Development and Decline of Sensory and Motor Skills

in a Normative Sample

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## Table of Contents

List of Tables and Figures  5

1  Introduction  13

2  Literature Review  21

   Sensory Skills  22

      Visual perception  22

      Auditory perception  23

      Tactile perception  25

   Motor Skills  27

      Motor coordination  27

      Motor speed  28

      Grip strength  29

      Postural control  30

      Left-right confusion  32

3  Methodology  33

   Participants  33
List of Tables and Figures

Tables

1. Confirmatory factor analysis goodness of fit indices 40
2. Confirmatory factor analysis regression weights 41
3. MANCOVA assumption of normality 45
4. Box’s M test of MANCOVA assumption of homogeneity of variance-covariance matrices 46
5. MANCOVA assumption of homogeneity of regression 47
6. Multivariate tests 48
7. Parameter estimation slopes 49

Figures

1. Scatterplot and curve estimation regression lines of Simple Sensory Skills mean W scores 42
2. Scatterplot and curve estimation regression lines of Cortical Motor and Complex Sensory Skills mean W scores 43
3. Scatterplot and curve estimation regression lines of Subcortical Motor and Auditory/Visual Acuity Skills mean W scores 44
4 Scatterplot and quadratic regression line of Simple Sensory Skills mean W scores for males  51

5 Scatterplot and quadratic regression line of Simple Sensory Skills mean W scores for females  51

6 Scatterplot and quadratic regression line of Cortical Motor and Complex Sensory Skills mean W scores for males  52

7 Scatterplot and quadratic regression line of Cortical Motor and Complex Sensory Skills mean W scores for females  52

8 Scatterplot and quadratic regression line of Subcortical Motor and Auditory/Visual Acuity Skills mean W scores for males  53

9 Scatterplot and quadratic regression line of Subcortical Motor and Auditory/Visual Acuity Skills mean W scores for females  53

10 Plot of performance at the 5th and 50th percentiles on Test 3, Visual Confrontation, of the D-WSMB for identification of movement in the right peripheral field  63

11 Plot of performance at the 5th and 50th percentiles on Test 3, Visual Confrontation, of the D-WSMB for identification of movement in the left peripheral field  63
12 Plot of performance at the 5th and 50th percentiles on Test 3, Visual Confrontation, of the D-WSMB for identification of simultaneous movement in the right and left peripheral fields 64

13 Plot of performance at the 5th and 50th percentiles on Test 8, Finger Identification, of the D-WSMB for identification of touch of fingers on the right hand 64

14 Plot of performance at the 5th and 50th percentiles on Test 8, Finger Identification, of the D-WSMB for identification of touch of fingers on the left hand 65

15 Plot of performance at the 5th and 50th percentiles on Test 9, Simultaneous Localization, of the D-WSMB for identification of touch on the right hand 65

16 Plot of performance at the 5th and 50th percentiles on Test 9, Simultaneous Localization, of the D-WSMB for identification of touch on the left hand 66

17 Plot of performance at the 5th and 50th percentiles on Test 9, Simultaneous Localization, of the D-WSMB for identification of touch on the both hands simultaneously 66

18 Plot of performance at the 5th and 50th percentiles on Test 9, Simultaneous Localization, of the D-WSMB for identification of simultaneous touch on a hand and the contralateral cheek 67
19 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 9, Simultaneous Localization, of the D-WSMB for identification of touch on the right hand or cheek 67

20 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 9, Simultaneous Localization, of the D-WSMB for identification of touch on the left hand or cheek 68

21 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 6, Palm Writing, of the D-WSMB for tactile identification of letters (i.e., X or O) and numbers written on the right palm 69

22 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 6, Palm Writing, of the D-WSMB for tactile identification of letters (i.e., X or O) and numbers written on the left palm 69

23 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 7, Object Identification, of the D-WSMB for tactile identification of objects placed in the right palm 70

24 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 7, Object Identification, of the D-WSMB for tactile identification of objects placed in the left palm 70

25 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 12, Construction, of the D-WSMB for accuracy in copying a figure of a cross 71
26 Plot of performance at the 5th and 50th percentiles on Test 12, Construction, of the D-WSMB for accuracy in drawing an analog clock displaying a specified time

71

27 Plot of performance at the 5th and 50th percentiles on Test 13, Coordination, of the D-WSMB for speed in completion of 20 supination-pronation sequences using the right hand on the right thigh

72

28 Plot of performance at the 5th and 50th percentiles on Test 13, Coordination, of the D-WSMB for speed in completion of 20 supination-pronation sequences using the left hand on the left thigh

72

29 Plot of performance at the 5th and 50th percentiles on Test 14, Mime Movements, of the D-WSMB for demonstration of specified actions

73

30 Plot of performance at the 5th and 50th percentiles on Test 15, Left-Right Movements, of the D-WSMB for accuracy in following commands requiring correct identification of left and right

73

31 Plot of performance at the 5th and 50th percentiles on Test 17, Expressive Speech, of the D-WSMB for accuracy in articulation of specified words and phrases

74

32 Plot of performance at the 5th and 50th percentiles on Test 2, Near Point Visual Acuity, of the D-WSMB for level of acuity in the right eye using a Snellen chart

75
33 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 2, Near Point Visual Acuity, of the D-WSMB for level of acuity in the left eye using a Snellen chart 75

34 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 5, Auditory Acuity, of the D-WSMB for identification of a rustling sound made next to the right ear 76

35 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 5, Auditory Acuity, of the D-WSMB for identification of a rustling sound made next to the left ear 76

36 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 10, Gait and Station, of the D-WSMB for fluidity and balance in completion of forward movement and stationary tasks 77

37 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 11, Romberg, of the D-WSMB for balance in maintaining specified stationary postures 77

38 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 13, Coordination, of the D-WSMB for accuracy in alternating movements of touching one’s nose and the examiner’s index finger using the right hand 78

39 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 13, Coordination, of the D-WSMB for accuracy in alternating movements of touching one’s nose and the examiner’s index finger using the left hand 78
40 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles for males on Test 16, Finger Tapping, of the D-WSMB for speed in tapping the index finger of the dominant hand  79

41 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles for females on Test 16, Finger Tapping, of the D-WSMB for speed in tapping the index finger of the dominant hand  79

42 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles for males on Test 16, Finger Tapping, of the D-WSMB for speed in tapping the index finger of the non-dominant hand  80

43 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles for females on Test 16, Finger Tapping, of the D-WSMB for speed in tapping the index finger of the non-dominant hand  80

44 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles for males on Test 18, Grip Strength, of the D-WSMB for strength when squeezing a hand dynamometer using the dominant hand  81

45 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles for females on Test 18, Grip Strength, of the D-WSMB for strength when squeezing a hand dynamometer using the dominant hand  81

46 Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles for males on Test 18, Grip Strength, of the D-WSMB for strength when squeezing a hand dynamometer using the non-dominant hand  82
47 Plot of performance at the 5th and 50th percentiles for males on Test 18, Grip Strength, of the D-WSMB for strength when squeezing a hand dynamometer using the non-dominant hand 82
Assessment of a patient’s sensory and motor functioning is an integral part of evaluating neuropsychological functioning. These data not only provide information about the integrity of cortical and subcortical brain structures but also allow clinicians to screen for difficulty in more complex cognitive functions, such as comprehending instructions or maintaining attention to tasks, which could compromise cognitive performance (Davis, Finch, Trinkle, & Dean, 2006; Volpe, Davis, & Dean, 2006).

Recent research has demonstrated that sensory and motor functioning plays a more important role in cognition than once thought. For instance, Brenneman, Decker, Meyers, and Johnson (2008) found that individuals with more extreme scores on the Lateral Preference Scale of the Dean-Woodcock Sensory Motor Battery, which measures lateralization on a continuum, exhibited poorer performance on measures of phonological awareness, auditory working memory, and reading comprehension. Lieberman (2001) reported that the basal ganglia, involved in motor control and sequencing, and other subcortical structures regulate circuits governing speech and language comprehension. Lieberman further noted that damage to these subcortical structures can result in permanent language impairments.
Historically, researchers have evaluated sensory and motor skills and interpreted outcomes based on an assumption that children and adults were functioning similarly (Arceneaux, Hill, Chamberlin, & Dean, 1997; Dean & Woodcock, 2003; Hill, Morris, Lewis, Dean, 2000; Lang, Hill, & Dean, 2001). Although researchers recognized differences in performance between children and adults, research on typical performance across the lifespan on tests of sensory and motor skills has been limited and typically has not been approached with the use of standardized measures (Arceneaux, Hill, Chamberlin, & Dean, 1997; Hill, Lewis, Dean, & Woodcock, 2000; Huttenlocher, Levine, Huttenlocher, & Gates, 1990; Lang, Hill, & Dean, 2001; Nici & Reitan, 1986; Steindl, Kunz, Schrott-Fischer, & Scholtz, 2006). For example, Lezak, Howieson, and Loring (2004) reported that the *Halstead-Reitan Battery*, a neuropsychological assessment battery commonly used in clinical practice, was not standardized on a representative sample of non-impaired adults. Furthermore, the battery is not suitable for analysis of differences in performance between children and adults, as administration is limited to adolescents and adults (Lezak, Howieson, & Loring, 2004). Similarly, the *Luria-Nebraska Neuropsychological Battery*, another assessment battery commonly used in clinical practice, is intended to be administered to adolescents and adults and included a limited number of “normal” participants (51 subjects) in the standardization process (Golden, Purisch, & Hammeke, 1991; Lezak, Howieson, & Loring, 2004). The lack of representative standardization increased the likelihood of error in identifying significant abnormal performance, whether by over-identification or under-identification of abnormality (Arceneaux, Hill, Chamberlin, & Dean, 1997; Lang, Hill, & Dean, 2001). It
also limited the ability to make comparisons in research findings and among clinical outcomes (Snow, 1987).

In 1997, Arceneaux, Hill, Chamberlin, and Dean published a paper comparing developmental trends in the mastery of sensory and motor skills as measured by the *Dean-Woodcock Sensory Motor Battery* (D-WSMB), published as part of the *Dean-Woodcock Neuropsychological Assessment System* (D-WNAS; Dean & Woodcock, 2003). The D-WSMB is a battery of tests which has standardized administration and interpretation based upon a normative group for all of the clinical neurological and neuropsychological measures included in the battery. The present study also sought to identify differences in gender present on these measures. Results of the Arceneaux et al. research indicated older children consistently performed better than younger children on all but a test of visual confrontation in a cross-sectional study (ages 4 through 13 years 11 months) but found no significant differences related to gender. The authors acknowledged limitations of the study due to a small sample size (n=119). Lang, Hill, and Dean (2001) later reported ages at which children reached performance comparable to adults when assessed with measures on the *Dean-Woodcock Sensory Motor Battery* (D-WSMB; Dean & Woodcock, 2003). The Lang, Hill, and Dean study built on the Arceneaux et al. investigation by extending the age range being assessed to children ages 4 through 15 years, 11 months and increasing the sample size (n=288).

Some researchers have attempted to identify normal developmental changes in which adults exhibit declining sensory and motor functions. For instance, Ruff and Parker (1993) evaluated age-related changes in motor speed and eye-hand coordination among
adults by evaluating performance on a finger tapping task and completion of a grooved pegboard task, finding no change in performance for either task for males but decreased performance at older ages for females. Vereeck, Wuyts, Truijen, and Van de Heyning (2008) identified age-level differences in postural control during stationary and walking tasks; tasks included a traditional Romberg test, a tandem Romberg test, stationary balance while standing on foam padding, tandem gait, the Timed Up and Go test (assessing time to rise from a seated position and walk several steps), and Dynamic Gait Index (assessment of gait under differing conditions, including walking on level, angled, and uneven surfaces, climbing stairs, and stepping over objects). With sensory skills, Anderson and Enriquez (2006) found age-related changes in visual perception by assessing accuracy in identifying likelihood of a collision with oncoming objects on a video screen under varying conditions of speed of movement of the object and simulated movement of the participant. Fitzgibbons and Gordon-Salant (2010) noted changes in auditory discrimination of tones for older adults in comparison to younger adults.

However, a review of research revealed no studies comparable to the Arceneaux et al. (1997) and Lang, Hill, and Dean (2001) studies applied to adult populations. Specifically, little published research was found evaluating age-related changes in a range of sensory and motor skills for a single group of participants utilizing standardized assessment.

Research into gender differences in sensory and motor skill performance has yielded variable results with some researchers noting differences (e.g., Dodrill, 1979; Ruff & Parker, 1993; Yeudall, Reddon, Gill, & Stefanyk, 1987) and others finding a lack of significant results (e.g., Arceneaux, Hill, Chamberlin, & Dean, 1997; Lietz, 1972;
Tucker, 1976; Witelson, 1976). At times, gender differences have been found for specific tasks at some age ranges but not at others (e.g., Steindl, Kunz, Schrott-Fischer, & Scholtz, 2006). Furthermore, evidence of structural gender differences in brain development has not always translated into functional differences (Arceneaux, Hill, Chamberlin, & Dean, 1997; Nanova, Lyamova, Hadjigeorgieva, Kolev, & Yordanova, 2008; Sadato, Ibañez, Deiber, & Hallett, 2000; Tucker, 1976).

This study expanded on the research of developmental differences in sensory and motor function across the lifespan for individuals without a history of neurological impairments, with consideration given to potential gender differences in “normal” functioning. A clear understanding of what is expected performance on neuropsychological assessments is critical in clinical practice to evaluate suspected impairments accurately. Identification of skills that exhibit variations in performance at different age levels for individuals without a history of neurological impairment can assist clinicians in conceptualizing the presence and severity of impairments in order to make appropriate recommendations for treatment or further evaluation. Although the Dean-Woodcock Sensory Motor Battery (D-WSMB; Dean & Woodcock, 2003) provides a standardized approach to assessing skills in the clinical setting, further analysis of the variability in scores at different age levels is important to appropriately interpret the results. Indeed, the impairment levels provided in the D-WSMB, which range from “WNL” (i.e., within normal limits) to “Severe,” include a level identified as “Mild to WNL” which relies on clinical judgment rather than objective data for determination of impairment (Dean & Woodcock, 2003). This study
aimed to identify the pattern of variability in performance on measures of sensory and motor skills to reduce ambiguity in the interpretation of low scores.

The use of the standardization sample of the *Dean-Woodcock Sensory Motor Battery* (D-WSMB; Dean & Woodcock, 2003) allowed for comparisons among the same participants for various skills. Given the range of ages included in standardization sample of the D-WSMB and the number of tests that comprise the battery, comparisons for each obtained score for each age level was considered to be too comprehensive to address in a single study. For this reason, scores of the D-WSMB were truncated into broad categories of skills to aid in comparisons. A factor analytic study by Hill, Lewis, Dean, and Woodcock (2000) found scores obtained on the D-WSMB could be factored into three groups labeled Sensory and Simple Motor Skills, Motor and Complex Sensory Skills, and Subcortical Motor Skills. However, 26 of the 44 scores included in the analysis had significant loadings on more than one factor and 3 did not load on any factor. A subsequent factor analysis was conducted by Davis, Finch, Dean, and Woodcock (2006) utilizing a larger sample than was available from the Hill et al. study. Results of this analysis also yielded a 3-factor model with factors reported as Simple Sensory Skills, Cortical Motor and Complex Sensory Skills, and Subcortical Motor and Auditory/Visual Acuity Skills. Of the 35 scores included in analysis, 5 loaded on more than one factor. Cross-loadings for the Davis et al. study were all between the first and second factors.

For the purposes of the present study, the factors hypothesized by the Davis, Finch, Dean, and Woodcock (2001) study were chosen to truncate D-WSMB scores for comparisons, as the Hill, Lewis, Dean, and Woodcock (2000) analysis included age as one of the
measure, which would have resulted in age serving as an independent variable as well as a component of one of the dependent variables if utilized in this study. In addition, fewer cross-loadings were noted in the Davis et al. analysis and the sample size included was more comparable to the dataset used for the current study. It was hypothesized that a confirmatory factor analysis of the Davis et al. factor model for the current dataset would result in a good fit.

Given the outcomes of previous research indicating children exhibited improved performance on sensory and motor D-WSMB tasks as a function of age (Arceneaux, Hill, Chamberlin, & Dean, 1997; Lang, Hill, & Dean, 2001), results of this study were expected to demonstrate a similar pattern of development through childhood and adolescence, with lower scores on the dependent variables obtained in the early years of the age continuum and higher scores obtained by adults. For the upper end of the age continuum, although some studies report variations in brain functioning tend to be individual and multidirectional (i.e., some skills improving while others decline), it was hypothesized that a downward trend would be noted, with scores on the dependent variables decreasing with age, consistent with evidence of declining performance in motor speed, coordination, postural control, and visual, auditory, and tactile perception noted in research (Aiken, 1998; Anderson & Enriquez, 2006; Fitzgibbons & Gordon-Salant, 2010; Ruff & Parker, 1993; Rybash, Roodin, & Hoyer, 1995; Stevens & Cruz, 1996; Thornbury & Mistretta, 1981; Vereeck, Wuyts, Truijen, & Van de Heyning, 2008).

In sum, analysis of sensory and motor skills by age was hypothesized to exhibit a curvilinear relationship demonstrating improvement of skills at lower ages and decline of
skills at upper ages. The relationship of age and performance on the measures of sensory and motor skills was evaluated using regression analysis with curve estimation.

Finally, it was hypothesized that gender would not be a significant factor in variability in performance of the dependent variables. As noted previously, research on gender differences in sensory and motor skills has yielded inconsistent results and evidence of differences in brain development has not resulted in differences in performance on tests of skills. Although the inconsistent results of previous research suggests gender could play a significant role in the outcomes of this study, combining measures into factors to form the dependent variables was expected to mask any differences that might be present. The impact of gender was evaluated using MANCOVA.
Merriam-Webster’s Dictionary defines sensory as “of or relating to sensation or to the senses” and motor as “one that imparts motion” or “any of various power units that develop energy or impart motion” (“Motor,” 2010; “Sensory,” 2010). From a neurological perspective, sensory skills are generally associated with the postcentral gyrus, also known as the somatosensory cortex, and voluntary motor skills are typically associated with the precentral gyrus, also known as the primary motor cortex, which are supported by subcortical structures involved in transmission of sensory information and coordination of basic motor movements (Hill, Lewis, Dean, & Woodcock, 2000; Lieberman, 2001; Zillmer & Spiers, 2001).

“Subcortical” refers to structures located below the cerebral cortex, or upper portion of the brain, and is divided into regions called the forebrain, midbrain, and hindbrain. These regions include such structures as the thalamus and hypothalamus, limbic system, basal ganglia, medulla, reticular activating system, and cerebellum (Lezak, Howieson, & Loring, 2004; Zillmer & Spiers, 2001).

Recent research has increasingly shown that sensory and motor skills are highly integrated (Gordon et al., 2011). Although sensory and motor skills are often researched
as distinct processes, researchers addressing sensory and motor skills need to recognize that the domains cannot be entirely separated (Gordon et al., 2011).

**Sensory Skills**

**Visual perception.**

The ability to perceive, interpret, and respond to visual information is an important function for individuals as they interact with the world around them. Difficulty with the process of receiving visual stimuli or with accurately identifying what one is seeing can significantly impact an individual’s ability to communicate effectively with others. Lang, Hill, and Dean (2001) found that the ability to perceive and label simple visual stimuli, such as pictures of common objects, is established by age 5, while children under age 5 without a history of neurological impairment may exhibit some difficulty in accurately identifying visual input. Similarly, the ability to perceive peripheral visual input accurately and consistently appeared to be mastered around age 5. Bub, Masson, and Lalonde (2006) noted that young children in their study made more errors on Stroop tasks of visual interference than older children. However, analysis of performance indicated that children as young as age 7, the youngest age group included in the study, were able to suppress (i.e., ignore input) visual information at a level comparable to older children. The authors attributed the poorer overall performance for young children to difficulty maintaining cognitive set rather than underdeveloped ability to suppress visual information.
Visual impairment is commonly expected among older adults. Often, changes in vision that come with age can be attributed to eye diseases and physical changes in the eyes that impact vision (Quillen, 1999). Research has demonstrated that increasing age also brings about changes in the cognitive aspects of visual perception. When evaluating ability to suppress visual information through Stroop-like tasks, studies have found that visual performance deteriorates with age (Cohn, Dustman, & Bradford, 1984; Swerdlow, Filion, Geyer, & Braff, 1995; Van der Elst, Van Boxtel, Van Breukelen, & Jolles, 2006).

Anderson and Enriquez (2006) found that older adults exhibit more difficulty judging speed and anticipating expansion of oncoming objects. As a result, when observing videos of oncoming objects, older adults were more likely to report that a collision was imminent. Research evaluating differences in visual perception skills by gender has generally found few differences between men and women, although variable results have been noted with performance on Stroop tasks, with some researchers noting no significant gender differences (e.g., Swerdlow, Filion, Geyer, & Braff, 1995) and some finding women outperform men across age ranges (e.g., Van der Elst, Van Boxtel, Van Breukelen, & Jolles, 2006).

**Auditory perception.**

The ability to perceive information through audition is an important skill for human development and a critical component in the development of human language. Indeed, dichotomous listening tasks, which require individuals to attend to differing stimuli presented simultaneously to each ear (e.g., one sentence heard in the left ear and a different sentence heard in the right ear) has often been used in clinical settings to
identify the dominant hemisphere for language (Asbjornsen & Helland, 2006). Research has indicated the capacity to hear is present well before birth, with fetuses responding to some frequencies as early as 19 weeks gestation and consistently demonstrating a startle response to sounds by 28 weeks gestation (Birnholz & Benacerraf, 1983; Hepper & Shahdullah, 1994).

Research on ability to discriminate sounds in infants and young children without a history of neurological impairment or risk factors for impairment is limited. However, Lang, Hill, and Dean (2001) demonstrated that by age 4 children were able to identify sounds heard in one ear or simultaneously in both ears at a level comparable to adults. Nanova, Lyamova, Hadjigeorgieva, Kolev, and Yordanova (2008) reported the underlying mechanisms used in auditory discrimination developed more quickly in girls than boys between the ages of 7 and 13, resulting in faster processing for girls in this age range. However, increased speed was not found to have a significant impact on overall performance in auditory discrimination.

A decline in auditory perception is often considered to be a normal part of aging. Longitudinal research has indicated statistically significant changes in hearing are detectable by age 35 for individuals initially assessed at age 20 (Brant & Fozard, 1990). However, Bergman and Rosenhall (2001) found that the majority of older adults (70%) test within the normal range on measures of auditory acuity, although nearly all older adults exhibit at least slight hearing impairment by age 88, the highest age at which participants were assessed in their study. The normal range for hearing was defined as the ability to hear a whispered voice at a distance of 5 meters. Bergman and Rosenhall noted
gender differences in hearing loss, with three times as many men as women exhibiting hearing impairment at age 70. Hearing loss does not appear to be solely responsible for decline in auditory perception among older adults, as discrepancies in ability to discriminate sound intervals have been found between young adults with normal hearing and older adults with no discernable hearing loss (Fitzgibbons & Gordon-Salant, 2010).

**Tactile perception.**

Lang, Hill, and Dean (2001) found that unilateral and bilateral perception of touch was comparable to adults in 4-year-old participants of their study. In addition, no significant improvement was made after age 4 in ability to discriminate between simple letters (X and O) written on the palm. By age 5, children demonstrated adult-level performance in discriminating touch to individual fingers on the dominant hand, although finger-touch perception in the non-dominant hand continued to develop to age 6. More complex perception appeared to take longer to develop. Ability to discriminate between numbers written on the palm did not plateau until age 9. Adult-level performance was also found at age 9 for tactile identification of common objects. Witelson (1976) reported tactile perception improved with age in a linear fashion when children ages 6 to 13 were asked to choose a shape that had been felt but not seen from a display of shapes. In a follow-up study, Etaugh and Levy (1981) found no significant age difference in performance; however, their study was based on a restricted age range (4- and 5-year-olds) and likely does not reflect the developmental trend in tactile perception throughout childhood and adolescence. Gender differences in performance on measures of tactile discrimination have been noted among 3-year-olds, with girls outperforming boys; however, boys and
girls have generally exhibited comparable performance by age 5 to 6 (Etaugh & Levy, 1981; Huttenlocher, Levine, Huttenlocher, & Gates, 1990; Witelson, 1976).

On the opposite end of the age spectrum, older adults have generally been found to exhibit impaired tactile discrimination in comparison to young adults. Studies have demonstrated decreased ability in older adults to identify line orientation and line length, to recognize patterns, and to discriminate between single-point touch and dual-point gaps, although some studies suggest decline in ability may be associated with decreasing peripheral nerve enervations rather than neurological changes in tactile discrimination (Manning & Tremblay, 2006; Stevens & Cruz, 1996; Thornbury & Mistretta, 1981). Research on gender differences in tactile performance for adults has generally found comparable performance for men and women. Sadato, Ibañez, Deiber, and Hallett (2000) noted no difference in performance for men and women for tactile discrimination of angles, widths, or Braille versus non-Braille characters, although they noted gender differences in cerebral blood flow during administration of the activities. However, the Sadato et al study may not be generalizable due to a very small sample size included in the study (n=14). Yeudall, Reddon, Gill, and Stefanyk (1987) found varying results on measures of tactile perception from the Halstead-Reitan neuropsychological test battery, with no gender differences noted on tactile form recognition or discrimination of numbers written on fingertips but some differences between men and women on recognition of simple finger touch. However, the study only included adults to age 40 and may not be applicable to older adults.
Motor Skills

Motor coordination.

Assessment of motor coordination takes many forms. Popular methods of addressing this skill include such tasks as finger-to-nose movements, pronation-supination hand movements, speech production tasks, completion of a grooved pegboard, and drawing of simple designs, such as a cross or a clock. Development of motor coordination as assessed by these activities has resulted in variations in age level at which children achieve mastery. Hill, Lewis, Dean, and Woodcock (2000) reported children exhibited the ability to perform finger-to-nose movements at a level equivalent to adults by age 5 to 6, while Lang, Hill, and Dean (2001) noted pronation-supination hand movements continued to develop at least until age 16. Initially, children appear to favor the dominant hand in performing pronation-supination hand movements. However, Snow, Blondis, Accardo, and Cunningham (1993) noted left-right differences in motor coordination skills observed in kindergarten children generally disappeared by completion of their 3-year longitudinal study.

Limited research has been published addressing changes in motor coordination among adults with no history of neurological impairment, with literature review searches by general topics and specific tests of motor coordination typically resulting in research on comparisons of adults with neurological impairments with a normative sample or a focus on motor speed rather than motor coordination when studying nonclinical adults. However, Ruff and Parker (1993) noted significant decline in performance on grooved pegboard tasks with increasing age, although no significant changes were noted between
the 16- to 24-year-old age group and the 25- to 39-year-old age group. Gender variability was noted in completion of grooved pegboard tasks, with women consistently performing faster than men throughout adulthood.

**Motor speed.**

Finger tapping speed has long been used to assess motor speed in children and adults. In child development, Lang, Hill, and Dean (2001) found continued increase in finger tapping speed through age 15, the upper limit of the age ranges included in the study. Among right-handed children, tapping speed is generally greater for the right hand than the left hand, with the gap in performance increasing with age according to a 3-year longitudinal study conducted by Snow, Blondis, Accardo, and Cunningham (1993). Research focusing on gender differences among children with no history of neurological impairment on tasks of motor speed, such as finger tapping and completion of a grooved pegboard, is virtually nonexistent in published literature, which could represent an untapped area of study but may also indicate a lack of significant results in unpublished studies.

As a group, males consistently outperform women in finger tapping speed. However, Dodrill (1979) demonstrated the difference is primarily related to hand size, noting comparisons between males and females with similar hand sizes yielded insignificant results. Gender differences were also found in the decline of finger tapping speed in older adults. Specifically, Ruff and Parker (1993) found decreased performance with age for women with the most significant drop occurring between the 40- to 54-year-old group and the 55- to 70-year-old group. Surprisingly, the study found no significant decrease in
performance for men from age 16 to age 70. Bornstein (1985) found decreased performance with age for both men and women with a significant age by gender interaction, although this interaction only held for the dominant hand.

**Grip strength.**

As with motor speed when measured by finger tapping speed, grip strength has been found to increase throughout childhood and adolescence (Ager, Olivett, & Johnson, 1984; Bowman & Katz, 1984; Lang, Hill, & Dean, 2001; Mathiowetz, Wiemer, & Federman, 1986). Research has indicated boys generally evidence greater strength than girls (Ager, Olivett, & Johnson, 1984; Butterfield, Lehnard, Loovis, Calodarci, & Saucier, 2009). However, a study by Bowman and Katz (1984) reported gender differences in grip strength were only significant for the left hand in right-hand dominant 6- to 9-year-olds. Although studies have generally found comparable improvement for boys and girls in development of grip strength throughout childhood, during adolescence boys have consistently exhibited a faster rate of increase than girls (Ager, Olivett, & Johnson, 1984; Butterfield, Lehnard, Loovis, Calodarci, & Saucier, 2009; Lang, Hill, & Dean, 2001).

Although research on changes in grip strength performance across age groups for adults without a history of neurological impairment is limited, available research has generally found declining strength with age with evidence of decreased strength as early as middle adulthood. Adult men generally exhibit significantly stronger grip strength than women throughout adulthood. However, as with finger tapping speed, differences in performance appeared to stem from differences in hand size and were resolved when comparisons
were made between men and women with similar hand sizes (Bornstein, 1985; Ruff & Parker, 1993).

**Postural control.**

Postural control appears to develop early for children, as Lang, Hill, and Dean (2001) report that gait and station has been found to be established by age 4. They also note that children are capable of a negative Romberg sign by age 4. A traditional Romberg task requires the individual to maintain balance with their eyes closed, feet together, and arms crossed over their chests, although other positions are sometimes used (e.g., heel-to-toe; Dean & Woodcock, 2003; Vereeck, Wuyts, Truijen, & Van de Heyning, 2008). A positive Romberg sign indicates difficulty maintaining balance.

To further assess development of postural control, Steindl, Kunz, Schrott-Fischer, and Scholtz (2006) designed a study in which they manipulated what they considered to be the three primary components of the sensory system involved in postural control: proprioceptive, visual, and vestibular. Participants attempted to maintain postural stability during various combinations of eyes open or blindfolded, fixed or moving surroundings, and fixed or swaying platform. Steindl et al. found that children were able to adjust for visual input by age 7 or 8 but continue to evidence improvement in adjusting for base mobility into adulthood. Patterns of improvement suggested the sensory system develops earlier for females than males to age 11 or 12, then briefly reverses with males showing more advanced skills through age 13 or 14. For some conditions, gender differences were noted but limited to certain age ranges. For instance, males were found to perform better than females in the 5- to 6-year-old group for the task involving eyes open, fixed
surroundings, and swaying platform. Males also performed significantly better than females on the eyes open, moving surroundings, and swaying platform task in the 5- to 6-year-old group and the 15- to 16-year-old group. Females performed significantly better than males for the blindfolded and swaying platform task in the 9- to 10-year-old group. In the adult group, no significant gender difference was found.

Research has indicated that postural control declines with age among adults. Vereeck, Wuyts, Truijen, and Van de Heyning (2008) studied postural control in adults ages 20 to 83 using a traditional Romberg position while standing on a solid surface and while standing on foam. Participants were assessed with their eyes open as well as with their eyes closed. The researchers found no decline in ability to maintain postural control throughout the age ranges assessed when the participants kept their eyes open. However, with eyes closed, significant decline in ability was found to begin when adults were in their 60’s. Vereeck et al. also found that adults exhibited no decline in postural stability with eyes open while holding a tandem Romberg position (heel to toe) but began to show decline in ability during their 50’s when eyes were closed. Assessment of stability while standing on one leg noted most participants could maintain posture for 10 seconds when their eyes were open but no participants in their 70’s could hold the position for 30 seconds. With eyes closed, a significant decline in performance was found to begin as early as the fourth decade of life. The authors also found a significant gender difference for postural control, with females age 50 and older exhibiting greater difficulty than males in maintaining balance.
**Left-right confusion.**

Research addressing ability to distinguish left from right in performing actions is limited for both children and adults. Fisher and Braine (1982) reported 3-year-old children were generally able to accurately identify left and right, although their study was limited by a small sample size (n=16). In a study of adult self-reports of left-right confusion, Wolf (1973) found that 17.5% of the female participants and 8.8% of the male participants reported experiencing confusion frequently or all of the time when selecting between “all the time,” “frequently,” “occasionally,” “seldom,” or “never.” Nearly 5% of the female participants selected “all the time.”
Participants

This study was a cross-sectional design utilizing an archival dataset obtained during standardization of the Dean-Woodcock Sensory Motor Battery (D-WSMB; Dean & Woodcock, 2003). Participants in the original standardization process were screened to exclude individuals with a history of neurological disorders. The original dataset consisted of 1651 participants. Seventy-six participants were removed due to missing data. The remaining 1575 participants ranged in age from 31 months (2 years, 7 months) to 1140 months (95 years, 0 months).

Participants included 739 males (46.9%) and 836 females (53.1%) which provided a slightly higher ratio of females to males than found with the 2000 U.S. Census population estimates (49.1% male; 50.1% female). Participants were predominantly white (84.0%), with 11.8% identified as black, 2.1% as Asian, 1.6% as Native-American, and 0.5% as other. These results were comparable to 2000 U.S. Census population estimates of 75.1% white, 12.3% black, 3.1% Asian, 2.2% Native-American, and 0.5% other (U.S. Bureau of the Census). The dataset included 8.7% of participants identified as Latino and 91.1% identified as non-Latino, which provided a slightly lower ratio of Latino than non-Latino
than found in the 2000 Census results (12.5% Latino; 87.5% non-Latino); 3 participants did not provide information regarding Latino versus non-Latino ethnicity.

Assessment

This study utilized assessment results for the *Dean-Woodcock Sensory Motor Battery* (D-WSMB) obtained during standardization of the battery. The D-WSMB is comprised of 18 subtests assessing sensory and motor skills. Many subtests include assessment of left versus right or dominant versus nondominant performance and, occasionally, simultaneous performance, resulting in 45 distinct scores obtained by converting the raw scores for each task to a *W* score. The subtests were developed from measures commonly used in clinical settings to identify deficits in neurological and neuropsychological functioning. An additional subtest was included to determine lateral preference but is not included in assessment of deficits. The D-WSMB was individually administered to each participant by advanced graduate students trained in assessment techniques.

The Sensory tests of the D-WSMB include Visual Acuity, Visual Confrontation, Naming Pictures of Objects, Auditory Acuity, Palm Writing, Object Identification, Finger Identification, and Simultaneous Localization. Naming Pictures of Objects was omitted from this study, as it was excluded from the factor analysis conducted by Davis, Finch, Dean, and Woodcock (2006) due to variability in how scores were recorded for the groups included in the analysis. Visual Acuity is a simple assessment of basic vision for the left and right eyes in which the examinee is required to read rows of letters from a card while covering the other eye, with the raw score determined by the row with the smallest print the examinee is able to read. Visual Confrontation assesses perception of
Peripheral visual information by having the examinee identify finger movements made by
the examiner in the examinee’s peripheral vision for the right eye, the left eye, or both
eyes simultaneously; assessment is done at the examinee’s eye level, as well as above and
below the examinee’s eye level. Raw scores for the Visual Confrontation task are
obtained by totaling the number of correct identifications of movement in the right and
left peripheral fields, as well as the total number of correct identifications of movement in
both peripheral fields at the same time. Simple hearing perception is assessed through
Auditory Acuity, in which the examiner makes a sound by rubbing his or her fingers next
to one or both of the examinee’s ears and asks the examinee to indicate in which ear(s) a
sound was heard. Similar to scoring of the Visual Confrontation task, raw scores for
Auditory Acuity are obtained by totaling the number of correct identifications for sounds
made next to the left and right ears and for sounds made next to both ears simultaneously.

Palm Writing, Object Identification, Finger Identification, and Simultaneous Localization
are completed with the examinee being blindfolded. Palm Writing initially requires the
examinee to identify whether an X or an O shape was drawn on the examinee’s palm,
followed by identification of which of five numbers was written on the palm. Finger
Identification requires the examinee to identify which finger the examiner has touched. In
Object Identification, the examinee is asked to identify objects without the use of vision
using only the hand in which the object is placed. In Simultaneous Localization, the
examinee initially identifies when the examiner touches the back of one or both of the
examinee’s hands; localization of hand touch is followed by identification of touch to a
hand, a cheek, or both. For the Palm Writing, Object Identification, Finger Identification,
and Simultaneous Localization tasks, raw scores are obtained by totaling the number of correct identifications.

The Motor tests of the D-WSMB include Gait and Station, Romberg, Construction, Coordination, Mime Movements, Left-Right Movements, Finger Tapping, Expressive Speech, and Grip Strength. Gait and Station utilizes a 5-point scale ranging from “unable to complete” to “within normal limits” to rate the examinee’s skills in basic walking, tandem walking, hopping, and stationary standing, with the scores for each task being totaled to obtain the raw score. The Romberg assessment uses the same scale to rate the examinee’s ability to stand with his or her feet together and eyes closed for 15 seconds; this test also extends the traditional Romberg assessment to look at ability to maintain balance while standing on one foot and standing in tandem alignment (i.e., heel-to-toe). As with the Gait and Station task, the raw score for the Romberg task is obtained by totaling the ratings for each of the conditions presented. With Construction, examinees draw a clock and a cross, which are assessed by assigning 1 or 0 points for meeting or not meeting specified criteria (e.g., cross is similar in size to presented stimulus, shakiness is not evident, numbers are drawn inside the clock) with the raw score for each task being the number of criteria met. The Coordination test involves a two upper extremity movement tasks. In the finger-to-nose task, the examinee alternately touches his or her nose with his index finger then attempts to touch the examiner’s index finger which is held a couple feet in front of the examinee and moved between successive touches to require the examinee to make movements above and below eye level and to cross midline; movements for the right and the left are rated separately in a 5-point scale
ranging from “limb is immobile” to “within normal limits” with the raw score being the rating assigned for each. The second coordination task involves hand-to-thigh movements in which the examinee is timed while making twenty pronation-supination movements of each hand on his or her thigh; two trials are completed for each hand, with the resulting times for each trial averaged to obtain the raw score. With Mime Movements, examinees are scored a 1 or a 0 for ability to coordinate movements while demonstrating how to perform a series of common tasks (e.g., brushing hair, pouring a drink) with the raw score being the total points earned for the five tasks administered. The Left-Right Movements test assesses for left-right confusion as the examinee follows commands involving raising a specified hand or using a specified hand to touch another specified body part (e.g., right knee, left ear) with the raw scoring being the total of commands correctly followed. In Finger Tapping, the examinee is timed for 10 seconds while tapping as rapidly as possible with the right or left hand on a finger-tapping board or a large calculator; five trials are used for each hand and an average is calculated for each hand to obtain the raw score. In Expressive Speech, the examinee repeats words or phrases provided by the examiner, with the accuracy of the pronunciation being rated on a 4-point scale identified as “two or more errors,” “one error,” “no errors, but response was awkward,” and “no errors detected.” The raw score for Expressive Speech is the sum of the ratings for each of the 10 items administered. The Grip Strength test uses a hand dynamometer to assess the examinee’s strength for each hand, with the raw score obtained by calculating an average of three trails for each hand.
Statistical Procedures

For this study, age and gender served as independent variables and performance on measures of sensory and motor skills served as dependent variables. Scores on the sensory and motor skills tasks were grouped according to results of a factor analysis conducted by Davis, Finch, Dean, and Woodcock (2006), which found 3 primary factors identified as Simple Sensory Skills, Cortical Motor and Complex Sensory Skills, and Subcortical Motor and Auditory/Visual Acuity Skills. Within the Davis, Finch, Dean, and Woodcock study, five measures (Palm Writing-Dominant, Palm Writing-Nondominant, Finger Identification-Left, Finger Identification-Right, and Left-Right Movements) were found to have significant loadings on more than one factor. In these cases, the measures were included with the factor that had the highest loading. Scores were grouped by summing the W scores for each measure in the factor and dividing by the number of measures in the factor to obtain mean factor scores for each participant.

A confirmatory factor analysis was conducted to assess the suitability of the factors for use with the dataset utilized in this study. A regression analysis using curve estimation calculations was conducted to identify the trajectory of performance along the age continuum. The curve estimation analyses included evaluation for linear, quadratic, cubic, growth, and exponential patterns in the data. Differences in mean performance within these factors were analyzed for significance using a MANCOVA procedure.

The confirmatory factor analysis was conducted utilizing the Amos 7 statistical software. The MANCOVA and regression analysis procedures were conducted using the SPSS version 15.0 software.
Hypothesis 1

The measures included in this study were organized into three broad categories based on a 3-factor structure proposed by Davis, Finch, Dean, and Woodcock (2006). It was hypothesized that a confirmatory factor analysis would identify the Davis et al. structure as a good fit for the current dataset. However, review of goodness of fit results for the CFA indicated the factor model generated in the Davis et al. (2006) analysis was not a good fit for the current dataset (see Table 1). Chi-square hypothesis testing was significant ($\chi^2$/df=40.572; $p<.001$), although this often occurs with large sample sizes. Analysis of the Root Mean Square Error of Approximation (RMSEA) also indicated a poor model fit (RMSEA=.159) using RMSEA>.10 as the threshold level for poor fit. The lower bound of the RMSEA confidence interval was also above the threshold level (RMSEA_{LO90}=.157). Comparative Fit Index (CFI) and Tucker-Lewis Index (TLI) both indicated a poor fit for the proposed model using values above .90 as the critical threshold level (CFI=.608; TLI=.581).
Analysis of regression weights indicated all scales included in the study loaded significantly on the factor to which each had been assigned in the model, although several scales exhibited low relationships (see Table 2). Specifically, Mime Movements and Finger Tap – Dominant had regression weights below 0.4. Object Identification Left and Right, Finger Tap – Nondominant, Left-Right Movements, and Expressive Speech had regression weights below 0.6.

Table 1

*Confirmatory factor analysis goodness of fit indices*

<table>
<thead>
<tr>
<th>Index</th>
<th>Value</th>
<th>Good fit threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chi-square</td>
<td>40.572,</td>
<td><em>p</em>&lt;.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>p</em>&gt;.05</td>
</tr>
<tr>
<td>RMSEA</td>
<td>0.159</td>
<td>&lt;.10</td>
</tr>
<tr>
<td>RMSEA_{LO90}</td>
<td>0.157</td>
<td>&lt;.10</td>
</tr>
<tr>
<td>CFI</td>
<td>0.608</td>
<td>&gt;.90</td>
</tr>
<tr>
<td>TLI</td>
<td>0.581</td>
<td>&gt;.90</td>
</tr>
</tbody>
</table>

RMSEA = Root Mean Square Error of Approximation  
CFI = Comparative Fit Index  
TLI = Tucker-Lewis Index
Table 2

*Confirmatory factor analysis regression weights*

<table>
<thead>
<tr>
<th>Simple Sensory Skills</th>
<th>Cortical Motor &amp; Complex Sensory Skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand and Cheek - Right</td>
<td>Grip Strength - Dominant</td>
</tr>
<tr>
<td>2.294</td>
<td>1.000</td>
</tr>
<tr>
<td>Hand and Cheek - Left</td>
<td>Grip Strength - Nondominant</td>
</tr>
<tr>
<td>2.257</td>
<td>0.986</td>
</tr>
<tr>
<td>Hand and Cheek - Both</td>
<td>Construction - Clock</td>
</tr>
<tr>
<td>2.089</td>
<td>0.865</td>
</tr>
<tr>
<td>Finger Identification - Left</td>
<td>Construction - Cross</td>
</tr>
<tr>
<td>1.237</td>
<td>0.837</td>
</tr>
<tr>
<td>Visual Confrontation - Left</td>
<td>Hand-Thigh Left</td>
</tr>
<tr>
<td>1.197</td>
<td>0.827</td>
</tr>
<tr>
<td>Finger Identification - Right</td>
<td>Palm Writing - Nondominant</td>
</tr>
<tr>
<td>1.190</td>
<td>0.778</td>
</tr>
<tr>
<td>Visual Confrontation - Both</td>
<td>Palm Writing - Dominant</td>
</tr>
<tr>
<td>1.146</td>
<td>0.777</td>
</tr>
<tr>
<td>Visual Confrontation - Right</td>
<td>Hand-Thigh Right</td>
</tr>
<tr>
<td>1.143</td>
<td>0.743</td>
</tr>
<tr>
<td>Simultaneous Localization - Left</td>
<td>Object Identification - Left</td>
</tr>
<tr>
<td>1.000</td>
<td>0.574</td>
</tr>
<tr>
<td>Simultaneous Localization - Right</td>
<td>Object Identification - Right</td>
</tr>
<tr>
<td>0.980</td>
<td>0.554</td>
</tr>
<tr>
<td>Simultaneous Localization - Both</td>
<td>Finger Tap - Nondominant</td>
</tr>
<tr>
<td>0.849</td>
<td>0.474</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Subcortical Motor &amp; Auditory/Visual Acuity Skills</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Auditory Perception - Left</td>
<td>Left-Right Movements</td>
</tr>
<tr>
<td>1.187</td>
<td>0.440</td>
</tr>
<tr>
<td>Romberg</td>
<td>Expressive Speech</td>
</tr>
<tr>
<td>1.127</td>
<td>0.440</td>
</tr>
<tr>
<td>Auditory Perception - Right</td>
<td>Mime Movements</td>
</tr>
<tr>
<td>1.058</td>
<td>0.371</td>
</tr>
<tr>
<td>Auditory Perception - Both</td>
<td>Finger Tap - Dominant</td>
</tr>
<tr>
<td>1.000</td>
<td>0.352</td>
</tr>
<tr>
<td>Gait &amp; Station</td>
<td></td>
</tr>
<tr>
<td>0.873</td>
<td></td>
</tr>
<tr>
<td>Finger-to-Nose - Right</td>
<td></td>
</tr>
<tr>
<td>0.757</td>
<td></td>
</tr>
<tr>
<td>Near Point Visual Acuity - Right</td>
<td></td>
</tr>
<tr>
<td>0.724</td>
<td></td>
</tr>
<tr>
<td>Near Point Visual Acuity - Left</td>
<td></td>
</tr>
<tr>
<td>0.671</td>
<td></td>
</tr>
<tr>
<td>Finger-to-Nose - Left</td>
<td></td>
</tr>
<tr>
<td>0.654</td>
<td></td>
</tr>
</tbody>
</table>
Hypothesis 2

It was hypothesized that analysis of sensory and motor skills groups by age would identify a curvilinear pattern with increasing scores at the lower end of the age continuum and decreasing performance at the upper end of the continuum. Regression curve estimation analyses were conducted to test the hypothesis. Results for Simple Sensory Skills noted a significant quadratic relationship with age ($\beta^2=-1.449$, $p<.001$). The negative $\beta$ value indicated the relationship was concave (i.e., increasing scores at the lower end of the age range and decreasing scores at older ages). The plot of the results for the Simple Sensory Skills regression analysis is displayed in Figure 1.

Figure 1. Scatterplot and curve estimation regression lines of Simple Sensory Skills mean W scores.
Cortical Motor and Complex Sensory Skills also exhibited a significant quadratic relationship with age ($\beta_2=-2.393, p<.001$). As with Simple Sensory Skills, the relationship for Cortical Motor and Complex Sensory Skills was noted to be concave. Figure 2 displays a plot of the results of the Cortical Motor and Complex Sensory Skills regression analysis.

*Figure 2*. Scatterplot and curve estimation regression lines of Cortical Motor and Complex Sensory Skills mean W scores.

Finally, results for Subcortical Motor and Auditory/Visual Acuity Skills found a significant quadratic relationship with age ($\beta_2=-1.470, p<.001$). The negative $\beta_2$ value
indicated the relationship was concave. The results of the analysis are displayed in Figure 3.

![Figure 3](image)

*Figure 3. Scatterplot and curve estimation regression lines of Subcortical Motor and Auditory/Visual Acuity Skills mean W scores.*

**Hypothesis 3**

It was hypothesized that gender would not be a significant factor in variability in performance of the dependent variables. The significance of age, gender, and possible age by gender interaction was evaluated using a MANCOVA analysis.
Evaluation of the MANCOVA assumptions indicated the assumption of normality was not violated for any of the dependent variables. Specifically, tests of skewness and kurtosis were non-significant for Simple Sensory Skills ($S=-3.990, \ SE=.062; K=18.778, \ SE=.123$), Cortical Motor and Complex Sensory Skills ($S=-1.798, \ SE=.062; K=4.638, \ SE=.123$), and Subcortical Motor and Auditory/Visual Acuity Skills ($S=-1.459, \ SE=.062; K=1.551, \ SE=.123$), indicating the null hypothesis that the variables were normally distributed could not be rejected (see Table 3).

Table 3

**MANCOVA assumption of normality**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Statistic</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Sensory Skills</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skewness</td>
<td>-3.990</td>
<td>0.062</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>18.778</td>
<td>0.123</td>
</tr>
<tr>
<td>Cortical Motor and Complex Sensory Skills</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skewness</td>
<td>-1.798</td>
<td>0.062</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>4.638</td>
<td>0.123</td>
</tr>
<tr>
<td>Subcortical Motor and Auditory/Visual Acuity Skills</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skewness</td>
<td>-1.459</td>
<td>0.062</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>1.551</td>
<td>0.123</td>
</tr>
</tbody>
</table>

A cursory evaluation of scatterplots for the dependent variables suggested the assumption of linearity was violated (see Figures 1-3). Although violation of the assumption of linearity reduces the power of a MANCOVA analysis, the violation was not considered to be a significant concern for this study due to the increased power derived from the large sample size (Tabachnick & Fidell, 2001).
Analysis of the assumption of homogeneity of variance-covariance matrices noted Box’s $M$ test was significant, $F(6, 17220939.081) = 6.722, p<.001$, indicating the covariance matrices were not equal (see Table 4).

**Table 4**

*Box’s $M$ test of MANCOVA assumption of homogeneity of variance-covariance matrices*

<table>
<thead>
<tr>
<th>Box’s M</th>
<th>40.415</th>
</tr>
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<tbody>
<tr>
<td>$F$</td>
<td>6.722</td>
</tr>
<tr>
<td>df1</td>
<td>6</td>
</tr>
<tr>
<td>df2</td>
<td>17220939.081</td>
</tr>
<tr>
<td>Sig.</td>
<td>0.000</td>
</tr>
</tbody>
</table>

The assumption of homogeneity of regression was found to be violated, as a significant gender by age interaction was noted for Simple Sensory Skills ($F=3.980, p=.046$), Cortical Motor and Complex Sensory Skills ($F=22.184, p<.001$), and Subcortical Motor and Auditory/Visual Acuity Skills ($F=5.767, p=.016$; see Table 5).
Table 5

**MANCOVA assumption of homogeneity of regression**

<table>
<thead>
<tr>
<th>Source</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simple Sensory Skills</td>
<td>1.815</td>
<td>0.178</td>
</tr>
<tr>
<td>Cortical Motor and Complex Sensory Skills</td>
<td>4.490</td>
<td>0.026</td>
</tr>
<tr>
<td>Subcortical Motor and Auditory/Visual Acuity Skills</td>
<td>4.591</td>
<td>0.032</td>
</tr>
<tr>
<td>Age</td>
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<tr>
<td>Simple Sensory Skills</td>
<td>0.306</td>
<td>0.580</td>
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<tr>
<td>Cortical Motor and Complex Sensory Skills</td>
<td>34.964</td>
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<tr>
<td>Subcortical Motor and Auditory/Visual Acuity Skills</td>
<td>729.403</td>
<td>0.000</td>
</tr>
<tr>
<td>Gender*Age</td>
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<tr>
<td>Simple Sensory Skills</td>
<td>3.980</td>
<td>0.046</td>
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<tr>
<td>Cortical Motor and Complex Sensory Skills</td>
<td>22.184</td>
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<tr>
<td>Subcortical Motor and Auditory/Visual Acuity Skills</td>
<td>5.767</td>
<td>0.016</td>
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</tbody>
</table>

A significant gender by age interaction for the combined dependent variables was noted, Wilks’ $\lambda = .983$, $F (3, 1569.000) = 8.809$, $p<.001$. Due to the significant Box’s $M$ test result, Pillai’s Trace test is generally preferred for analysis (Tabachnick & Fidell, 2001). Results of Pillai’s Trace also noted a significant gender by age interaction, Pillai’s Trace $= .017$, $F (3, 1569.000) = 8.809$, $p<.001$ (see Table 6).

Analysis parameter estimates (see Table 7) for gender by age interact slopes noted age was not significant for Simple Sensory Skills ($b_1=-.002$, $p=.054$), while the interaction of gender and age was significant and positive for males ($b_1=.003$, $p=.046$). For Cortical Motor and Complex Sensory Skills, age was not significant ($b_1=.001$, $p=.362$) but the interaction of gender and age was significant and positive for males ($b_1=.009$, $p<.001$).
The reported slope for age was significant for Subcortical Motor and Auditory/Visual Acuity Skills ($b_1 = -0.031, p < 0.001$) with a significant and positive gender by age interaction slope for males ($b_1 = 0.005, p = 0.016$). The significant slopes suggest scores on each dependent variable increase with age, with the relationship being stronger for males than females. However, slopes are based on an assumption of linearity. Due to concerns that the assumption of linearity was violated, the slopes may not accurately reflect the relationships between the independent and dependent variables.

Table 6

*Multivariate tests*

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<th>F</th>
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<th>Error df</th>
<th>Sig.</th>
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<tr>
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Table 7

Parameter estimation slopes

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<td>Female by age</td>
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<tr>
<td>Female by age</td>
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<tr>
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<td>Female by age</td>
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(a) Set to 0 due to redundancy

Regression curve estimation analyses were conducted separately for males and females to determine if the observed quadratic relationships between age and the dependent variables continued to hold true regardless of gender. Results for Simple Sensory Skills noted a significant quadratic relationship by age for males ($\beta_2=-1.306$, $p<.001$). Analysis for females also found a significant quadratic relationship ($\beta_2=-1.565$, $p<.001$). The pattern of the relationship was concave for both genders (see Figures 4 & 5).
Cortical Motor and Complex Sensory Skills exhibited a significant quadratic relationship with age for males ($\beta^2 = -2.324, p < .001$). Females also exhibited a significant quadratic relationship for age ($\beta^2 = -2.413, p < .001$). For both genders, the relationship was concave (see Figures 6 & 7).

Results of curve estimation analyses Subcortical Motor and Auditory/Visual Acuity Skills noted a significant quadratic relationship with age for males ($\beta^2 = -1.413, p < .001$). A significant quadratic relationship with age was also noted for females ($\beta^2 = -1.503, p < .001$). The relationships were concave for both genders (see Figures 8 & 9).
Figure 4. Scatterplot and quadratic regression line of Simple Sensory Skills mean W scores for males.

Figure 5. Scatterplot and quadratic regression line of Simple Sensory Skills mean W scores for females.
Figure 6. Scatterplot and quadratic regression line of Cortical Motor and Complex Sensory Skills mean W scores for males.

Figure 7. Scatterplot and quadratic regression line of Cortical Motor and Complex Sensory Skills mean W scores for females.
**Figure 8.** Scatterplot and quadratic regression line of Subcortical Motor and Auditory/Visual Acuity Skills mean W scores for males.

**Figure 9.** Scatterplot and quadratic regression line of Subcortical Motor and Auditory/Visual Acuity Skills mean W scores females.
Chapter 5

This study was conducted to evaluate the relationship of age to measures of sensory and motor skills as assessed by scales from the D-WSMB. The following research questions were proposed for the outcomes of the data:

1. The three-factor structure for the D-WSMB identified by Davis, Finch, Dean, and Woodcock (2001) were labeled as Simple Sensory Skills, Cortical Motor and Complex Sensory Skills, and Subcortical Motor and Auditory/Visual Acuity Skills. This structure was thought to be a good fit for grouping the scales in the dataset used in this study.

2. The relationship of age to each of the factors would reveal a curvilinear pattern with increasing scores at younger ages and decreasing scores at older ages.

3. It was thought that gender would not be a significant factor in variability in performance of the dependent variables.

Analysis of Research Questions

Factor structure.
Contrary to the original consideration, evaluation of goodness of fit statistics for the Davis et al. (2001) factor structure indicated the model was not a good fit for the dataset used in this study. Although the model fit indices argued against use of the Davis et al. model, the significant regression weights for the included scales suggested the model remained useful for this study.

While an exploratory factor analysis, as conducted in the Davis et al. analysis, does not anticipate a perfect fit for variables included in the analysis, a confirmatory factor analysis assumes each variable will only correlate with its designated factor. However, the Davis et al. study noted five scales had cross-loadings, which can reduce goodness of fit results, which could have impacted the goodness of fit results for the current study. Consideration was given to conducting an exploratory factor analysis on the dataset used for the current study. However, the resulting model would be expected to exhibit similar limitations, as a factor analysis by Hill, Lewis, Dean, and Woodcock (2000) also resulted in multiple cross-loadings.

The fit of the Davis et al. (2006) factor structure may also have been impacted by shared commonalities between some measures within a factor that extend beyond the shared relationships with the remaining measures in the factor. Specifically, multiple measures included in the study involve a single activity assessed individually for left and right sides (and sometimes for simultaneous involvement of both sides) or dominant and non-
dominant hands. For example, Finger Tap has separate values for dominant and non-dominant hand performance and Object Identification has entries for the left hand and right hand. These variables may be correlated with one another in ways that are independent of their shared correlation with other variables within the factor (e.g., Finger Tap – Dominant and Finger Tap – Nondominant may relate to one another in ways not shared with other scales identified as Cortical Motor and Complex Sensory Skills). These extraneous relationships may have impacted calculations of model fit.

**Developmental trajectory.**

Regression analyses demonstrated quadratic relationships between age and performance on sensory and motor tasks, which supported the initial hypothesis that performance on the tasks, as measured by the D-WSMB, would improve at the lower end of the age continuum and decline at the upper end of the continuum. The evidence of development of skills in childhood and adolescence was consistent with a large body of research indicating performance on sensory and motor tasks improves at the lower end of the age continuum (e.g., Ager, Olivett, & Johnson, 1984; Arceneaux, Hill, Chamberlin, & Dean, 1997; Bowman & Katz, 1984; Butterfield, Lehnhard, Loovis, Calodarci, & Saucier, 2009; Bub, Masson, & Lalonde, 2006; Hill, Lewis, & Dean, 2000; Lang, Hill, & Dean, 2001; Mathiowetz, Wiemer, & Federman, 1986; Parker, Larkin, & Ackland, 1993; Snow, Blondis, Accardo, & Cunningham, 1993; Steindl, Kunz, Schrott-Fischer, & Scholtz, 2006; Witelson, 1976). The results were not consistent with a study by Etaugh and Levy (1981), which found no significant age difference in tactile perception. However, the
Etaugh and Levy study was restricted to 4- and 5-year-olds and focused on one measure of tactile perception.

At the upper end of the age continuum, research has largely reported declining performance in sensory and motor skills, consistent with the results of this study (Aiken, 1998; Anderson & Enriquez, 2006; Bornstein, 1985; Cohn, Dustman, & Bradford, 1984; Fitzgibbons & Gordon-Salant, 2010; Ruff & Parker, 1993; Rybash, Roodin, & Hoyer, 1995; Stevens & Cruz, 1996; Swerdlow, Filion, Geyer, & Braff, 1995; Thornbury & Mistretta, 1981; Van der Elst, Van Boxtel, Van Breukelen, & Jolles, 2006; Vereeck, Wuyts, Truijen, & Van de Heyning, 2008). However, in regards to tactile perception, Manning and Tremblay (2006) noted that age-related changes might be attributable to decreasing nerve enervations rather than neurological changes. Similarly, for this study, results could have been influenced by physical factors at both ends of the age continuum. For example, poorer performance on the grip strength task for young children and older adults in comparison to adolescents and younger adults could reflect normal changes in muscle strength as opposed to changes in the neurological functioning.

**Differences in age and gender.**

Contrary to the original consideration that gender would not have a significant impact on variability in performance, the results of a MANOVA noted a significant interaction between age and gender for each dependent variable, suggesting the relationship between age and the dependent variables may be different for males and females at some points on the age continuum. The results were particularly noteworthy because the MANCOVA assumption of linearity was violated, which reduces the power of the analysis.
Although some research had demonstrated gender differences in performance on sensory and motor tasks (e.g., Dodrill, 1979; Ruff & Parker, 1993; Yeudall, Reddon, Gill, & Stefanyk, 1987), it was anticipated that combining multiple measures to form the dependent variables would mask any differences that might be present. Nevertheless, results were consistent with a study by Steindl, Kunz, Schrott-Fischer, and Scholtz (2006), which found an age-gender interaction for postural control, as well as a study by Bowman and Katz (1984), which reported an age-gender interaction for grip strength.

**Statistical Considerations**

As noted previously, results of CFA goodness of fit statistics indicated the proposed factor model of the Davis, Finch, Dean, and Woodcock (2006) analysis was a poor fit for the dataset used in this study. Although continued use of the model was justified through analysis of regression weights, the low correlations for some scales likely introduced additional error in the analyses. Further analysis of possible influences that may account for the low correlations and indications of poor model fit was considered to be outside the scope of this research study. However, statistical procedures are available to evaluate these potential influences and may warrant further research. In particular, a Bayesian analysis could be applied to the CFA procedures to adjust for unknown parameters (or influences). Ansari, Jedidi, and Dube (2002) provide a detailed example of the application of a hierarchical Bayesian analysis to confirmatory factor analysis when heterogeneity is suspected.
The current study was designed as a cross-sectional analysis of a longitudinal question, as evaluating changes in performance in the scales throughout the lifespan would be unrealistic for an individual researcher to conduct. However, cross-sectional studies have inherent weaknesses. Of particular concern to this study is the possibility of cohort effects. The participants in this study range from 2 years, 7 months old to 95 years old, allowing for significant variability in life experiences and ages at which exposure to potential environmental influences may have occurred. For example, recent changes in technology, such as the introduction and increasing use of video games, computers, text messaging, etc. expose younger participants to sensory and motor experiences that were unavailable to older participants at the same age. These experiences could impact the neurological functioning of motor and sensory pathways assessed with the D-WSMB, resulting in variations in performance related to the differences in experiences rather than age-related changes. Although a lifespan longitudinal study may not be feasible, longitudinal studies could be conducted for shorter periods (e.g., 3 years, 5 years, 10 years) to evaluate changes over time for participants in the same cohort. In particular, longitudinal studies involving participants at the lower and upper end of the age continuum may be beneficial, as the results of this study noted significant changes in performance at each end of the continuum.

For ease in comparisons of skills across ages, individual scale scores from the D-WSMB were truncated into broad categories based on the Davis, Finch, Dean, and Woodcock (2001) factor analysis to form the dependent variables for this study. Although the dependent variables each exhibited a significant pattern of development and decline, the
scales that comprise the variables cannot be assumed to exhibit the same pattern. Further analysis of individual scales or groups of related scales (e.g., Grip Strength – Dominant and Grip Strength – Nondominant) would be necessary to identify patterns in development and decline of specific skills. This could be accomplished by applying the regression curve estimation procedure utilized in this study to evaluate the developmental trajectories of each measure separately.

Analysis of MANCOVA results noted a significant age by gender interaction for each of the dependent variables with the slopes for each suggesting the relationship between age and gender was stronger for males than for females. In a linear relationship, this pattern would indicate that scores for each dependent variable increased with age (i.e., older participants had higher scores than younger participants). However, regression analysis demonstrated that the dependent variables were not linear, which limits the interpretability of the results. Linearity was not considered to be a significant concern for this study, as the focus was on identifying the developmental trajectory for sensory and motor skills assessed on the D-WSMB and was expected to be non-linear. However, further analysis of the relationships between the independent and dependent variables could be conducted by creating a linear relationship in the data through a log transformation. This approach may be useful in evaluating the relative contributions of age and gender in the performance changes observed.

**Outcomes and Future Research**

Each of the dependent variables exhibited a significant pattern of development and decline in performance across the age continuum. This pattern has implications for
interpretation of performance on sensory and motor tasks in clinical settings, as clinicians would need to modify their perceptions of what constitutes normal and impaired performance based on the age of the individual being assessed. The plots of the regression results provide general guidelines for ages at which children may be expected to have mastered skills and when adults may begin to exhibit declining performance. However, the plots do not specify for clinicians when those observed changes are considered to be statistically significant. Further research using statistical smoothing would allow for identification of points on the age continuum at which changes in scores would be considered significant, thereby providing additional clarification of differences observed in clinical settings.

Statistical smoothing would also allow for comparison between the variables to evaluate whether they develop and decline at the same rate or at differing rates (e.g., Do children reach adult-like performance on Simple Sensory Skills and Cortical Motor and Complex Sensory Skills at approximately the same age or does one reach a plateau at an earlier age than the other?). Given the observed significant interaction between age and gender in this study, the smoothed data could be evaluated for gender differences in development and decline of skills. This approach may also be useful in identifying specific points of improving and decline performance on individual measures if a regression curve estimation analysis identified a quadratic relationship.

Addendum

The dependent variables in this study were developed by combining individual measures of the D-WSMB into broader skill categories. Although the resulting plots of the
regression analyses provide an overview of “normal” development and decline of sensory and motor skills assessed in clinical settings, the pattern of development and decline observed for individual measures is likely to have more practical utility for clinicians. As an addendum to this study, the developmental trajectories of the measures forming the dependent variables were plotted (see Figures 10-47). Previous research reported gender differences in performance on grip strength and finger tapping tasks, which appear to largely attributable to hand size (Bornstein, 1985; Dodrill, 1979; Ruff & Parker, 1993). Therefore, the trajectories for the Grip Strength and Finger Tapping measures of the D-WSMB were plotted separately for males and females.
Simple Sensory Skills

Figure 10. Plot of performance at the 5th and 50th percentiles on Test 3, Visual Confrontation, of the D-WSMB for identification of movement in the right peripheral field.

Figure 11. Plot of performance at the 5th and 50th percentiles on Test 3, Visual Confrontation, of the D-WSMB for identification of movement in the left peripheral field.
Figure 12. Plot of performance at the 5th and 50th percentiles on Test 3, Visual Confrontation, of the D-WSMB for identification of simultaneous movement in the right and left peripheral fields.

Figure 13. Plot of performance at the 5th and 50th percentiles on Test 8, Finger Identification, of the D-WSMB for identification of touch of fingers on the right hand.
Figure 14. Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 8, Finger Identification, of the D-WSMB for identification of touch of fingers on the left hand.

Figure 15. Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 9, Simultaneous Localization, of the D-WSMB for identification of touch on the right hand.
Figure 16. Plot of performance at the 5th and 50th percentiles on Test 9, Simultaneous Localization, of the D-WSMB for identification of touch on the left hand.

Figure 17. Plot of performance at the 5th and 50th percentiles on Test 9, Simultaneous Localization, of the D-WSMB for identification of touch on the both hands simultaneously.
Figure 18. Plot of performance at the 5th and 50th percentiles on Test 9, Simultaneous Localization, of the D-WSMB for identification of simultaneous touch on a hand and the contralateral cheek.

Figure 19. Plot of performance at the 5th and 50th percentiles on Test 9, Simultaneous Localization, of the D-WSMB for identification of touch on the right hand or cheek.
Figure 20. Plot of performance at the 5th and 50th percentiles on Test 9, Simultaneous Localization, of the D-WSMB for identification of touch on the left hand or cheek.
Cortical Motor and Complex Sensory Skills

Figure 21. Plot of performance at the 5th and 50th percentiles on Test 6, Palm Writing, of the D-WSMB for tactile identification of letters (i.e., X or O) and numbers written on the right palm.

Figure 22. Plot of performance at the 5th and 50th percentiles on Test 6, Palm Writing, of the D-WSMB for tactile identification of letters (i.e., X or O) and numbers written on the left palm.
Figure 23. Plot of performance at the 5th and 50th percentiles on Test 7, Object Identification, of the D-WSMB for tactile identification of objects placed in the right palm.

Figure 24. Plot of performance at the 5th and 50th percentiles on Test 6, Palm Writing, of the D-WSMB for tactile identification of letters (i.e., X or O) and numbers written on the left palm.
Figure 25. Plot of performance at the 5th and 50th percentiles on Test 12, Construction, of the D-WSMB for accuracy in copying a figure of a cross.

Figure 26. Plot of performance at the 5th and 50th percentiles on Test 12, Construction, of the D-WSMB for accuracy in drawing an analog clock displaying a specified time.
Figure 27. Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 13, Coordination, of the D-WSMB for speed in completion of 20 supination-pronation sequences using the right hand on the right thigh.

Figure 28. Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 13, Coordination, of the D-WSMB for speed in completion of 20 supination-pronation sequences using the left hand on the left thigh.
**Figure 29.** Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 14, Mime Movements, of the D-WSMB for demonstration of specified actions.

**Figure 30.** Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 15, Left-Right Movements, of the D-WSMB for accuracy in following commands requiring correct identification of left and right (e.g., “Touch your left ear with your right hand”).
Figure 31. Plot of performance at the 5th and 50th percentiles on Test 17, Expressive Speech, of the D-WSMB for accuracy in articulation of specified words and phrases.
Subcortical Motor and Auditory/Visual Acuity Skills

**Figure 32.** Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 2, Near Point Visual Acuity, of the D-WSMB for level of acuity in the right eye using a Snellen chart.

**Figure 33.** Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 2, Near Point Visual Acuity, of the D-WSMB for level of acuity in the left eye using a Snellen chart.
Figure 34. Plot of performance at the 5th and 50th percentiles on Test 5, Auditory Acuity, of the D-WSMB for identification of a rustling sound made next to the right ear.

Figure 35. Plot of performance at the 5th and 50th percentiles on Test 6, Palm Writing, of the D-WSMB for identification of a rustling sound made next to the left ear.
Figure 36. Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 10, Gait and Station, of the D-WSMB for fluidity and balance in completion of forward movement and stationary tasks (i.e., Free Walking, Heel-to-Toe, Hopping, Station).

Figure 37. Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles on Test 11, Romberg, of the D-WSMB for balance in maintaining specified stationary postures (i.e., Feet Together, Toe-to-Heel, One Foot) with eyes closed.
Figure 38. Plot of performance at the 5th and 50th percentiles on Test 13, Coordination, of the D-WSMB for accuracy in alternating movements of touching one’s nose and the examiner’s index finger using the right hand.

Figure 39. Plot of performance at the 5th and 50th percentiles on Test 13, Coordination, of the D-WSMB for accuracy in alternating movements of touching one’s nose and the examiner’s index finger using the left hand.
Finger Tap and Grip Strength by Gender

16 Finger Tapping – Male Dominant

Figure 40. Plot of performance at the 5th and 50th percentiles for males on Test 16, Finger Tapping, of the D-WSMB for speed in tapping the index finger of the dominant hand.

16 Finger Tapping – Female Dominant

Figure 41. Plot of performance at the 5th and 50th percentiles for females on Test 16, Finger Tapping, of the D-WSMB for speed in tapping the index finger of the dominant hand.
**Figure 42.** Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles for males on Test 16, Finger Tapping, of the D-WSMB for speed in tapping the index finger of the non-dominant hand.

**Figure 43.** Plot of performance at the 5\textsuperscript{th} and 50\textsuperscript{th} percentiles for females on Test 16, Finger Tapping, of the D-WSMB for speed in tapping the index finger of the non-dominant hand.
**Figure 44.** Plot of performance at the 5th and 50th percentiles for males on Test 18, Grip Strength, of the D-WSMB for strength when squeezing a hand dynamometer using the dominant hand.

**Figure 45.** Plot of performance at the 5th and 50th percentiles for females on Test 18, Grip Strength, of the D-WSMB for strength when squeezing a hand dynamometer using the dominant hand.
Figure 46. Plot of performance at the 5th and 50th percentiles for males on Test 18, Grip Strength, of the D-WSMB for strength when squeezing a hand dynamometer using the non-dominant hand.

Figure 47. Plot of performance at the 5th and 50th percentiles for females on Test 18, Grip Strength, of the D-WSMB for strength when squeezing a hand dynamometer using the dominant hand.
References


Amos (Version 7) [Computer software]. Armonk, NY: IBM.


