB employees were initially contacted by email and offered the opportunity to participate in a research study. In return for their participation, TCB employees received a certificate for 3 ½ hours of disability training. The certificate was used to meet part of their job requirements for disability training. A second group of sighted subjects was obtained from a group of students who were taking an undergraduate assessment class in the Rehabilitation Department at the University of North Texas. These students received extra credit in their assessment class in return for their voluntary participation in the study. None of the subjects received monetary compensation. A copy of the informed consent letter can be found in Appendix A.

The sighted subjects consisted of 15 males (34.9%) and 28 females (65.1%), with ages ranging from 19 to 65 (M = 42.8, SD = 11.5). The distribution by race was as follows: 33 (76.7%) Caucasian, 4 (9.3%) African American, and 6 (13.9%) Hispanic. A right hand preference was reported by 93.0 % of the sighted subjects, while 7.0 % reported a left hand preference.

Subjects in both the VI/B group and the sighted group were selected based on the following criteria:

1. The Comprehensive Vocational Evaluation System was administered to all subjects.
2. All subjects were between the ages of 18-65.
3. Subjects with the following secondary disabilities were excluded: brain damage; seizure disorder; mental retardation; cerebral palsy; learning disorder; history of substance abuse; renal failure, peripheral neuropathy, and hearing impairment.

In addition, subjects who were visually impaired/blind (VI/B) were selected based on a corrected visual acuity of 20/70 or less. Sighted subjects were free of visual impairment (corrected visual acuity better than 20/70).

Instruments

Neuropsychological data was obtained using the Comprehensive Vocational Evaluation System (CVES; Dial, Chan, et al., 1991). The CVES is a neuropsychological system that assesses behavior in three factors: verbal-spatial-cognitive; sensory-motor; and emotional-coping. The CVES was adapted for use with the blind from the McCarron-Dial System ® (MDS ®), which was originally developed for vocational assessment (Blackwell, Dial, Chan, & McCollum, 1985; Packard, Hencke, & McCollum, 1976). The MDS was later utilized as a neuropsychological assessment battery and successfully differentiated brain damaged from non-brain damaged groups at 93% accuracy (Dial, Chan, and Norton, 1990), a level comparable to that of the Halstead-Reitan and Luria-Nebraska assessment batteries (Goldstein & Shelly, 1984; Kane, Sweet, Golden, Parsons, & Moses, 1981). The CVES was normed on a sample of 1,100 subjects that were visually impaired. In a subset of that group containing 300 brain damaged and 300 non-brain damaged subjects, the CVES correctly classified 85% of the subjects (Dial, Chan, et al., 1991). Data for the current study was obtained from those parts of the CVES battery that pertained to perceptual motor skills, including selected subtests of the Cognitive Test for the Blind (CTB); the Haptic Sensory Discrimination Test (HSDT); and the McCarron Assessment of Neuromuscular Development – Blind Adaptation (MAND-BA). The sighted subjects were also given the Wechsler Adult Intelligence Scale – Revised for a separate study.

The Cognitive Test for the Blind.

The Cognitive Test for the Blind (Dial, Mezger, Gray, Chan, & Massey, 1991) is an intellectual assessment designed for use with VI/B populations. The CTB was normed on individuals who were visually impaired or blind. The current study utilized four measures from the CTB: the Verbal Factor score was used to obtain an estimate of the overall verbal ability of the subjects; the Pattern Recall and Spatial Analysis subtests were used to obtain estimates of specific spatial abilities of VI/B and sighted persons; finally, the Spatial Factor score was examined to obtain estimates of overall spatial abilities. Please see Appendix B for a detailed description of the CTB variables used in the analysis.

The Haptic Sensory Discrimination Test.

The primary sensory component of the CVES is the Haptic Sensory Discrimination Test (McCarron & Horn, 1979). Haptic ability involves manipulation of objects with the hand in such a way that an accurate mental representation of the object and its characteristics can be formed. The HSDT measures haptic memory and the ability to discriminate shapes, sizes, textures, and spatial configurations. An HSDT total standard score is obtained, along with standard scores for the right and left sides of the body. See Appendix B for detailed information on the HSDT.

The McCarron Assessment of Neuromuscular Development – Blind Adaptation.

The McCarron Assessment of Neuromuscular Development – Blind Adaptation (MAND-BA; McCarron & Dial, 1986) consists of five fine and five gross motor tests. The tests are combined to form an overall motor factor score, fine and gross motor index scores, and four factor scores, which include Kinesthetic Integration (KI), Bimanual Dexterity (BD), Muscle Power (MP), and Persistent Control (PC). These tests tap into a variety of neuromuscular functions, including body strength, balance, coordination, and speed and direction of movement. The MAND-BA has shown excellent test-retest reliability ($\underline{r} = .99$; McCarron & Dial, 1986). See Appendix B for information on MAND subtests and Factor Scores.

Procedure

The testing procedure for sighted subjects was essentially the same as the VI/B subjects experienced in the clinical office. Initially subjects read and signed an informed consent form (Appendix A). Subjects were then provided with a brief description of the purpose of the study. They were also informed of the intended use of their test scores as part of a sighted group to be compared to groups of VI/B individuals. The subjects were told that testing would include assessment of perceptual and motor skills as well as problem solving abilities. Subjects were also informed prior to the initiation of testing of the need to wear a blindfold during some of the testing. Rationale for the blindfold was provided (e.g. to simulate the experience of blind individuals during testing). Sighted subjects were blindfolded during administration of the CTB, HSDT, and verbal WAIS-R subtests. Well-trained doctoral students in psychology collected and scored the sighted group data. Demographic data were obtained at initiation of testing, including information about gender, ethnicity, age, hand preference, occupation, and educational level.

Data analysis

The purpose of the current study was to investigate perceptual-motor differences that may exist between VI/B and sighted populations. CVES data for both the blind and sighted groups were transformed to scaled or standard scores using the means and standard deviations derived from the blind group's raw scores. Demographic data were then analyzed to determine if the blind and sighted groups differed on any of these variables. Differences in age or years of education were examined using *t*- tests. Chi-square analyses were used to examine differences in gender, race, and handedness.

The statistical technique of analysis of covariance (ANCOVA) was used to compare the perceptual motor abilities of persons with blindness and sighted individuals. All analyses were performed using the Statistica Version 5.1 (1996) software program. The first analysis focused on investigating differences between blind and sighted groups. The goal of the second analysis was to determine if differences exist within the VI/B group based on level of visual impairment. Three levels of visual impairment were examined: Visually Impairment (visual acuity from 20/70 to 20/200); Legal Blindness (visual acuity of 20/200 or less; and Total Blindness (no vision or can discern only light and dark). Classification of level of visual impairment had been made at the time of assessment based on review of records and communication with the referral source. The third analysis examined the influence that age at onset of blindness had on perceptual motor abilities. Age of Onset was examined using four operationally defined levels: Congenital (0-1 years); Early (2-5 years); School Age (6-18 years); and Adult (over 18). Dependent variables for all analyses were obtained from the CVES battery, and included CTB, HSDT, and MAND variables that contained a perceptual motor component. See Table 1 (Appendix C) for a list of the CVES variables included in the analyses. Based on analysis of demographic data, Education was used as a covariate for the analysis of blind versus sighted groups. Age of onset of blindness served as a covariate for the analysis of the level of Visual Impairment. Finally, level of Visual Impairment served as the covariate for the analysis of Age of Onset of Visual Impairment.

CHAPTER 3

RESULTS

Comparisons of Blind and Sighted Persons

were used to evaluate Differences in age and education between the blind and sighted group were analyzed using *t*- tests, while Chi-square analyses were used to analyze differences in gender, ethnicity, and handedness. Demographic information is presented in Tables 3 and 4 (Appendix C). As seen in Table 3, significant differences were observed for age, $\underline{t}$ (514) = 6.20, $\underline{p} < .001$, with the blind group ($\underline{M} = 30.5$) lower than the sighted group ($\underline{M} = 42.7$). Differences were also found for years of education $\underline{t}$ (401) = 15.09, $\underline{p} < .001$, with the blind group ($\underline{M} = 12.1$) significantly lower than the sighted group ($\underline{M} = 15.8$). As shown in Table 4, significant differences were observed for gender, with more males in the VI/B group and more females in the sighted group, χ^2 (1, $\underline{N} = 514$) = 8.68, $\underline{p} < .01$. Differences were also observed for race, with the blind group containing a lower percentage of Caucasians and a greater percentage of African Americans and Hispanics than the sighted group, χ^2 (3, $\underline{N} = 514$) = 12.11, $\underline{p} < .01$ (See Table 4). Non-significant differences were observed for handedness χ^2 (1, $\underline{N} = 514$) = 1.55, $\underline{p} > .05$. Age, Gender, and Ethnicity differences were controlled for by standard norming procedures of the CTB, HSDT, and MAND. Analysis of covariance (ANCOVA; Covariate: Education) was used to control for differences in education. Post-hoc analysis of significant variables was performed using Tukey's Honestly Significant Difference (HSD).

The means, standard deviation, and ANCOVAs for all CVES components are presented in Table 5 (Appendix D). Results for the CTB indicated no differences in verbal intellectual ability between the two groups, once the effects of education were covaried. Therefore, differences in perceptual motor abilities could not be due to differences in verbal intelligence. No differences in spatial ability were found between the blind and sighted groups.

Sensory composite scores were not different. However, differences were found in specific sensory discrimination abilities. The Shape and Configuration scaled scores were higher in the blind than in the sighted group, with both tests reaching a significance level of $\underline{p} < .05$. The Texture scaled score difference approached significance, $\underline{p} = .06$, with the sighted group having higher scores than the blind group.

Sighted adults had significantly better motor abilities than adults with blindness. Several MAND subtests scores were significantly higher for sighted persons, including Beads in a Box, Beads on a Rod, Nut and Bolt, Finger Nose Finger, and Heel-Toe Walk, all at $\underline{p} < .001$ significance level. Additionally, the Standing On One Foot subtest was significant at the $\underline{p} < .01$ level, while the Hand Strength and Jumping subtests were significant at the $\underline{p} < .05$ level. Only the Rod Slide subtest showed a significant advantage for persons with blindness over sighted persons, $\underline{p} < .001$.

Six of the seven MAND factor scores also revealed significant differences between blind and sighted groups, with the sighted group having better scores in each case. The Total Motor Score, Gross Motor Index, Kinesthetic Integration and Bimanual Dexterity were all significant at $\underline{p} < .001$. The Fine Motor Index showed a significance level of $\underline{p} < .01$, while the Muscle Power score was significant at $\underline{p} < .05$.

Comparisons within the Blind Group

Visual Status.

The second analysis used Visual Status as the Independent Variable, with three levels: Visual Impairment (VI), Legal Blindness (LB), and Total Blindness (TB). ANCOVAs were used to evaluate age, education, and age at onset differences between the three visual status groups. Differences were observed for age, F (2, 468) = 6.44, p < .01 and for age at onset of visual impairment, F (2, 406) = 14.66, p < .001. No differences were observed between the groups based on years of education, F (2, 468) = .52, p > .05. Chi-square was used to analyze differences in gender and ethnicity. No differences were found for gender, χ^2 (2, N = 471) = .98, p > .05, or ethnicity χ^2 (6, N = 471) = 3.14, p > .05.

Differences in age were controlled by the previous norming procedures of the CTB, HSDT, and MAND. The possible influence of age at onset of visual impairment was accounted for by making age at onset a covariate in the subsequent analysis. The means, standard deviations, and ANCOVA (Covariate: Age at onset) for all CVES components are presented in Table 6 (Appendix D). Tukey's HSD was used for post hoc analysis whenever overall significant differences were found.

No differences in verbal ability were found among the groups. Likewise, spatial abilities were not different. Differences were found in the ability to discriminate shape and texture. The Shape scaled score was different, F (2,414) = 3.56, p < .05, with post-hoc analysis revealing that the TB group (M = 11.5) had better shape discrimination than the VI group (M = 10.0), p < .05. Texture discrimination was also different, F (3, 509) =

4.15, $p < .01$, with post-hoc tests revealing better texture identification skills in the TB group ($M = 11.6$) than in the VI ($M = 9.8$) and LB groups ($M = 9.9$), $p < .01$.

HSDT standard scores include information about overall sensory discrimination ability and right and left side of the body scores. Results showed significant differences for the Total HSDT score, F (2, 414) = 3.97, $p < .05$, and the Left HSDT score, F (2, 414) = 3.42, $p < .05$. Post-hoc analysis of the Total HSDT score revealed that the TB group ($M = 105.0$) had better overall tactile discrimination than the VI group ($M = 97.6$), $p < .05$. Post-hoc of the Left side HSDT score showed a clear advantage for the TB group ($M = 105.2$) compared to the VI group ($M = 97.8$), $p < .05$.

Somewhat surprisingly, the motor abilities were not significantly different between the groups, with the exception of a test of lower body strength. Scores on the Jumping subtest of the MAND were different, F (2,414) = 4.29, $p < .05$, with post-hoc tests revealing that the VI ($M = 101.1$) and LB ($M = 100.5$) groups had more lower body strength than the TB group ($M = 92.6$), $p < .05$. No other differences were noted on MAND subtests or factor scores. See Table 6 (Appendix D) for the means, standard deviations, and ANCOVAs for the visual status comparisons.

Comparisons Based on Age at Onset of Blindness.

The third main analysis focused on understanding the effects of age at onset of blindness on perceptual motor abilities. Four age levels were specified, including Congenital Blindness (CB: ages zero to one); Early Blindness (EB: ages two to five); School Age Blindness (SB: ages six to 18); and Adult Blindness (AB: over 18). An ANOVA was used to evaluate possible differences in educational level. The differences between the groups were not significant, F (3, 405) = 1.59, $p > .05$. Chi-square was used to evaluate differences in gender, race, and visual status. No differences were found for gender, χ^2 (3, N = 409) = .73, $p > .05$, or ethnicity χ^2 (9, N = 409) = 8.02, $p > .05$. A significant difference was found for visual status, χ^2 (6, N = 409) = 50.01, $p < .001$. An ANCOVA was used to examine differences between the groups, with visual status as the covariate. Table 7 (Appendix D) shows the means, standard deviations, and ANCOVAs for this analysis. Tukey's HSD was utilized whenever post-hoc analysis was necessary.

CTB verbal and spatial abilities were not significantly different between the groups. Haptic sensory discrimination abilities were different in the areas of shape and texture. For shape, F (3,404) = 2.84, $p < .05$, no significant post-hoc differences were found. For texture, F (3,404) = 10.85, $p < .001$, post-hoc revealed that the AB group (M = 8.6) had less ability to identify textures than the CB (M = 10.4), $p < .001$, and EB (M = 10.1), $p < .05$ groups.

Several differences in motor abilities were noted, all of which were small in magnitude. On the MAND, the groups differed on the Beads on a Rod, Rod Slide, and HTW subtests. For Beads on a Rod, F (3,404) = 4.34, $p < .01$, post-hoc analysis indicated that the SB group (M = 106.1) performed better than the EB group (M = 94.4), $p < .01$. For the Rod Slide subtest, F (3,404) = 2.78, $p < .05$, post-hoc revealed a significant advantage for the AB group (M = 104.2) over the EB group (M = 93.8), $p < .05$. The HTW subtest also showed a significant effect, F (3,404) = 2.76, $p < .05$, but post-hoc analysis did not show significant differences between the groups. The only MAND factor score that was different between the groups was Persistent Control, F (3,404) = 2.95, $p < .05$. Post-hoc analysis did not indicate significant differences between the groups.

CHAPTER 4

DISCUSSION

The following section provides a discussion of the findings, with emphasis on how the results can be applied to the real world problems of persons with blindness. Limitations of the study and recommendations for future research are also presented. In general, tactile perceptual abilities of adults with blindness are at least equal to those of sighted adults. In contrast, the motor abilities of VI/B adults are inferior to those of sighted persons.

Perceptual Abilities

No differences were found in the spatial abilities of blind and sighted adults, supporting Juurmaa's (1973) hypothesis that the slow improvement of haptic ability in persons with blindness may, over time, lead to concurrent improvements in spatial ability. This finding contradicts earlier research that found better spatial abilities in sighted children than in blind children (Fletcher, 1980). Equal spatial abilities in blind and sighted adults suggests important implications for the education of persons with blindness, especially if future research links the development of haptic imagery with improvements in spatial functioning.

Haptic sensory discrimination is a particularly important skill for blind individuals. Sensory discrimination correlates with job success, while texture identification is necessary for Braille reading. (McCarron & Dial, 1986). The current study found that adults with blindness were better able to discriminate shape and configuration than sighted adults. These findings are similar to those found in earlier research (Davidson et al., 1974; Heller, 1989b; Heller & Kennedy, 1990). The blind group's advantage may be related to kinesthetic integration; moving their fingers around objects and developing a haptic image of the objects may help persons with blindness to form an understanding of simple and complex spatial configurations.

Analysis within the blind subgroups showed that persons who became blind earlier in life had better shape and texture abilities than persons who became blind as adults (c.f. ttt & Moylan, 1994). However, interaction with level of visual impairment is found in that persons who are totally blind have better shape and texture identification ability than those who retain some vision. Texture identification skills are actually better when blindness occurs earlier in life and to the extent that the blindness is total. To the extent that VI/B persons have more residual vision, regardless of age of onset, they tend to have less ability to identify textures. One would assume the totally blind congenital group would have better haptic abilities than even sighted persons, but this could not be analyzed directly because not enough totally blind congenital cases were available. From this result, the argument can be made that haptic discrimination ability improves as haptic imagery replaces visual imagery.

Later onset of blindness and the preservation of some residual vision were associated with decreased ability to identify textures. The finding suggests that only with congenital blindness is rewiring of brain mechanisms likely to occur. Later onset blindness does not lead to the refocusing of attentional states necessary for the development of tactile imagery. The use of vision enables sighted persons to see textures and make strong associations with specific surfaces. Individuals who are VI/B and retain some vision may have difficulty making the shift from dependence on visual analysis to dependence on haptic analysis for texture identification. The findings suggest some interesting hypotheses that could explain the occipital activation of individuals with blindness that occurs during processing of non-visual tasks.

The occipital lobes of totally blind persons are activated during tactile processing tasks (Roder et al., 1996; Roder et al., 1997; Rosler et al., 1993). Whether this activation is functional or generalized is unclear. The current study provides evidence that the occipital activation may be functional in nature. The blind group as a whole had better ability to discriminate simple and complex shapes than the sighted group. More importantly, the totally blind group had better ability to discriminate simple shapes and textures than the visually impaired and legally blind groups. Totally blind individuals may make use of the occipital lobes as they develop new neural connections to process tactile information and develop haptic images. It makes intuitive sense that occipital activation would occur during the development of images, whether visual or haptic. This possibility has profound implications for the education and training of individuals who are blind. Future research combining brain imaging tools and neuropsychological tests may provide a clearer understanding of this topic.

Motor abilities

This study found that the motor skills of sighted adults, almost without exception, were much better than the motor skills of adults who are blind. These findings are similar to previous research showing that children with blindness are less physically fit than sighted peers, have deficits in posture and balance, delays in self-initiated locomotion, and are physically weaker than sighted peers (George et al., 1975; Jarowski & Evans, 1981; Seelye, 1983; Troster et al., 1994; Wyatt, 1997). Unlike the spatial abilities of blind adults, it appears that the motor functioning of persons with blindness does not improve with time.

There are several possible explanations for the motor deficits experienced by adults with blindness. Persons with blindness may fear participation in a variety of physical activities due to concerns of injury. This could lead to decreased muscle strength beginning in early childhood and continuing on into adulthood. Interestingly, no differences in strength were found based on age at onset of blindness. In contrast, the amount of residual vision appears to affect strength; persons who had some residual visual were stronger than persons who were totally blind. Residual vision may influence an individual's willingness to engage in physical activity.

Deficits in balance and coordination were found in individuals with blindness. Visual cues help sighted persons to maintain balance, while VI/B persons must rely on proprioceptive and kinesthetic cues. Current findings indicate that individuals who are totally blind have less ability to maintain balance and integrate kinesthetic cues than do individuals who are visually impaired or legally blind.

The Rod Slide was the only motor task in which persons with blindness performed better than sighted persons. The Rod Slide is a test that measures the ability to make slow, controlled movements of the arm and hand. Several possible explanations for this finding were considered. The most plausible explanation was that the sighted group experienced some performance anxiety that was not present in the blind group. The Rod Slide is the most sensitive motor measure of anxiety on the MAND (J. G. Dial, personal communication, October 22, 2001). The sighted group was made up mainly of welleducated professionals and college students; the perceived demand characteristics of the testing by the sighted group may have made them overly concerned with performance, thus having difficulty with a task involving inhibition of their responses.

Recommendations.

Based upon the findings of this study, several recommendations can be offered in hopes of optimizing the functioning and capabilities of individuals who are blind. The finding that texture identification was better in persons who are totally blind provides important information that is applicable to Braille reading. Persons who are totally blind have better aptitude in the skills necessary for Braille reading than individuals who are visually impaired or legally blind. Individuals with residual vision will likely find Braille reading a difficult and cumbersome task due to their (relative) deficits in texture discrimination. The Texas Commission for the Blind recently adopted a policy requiring that all VI/B individuals receive training in Braille reading (Murphy, 1997). Visually impaired individuals who can read large print would be better served by receiving training in the use of CCTV machines, large print books, and the like.

A greater emphasis should be placed on physical fitness activities for individuals with blindness. Along with mobility training, weight and cardiovascular training programs should be offered. Accommodations should be developed to encourage participation of persons who are blind. While some of the motor deficits of blind individuals are inherent (i.e. balance and coordination), other deficits are somewhat correctable (i.e. strength and endurance). Weight training is an example of a relatively safe physical activity for persons with blindness. In addition, counselors and health care providers of persons with blindness should increase their awareness of the likelihood of motor deficits in their consumers and encourage an active exercise regime.

This study has laid the groundwork for future research in which some specific hypotheses can be tested. Future studies should compare spatial abilities in adults with blindness and sighted adults; a reasonable hypothesis might be that no differences in spatial abilities would be expected. Perceptual abilities might also be examined, with a possible hypothesis that sensory discrimination tasks involving analysis of simple and complex shapes would be performed better by individuals who were blind than by sighted persons. A prospective study examining the motor abilities of blind adults, some of whom received mobility training as children, would help us to understand the effects of mobility training on motor abilities.

Limitations

The exploratory nature of this study precludes causal statements about the findings. Although an effort was made to find sighted subjects who were similar to the blind group, several demographic differences were found between the blind and sighted groups. These included differences in age, gender, ethnicity, and education. Demographically corrected norms and covariates were utilized to correct these differences.

Differences in perceptual-motor abilities based on the analysis of subsets of blind groups were found, including visual status and age of onset of blindness. Other important subsets likely exist. For example, etiology of blindness can affect perceptual motor abilities. Persons with insulin dependent Diabetes Mellitus have shown neuropsychological deficits (Ryan & Williams, 1993). The current study excluded persons with diabetes who also had peripheral neuropathy, but the remaining diabetic group may have contributed some error variance. Individuals who became blind as a result of complications of diabetes are likely to present a different neuropsychological profile than individuals whose blindness was caused by macular degeneration (e.g. Stargardt's Disease).

There are inherent variables associated with age of onset of blindness that have neuropsychological implications. For example, Retinopathy of Prematurity (ROP) is a common congenital onset problem that has a high incidence of right parietal dysfunction, which could affect spatial and tactile abilities. In future research, etiology of blindness needs to be taken into account when attempting to explain differences between blind subgroups.

A related point involves multivariate analysis. This study could have been improved by multivariate analysis combining level of visual functioning with age of onset of blindness. Regrettably, this was not possible due to the limited number of totally blind individuals, but it points to the need of taking into account the various influences on blindness. "The blind" should not be studied as a singular entity, a mistake that many researchers make at one level or another. Instead, variables such as level of visual functioning, age at onset of blindness, etiology of blindness and the influence of education should be assessed at the multivariate level.

APPENDIX A

INFORMED CONSENT

Informed Consent

I agree to participate in a study investigating the perceptual and motor abilities of blind and sighted adults. Specifically, this study will compare the abilities of blind and sighted adults on a variety of neuropsychological measures.

I understand that as a participant in the sighted group, my involvement is contingent upon my meeting the following criteria:

1. I must be between the ages of 18 and 65
2. I must have no history of:
    a. brain damage (traumatic brain injury; seizures)
    b. alcohol or chemical dependency
    c. sensory impairment (glasses and hearing aids are acceptable if they fully correct and must be worn during the study as needed)
    d. diagnosed or suspected learning disability or attention-deficit disorder

I also understand that my participation will include approximately four and one-half hours of neuropsychological evaluation. Roughly three hours of the evaluation will require my wearing a blindfold to simulate conditions of blindness. I will be allowed breaks as needed. This evaluation will include tasks assessing general intelligence, problem solving, sensory and motor functions, memory, and attention. I will also be asked to provide demographic information including my age, race, education level, and occupation. I understand that all information will be confidential and anonymous. I will be assigned a three-digit code, which will replace my name on all data collection forms.

I understand that there is no personal risk or discomfort directly involved with this research. Furthermore, I understand that my participation is voluntary and that I am free to withdraw my consent and discontinue participation in this study at any time without penalty, prejudice or loss of benefits.

If I have questions or problems that arise in connection with my participation in this study, I should contact either Arthur Joyce (Health Psychology student investigator) or Dr. Harrell (project supervisor) at (940) 565-2339.

I have received a copy of this written informed consent.

______________________________________ ____________________

Signature Date

______________________________________ ____________________

Experimenter Date

This project has been reviewed and approved by the UNT Committee for the Protection of Human Subjects. Please contact Shelia Bourns (Institutional Review Board Secretary) if you have further questions (940) 565- 3940.

APPENDIX B

TEST DESCRIPTION

Test Description

Haptic Sensory Discrimination Test (HSDT). Tactile discrimination involves the manipulation of objects in the hand to discriminate their particular shape, size, texture, and spatial arrangements and to conceptually integrate these sensations to form an accurate mental representation of the total object. Geometrically shaped and textured objects are obscured from the visual field and manipulated in one hand for a ten-second time period. After feeling and manipulating the object in the hand, the person attempts to haptically identify a correct replica of the object from a set of five similar objects. A raw score is derived from the number of objects correctly identified. While haptic-visual discrimination is partly a cognitive function and associated with intelligence, the ability to recognize objects by haptic manipulation primarily involves sensory (cutaneokinsesthetic) processes. Higher cortical functions involved in organization of sensory input and conceptualization appear related to performance of haptic tasks. From a psychological perspective, the task requires a synthesis and integration of particular elements into a unified whole.

The parietal-occipital areas of the brain process tactile discrimination and integration skills. Higher cortical functions involving organization and integration of bimodal sensory information are involved in the performance of the task (Luria's Unit II, primary detection, recognition, and association of haptic-kinesthetic sensory information). The association of complex tactile information with short-term memory processes requires the integration of sensory inputs by the tertiary zones of Unit II (angular and supramarginal gyri). These same areas also participate in the mediation of very complex cognitive functions, perceptions, learning, and the performance of language and academic tasks. Therefore, tactile deficits in either or both sides of the body may be identified by the HSDT and subsequently related to educational and vocational potential. Thus, a relationship exists between the performance scores on instruments that assess complex tactile integration and cognitive skills. Poor HSDT performance on the right as contrasted to the left side of the body may suggest neuropsychological dysfunction involving the left, language hemisphere. This disparity is most obvious in individuals with known traumatic lesions of this hemisphere but can also be observed in some cases of learning disabled individuals. These persons my perform poorly in basic academic subjects such as reading, spelling, and arithmetic due to a congenital anomaly of development involving the left parietal associative area. In contrast, lateralized deficits to the right cerebral hemisphere may be suggested by low left hand performance. In these cases, problems in spatial analysis and specific learning disabilities involving poor academic performance in arithmetic and probably expressive writing may be observed. Tactile discrimination difficulties may also lead to problems with basic prevocational and vocational skills such as appropriate use of small hand tools, and discrimination among small parts and assembly tasks.

The HSDT materials consist of: a cloth screen to obscure the individual's vision of the hand used to manipulate objects; a series of geometric and textured shapes; a series of plates with shapes on them; and scoring sheets. The HSDT is relatively easy to administer and score and has a reliability of .92. The predictive validity with work potential has been reported at .67 for individuals with visual impairments (Kaskel, 1994).

<u>McCarron Assessment of Neuromuscular Development – Blind Adaptation.</u>

The MAND is the primary CVES measure used to assess the motor factor in vocational, educational and clinical neuropsychological assessment. The MAND consists of five fine and five gross motor tests combined to produce a total motor score. In vocational and educational evaluation of adolescents and adults, the MAND total raw score and separate raw score totals for the fine and gross motor sections are computed and used in developing individual program plans. Various factor scores and subtest scores from the MAND are also used in this process. The MAND has demonstrated excellent reliability (test-retest correlation of .99) for use with brain-damaged groups. The predictive validity between the MAND and work performance is significant ($\underline{r} = .70$, $\underline{p} < .001$).

Since many neuropsychological and vocational assessment procedures tend to redundantly measure only bimanual dexterity or hand strength, it is important to include a comprehensive yet efficient measure of neuro-motor skills. The MAND provides such a comprehensive assessment of the individual's neuromuscular functioning. The following sections describe these factors:

Persistent Control. This factor is assessed by the Rod Slide and Finger-Nose-Finger subtests. This factor involves the integration of perceptual skills with the regulation of hand-arm movement. The tasks require controlled hand-arm coordination (cerebellum), the ability to focus attention while inhibiting extraneous motor movements (Unit I reticular formation and Unit II parietal area). Inadequate persistent control may also suggest poorly focused attention. In a vocational setting, depressed persistent control scores may be associated with poor quality in workmanship, tendencies to make frequent errors and increased risk for accidents.

Muscle Power. This factor is measured by the Hand Strength and Jumping subtests. This factor involves the healthy functioning of the skeletal muscles reflecting timing and coordination. The greatest muscle power is elicited when the muscles are contracted simultaneously. The tasks include a measure of hand/arm strength and a measure of leg strength. In children, poor muscle power may interfere with recreational activities and participation in sports, thus leading to secondary social/emotional problems. In a vocational setting, depressed muscle power may interfere with tasks that require lifting, carrying, pushing, or pulling. In clinical assessment, reduced muscle power, particularly to the upper body, may indicate cortical level brain damage (posterior frontal lobes – Luria's Unit III).

Kinesthetic Integration. The Heel-Toe Walk and the Standing on One Foot subtests measure this factor. The factor is defined as the control of balance and orientation of the body in space. Performance on these subtests involves static balance and equilibrium as well as dynamic balance with the integration of sensorimotor input from large muscle systems. Deficits in balance and gross motor coordination may interfere with play and recreational activities. Deaf and visually impaired/blind individuals may experience problems in kinesthetic integration. Work tasks that require extended reaching, crawling, climbing, etc., may be hazardous or require individual accommodation. In clinical diagnosis, severe deficits may be observed in persons with subcortical vestibular system and cerebellar lesions.

Bimanual Dexterity. This factor is measured by the Beads-on-a-Rod and Nut and Bolt subtests. Adequate performance on the bimanual dexterity factor requires integration of proprioceptive and kinesthetic information with fine motor coordination of both hands.

The Nut-and-Bolt subtest requires inhibition of movement of one hand while simultaneously manipulating the fingers and wrist of the other hand. A good score in this area requires precise bimanual coordination. Deficits in bimanual dexterity have a negative impact on a wide range of daily living and work activities. Slow and uncoordinated performance may interfere with a variety of work tasks. Activities such as operating powered machinery may also be compromised. In clinical assessment, these deficits may be associated with lateralized lesions involving predominant impairment on one side of the body.

In addition to the four factors, specific MAND scores related to speed, strength, and fine motor coordination are combined to form a Hand Preference Index (HPI) for both the right and left hands. The assessment procedures may be used with the sighted, deaf, or visually impaired/blind populations.

Reprinted from the McCarron-Dial Evaluation System (1986)

Cognitive Test for the Blind. The CTB is the chief CVES measure of cognitive, intellectual, and information processing skills. It consists of a verbal and a non-visual performance scale from which a total score is derived. Early studies of the CTB indicate very good test-retest reliability (r = .95). The two CTB subtests used for this study were the Pattern Recall and Spatial Analysis.

Pattern Recall. The Pattern Recall subtest measures complex immediate and short-term spatial memory by presenting subjects with various textured patterns and asking that they remember the pattern. The alternate form reliability of the Pattern Recall subtest was .94 (Dial, Mezger, et al., 1991).

Spatial Analysis. This subtest measures complex spatial analysis and orientation. Subjects match shapes and assemble patterns using wooden shapes and tactile frames for reference. Test-retest reliability of the Spatial Analysis subtest was .92 (Dial, Mezger, et al., 1991). In addition, a Spatial Factor was obtained using the Pattern Recall and the Spatial Analysis subtests. This factor is thought to measure spatial organization and analysis.

Spatial Factor. This standard score is obtained by averaging the Pattern Recall and Spatial analysis subtests.

APPENDIX C

ANALYSIS OF DEMOGRAPHIC VARIABLES

Table 1

CVES Variables Used in All Analyses

Cognitive Test for the Blind	
Pattern Recall	Verbal Factor Score
Spatial Analysis	Spatial Factor Score
Haptic Sensory Discrimination Test	
Shape Scaled	Right Standard
Size Scaled	Left Standard
Texture Scaled	Total Standard
Configuration Scaled	
McCarron Assessment of Neuromuscular Development Subtests	
Beads in Box	Hand Strength
Beads on Rod	Finger Nose Finger
Finger Tapping	Jumping
Nut and Bolt	Heel Toe Walk
Rod Slide	Standing on One Foot
McCarron Assessment of Neuromuscular Development Factors	
Persistent Control	NDI
Muscle Power	Fine Motor Index
Kinesthetic Integration	Gross Motor Index
Bimanual Dexterity	

Table 2

Etiology of Blindness*

Etiology	Number	Percentage
ALBINISM:	34	2.8
APHAKIA DEVEL. ANOMALY NOS	35	7.4
CATARACTS:	72	15.3
COLOBOMA:	13	2.7
NYSTAGMUS/STRABISMUS:	93	19.7
DEMOISIERS SYNDROME:	1	0.2
DIABETES	44	9.3
GLAUCOMA :	69	14.6
INFECTIOUS DISEASE	7	1.5
LAURENCE MOON BIEDL SYNDROME	5	1.1
LEBERS AMAUROSIS	9	1.9
MACULAR DEGENERATION	38	8.1
OPTIC ATROPHY, HYDROPLASIA	61	12.9
RETINAL DETACHMENT	26	5.5
RETROLENTAL FIBROPLASIA/	23	4.9
RETINOPATHY OF PREMATURITY	61	11.0

(*table continues*)

Table 2 (continued)

Etiology	Number	Percentage
RETINITIS PIGMENTOSA	68	14.4
STARGARDTS DISEASE	18	3.8
TOXIC EXPOSURE	3	0.6
PHYSICAL TRAUMA TO THE EYE	21	4.5
TUMOR	5	1.1

*Note: Multiple etiologies were prevalent in many cases.

Table 3

Means, Standard Deviations, and *t*-tests for Blind and Sighted Groups Demographic Characteristics

Variable	Blind Mean/SD	Sighted Mean/SD	t
Age (541)	30.5/12.5	42.7/11.4	6.20***
Education (401)	12.1/1.8	15.8/1.8	15.09***

*** $p < .001$

Table 4

Chi-Square Analyses for Blind and Sighted Groups Demographic Characteristics

Variable	Chi-Square
Sex	$\chi^2(1, N=514) = 8.68$**
Race	$\chi^2(3, N = 514) = 12.11$**
Handedness	$\chi^2(1, N = 514) = 1.44$

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

APPENDIX D

MEANS, STANDARD DEVIATIONS, AND ANCOVAS

Table 5

Means, Standard Deviations, and ANCOVAs (Covariate: Education) for Blind and Sighted Groups

Variable	Blind Mean SD	Sighted Mean SD	F (1, 511)
CTB			
Pattern Recall	10.5 2.9	11.3 2.9	.01
Spatial Analysis	10.5 3.0	10.2 3.5	.75
Verbal	100.5 15.1	109.8 13.4	.61
Spatial	101.6 15.0	100.6 11.7	.19
HSDT SCALED			
Shape	10.4 3.0	9.9 2.9	4.26*
Size	10.5 3.0	11.0 2.6	1.23
Texture	10.1 3.0	11.6 3.1	3.45 (p=.06)
Config	10.5 3.0	9.2 3.6	6.26*

*p<.05 **p<.01 ***p<.001

(*table continues*)

Table 5 cont.

Variable	Blind Mean SD	Sighted Mean SD	F (1, 511)
HSDT STANDARD			
Right	100.4 15.1	101.9 13.0	.29
Left	100.7 13.9	105.4 16.4	.13
Total	100.9 14.2	104.4 14.2	.22
MAND SUBTESTS			
BB	100.5 14.9	122.6 11.6	57.99***
BR	100.7 15.0	122.5 7.6	63.99***
FT	100.5 15.0	105.1 9.2	1.12
NB	100.4 15.0	111.8 9.8	15.68***
RS	101.1 16.1	89.6 24.2	17.62***
HS	100.7 15.1	107.3 17.4	5.20*
FNF	100.8 14.9	112.0 6.3	15.17***

*p<.05 **p<.01 ***p<.001

(*table continues*)

Table 5 cont.

Variable	Blind Mean SD	Sighted Mean SD	_F_ (1, 511)
JUMP	100.5 15.0	106.9 15.9	4.01*
HTW	100.5 15.0	117.9 9.9	39.80***
SOF	100.5 15.0	110.3 9.5	9.68**
MAND FACTOR SCORES			
FMI	100.5 15.0	110.7 6.5	10.85**
GMI	100.5 15.0	111.3 8.2	14.67***
NDI	100.5 15.0	111.1 5.7	12.23***
PC	100.5 14.9	101.1 12.1	.11
MP	100.6 15.0	107.3 15.0	5.36*
KI	100.5 15.0	114.3 8.5	23.09***
BD	101.3 11.5	117.5 7.3	57.92***

*_p_<.05 **_p_<.01 ***_p_<.001

Table 6

Means, Standard Deviations, and ANCOVAs (Covariate: Age of Onset) for Visual Status

Variable	VI Mean SD	LB Mean SD	TB Mean SD	F (2,414)
CTB				
Pattern Recall	10.2 3.4	10.7 2.5	10.6 3.6	.74
Spatial Analysis	10.5 3.0	10.5 3.0	10.5 2.9	.23
Verbal	100.6 16.4	100.3 14.0	102.6 15.3	.27
Spatial	99.7 16.4	101.2 14.1	100.5 17.9	.60
HSDT SCALED				
Shape	10.0 3.7	10.3 2.8	11.5 2.3	3.56*
Size	10.0 3.1	10.6 2.9	10.9 3.1	2.17
Texture	9.8 3.1	9.8 2.9	11.6 2.4	5.55**
Config	10.3 3.3	10.4 2.9	10.4 3.4	.16

*p<.05 **p<.01 ***p<.001

(*table continues*)

Table 6 cont.

Variable	VI Mean SD	LB Mean SD	TB Mean SD	F (2,414)
HSDT STANDARD				
Right	97.4	100.2	103.2	2.70
	16.0	14.5	16.1	
Left	97.8	100.6	105.2	3.42*
	15.5	13.0	13.5	
Total	97.6	100.7	105.0	3.97*
	15.8	13.1	14.4	
MAND SUBTESTS				
BB	100.3	100.5	100.5	.01
	14.7	14.0	22.8	
BR	100.3	102.7	98.5	1.45
	14.8	14.9	18.4	
FT	99.6	101.4	101.8	.41
	14.5	15.4	15.8	
NB	98.7	101.3	97.0	1.56
	17.8	13.0	22.3	
RS	97.8	102.4	102.8	2.60
	21.2	13.5	7.8	
HS	100.3	100.4	100.1	.01
		13.5	15.5	20.6
FNF	100.6	101.1	95.7	1.82
	15.5	13.8	18.8	
JUMP	101.1	100.5	92.6	4.29*
	15.9	14.5	13.2	

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

(*table continues*)

Table 6 cont.

Variable	VI Mean SD	LB Mean SD	TB Mean SD	_F_ (2,414)
HTW	100.3 15.8	100.4 14.5	95.3 18.4	2.41
SOF	98.9 15.7	100.9 14.3	96.7 16.2	1.03
MAND FACTOR SCORES				
FMI	98.4 16.3	102.1 14.1	99.8 19.6	1.72
GMI	100.2 15.3	100.6 14.6	93.9 17.6	2.61
NDI	99.4 15.6	101.4 14.5	96.4 19.3	1.48
PC	98.5 17.7	101.5 13.1	98.4 13.8	1.45
MP	100.6 14.4	100.4 15.0	95.7 17.5	1.41
KI	100.1 15.9	100.8 14.6	95.3 16.8	1.60
BD	100.3 12.6	102.6 10.7	98.6 17.0	2.21

*_p_<.05 **_p_<.01 ***_p_<.001

Table 7

Means, Standard Deviations, and ANCOVAs (Covariate: Visual Status) for Age of Onset of Blindness

Variable	Congenital Mean SD	Early Mean SD	School Mean SD	Adult Mean SD	F (3,404)
CTB					
Pattern Recall	10.5 3.1	10.0 3.1	10.8 2.3	10.8 2.2	.44
Spatial Analysis	10.8 2.9	10.3 3.1	10.4 3.1	10.0 3.0	1.88
Verbal	101.8 15.5	100.4 16.7	96.9 10.3	98.9 13.5	1.91
Spatial	101.5 15.8	98.8 17.1	101.1 12.9	99.4 12.7	.74
HSDT SCALED					
Shape	10.6 3.2	10.4 3.4	9.9 2.2	9.7 2.9	2.84*
Size	10.4 3.0	10.1 3.2	10.8 2.9	10.5 2.9	.18
Texture	10.4 3.0	10.1 2.6	9.7 3.2	8.6 2.7	10.85***
Config	10.5 3.0	10.6 3.9	10.1 3.0	10.1 2.7	.81

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

(*table continues*)

Table 7 cont.

Variable	Congenital Mean SD	Early Mean SD	School Mean SD	Adult Mean SD	F (3,404)
HSDT STANDARD					
Right	100.4 15.0	99.4 18.9	99.6 14.7	99.7 14.3	1.20
Left	99.7 14.2	100.4 14.2	97.4 15.5	100.9 11.6	.70
Total	100.4 14.5	100.1 17.2	98.4 13.8	99.5 12.1	.63
MAND SUBTESTS					
BB	100.1 13.9	96.7 16.6	102.4 14.2	99.0 14.2	1.64
BR	101.4 15.1	94.4 15.6	106.1 15.4	101.8 13.6	4.34**
FT	100.3 15.9	98.7 16.1	102.9 14.6	102.2 13.4	.65
NB	99.1 16.5	103.1 15.6	101.1 16.2	100.5 11.1	.79
RS	100.8 16.5	93.8 24.4	101.4 13.2	104.2 10.3	2.78*
HS	99.9 15.1	99.7 16.7	101.0 18.2	100.1 14.3	.14
FNF	100.2 15.1	98.8 18.0	100.1 13.3	101.8 13.2	.81

*p<.05 **p<.01 ***p<.001

(*table continues*)

Table 7 cont.

Variable	Congenital Mean SD	Early Mean SD	School Mean SD	Adult Mean SD	F (3,404)
JUMP	100.1	101.2	99.3	100.0	.02
	15.1	15.7	14.9	14.8	
HTW	99.1	99.4	102.0	102.8	2.76*
	15.9	17.2	10.3	14.0	
SOF	98.6	99.4	101.9	102.3	1.92
	15.0	17.5	14.4	13.3	
MAND FACTOR SCORES					
FMI	100.0	95.4	103.6	102.1	2.45 (p=.06)
	15.4	18.7	14.4	12.1	
GMI	99.1	99.1	100.8	101.4	1.20
	15.6	16.9	14.3	13.4	
NDI	99.3	97.2	102.7	102.0	2.21
	15.5	17.3	14.6	12.0	
PC	99.8	95.2	100.4	103.2	2.55 (p=.055)
	15.6	19.5	12.0	10.6	
MP	99.9	100.3	100.1	100.0	.07
	15.0	14.9	17.3	14.8	
KI	98.6	99.1	102.0	102.8	2.95*
	15.4	18.0	12.2	14.0	
BD	101.0	99.7	104.0	101.7	.18
	12.6	12.5	11.2	9.0	

*p<.05 **p<.01 ***p<.001

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