6-12-2007

Does a Continuous Measure of Handedness Predict Reading Related Processes and Reading Skills across the Lifespan?

Michele Harrison Brenneman

ACCEPTANCE

This dissertation, DOES A CONTINUOUS MEASURE OF HANDEDNESS PREDICT READING RELATED PROCESSES AND READING SKILLS ACROSS THE LIFESPAN?, by MICHELE HARRISON BRENNEMAN, was prepared under the direction of the candidate's Dissertation Advisory Committee. It is accepted by the committee members in partial fulfillment of the requirements for the degree Doctor of Philosophy in the College of Education, Georgia State University.

The Dissertation Advisory Committee and the student's Department Chairs, as representatives of the faculty, certify that this dissertation has met all standards of excellence and scholarship as determined by the faculty. The Dean of the College of Education concurs.

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ABSTRACT

DOES A CONTINUOUS MEASURE OF HANDEDNESS PREDICT READING RELATED PROCESSES AND READING SKILLS ACROSS THE LIFESPAN?
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The purpose of this research was to investigate the relationship between handedness, reading skills, and reading related cognitive processes. The research results with regard to handedness, specific reading skills, and reading related cognitive processes are ambiguous at best. The method in which handedness is measured contributes to these diverse research findings, therefore the present investigation addressed these methodological limitations. A large normative sample of up to 1383 participants that ranged in age from 4 to 80 completed the *Woodcock Johnson Psycho-Educational Battery-Revised* (Woodcock & Johnson, 1989a; Woodcock & Johnson, 1989b) or the *Woodcock Johnson Psycho-Educational Battery-Third Edition* (Woodcock, McGrew, & Mather, 2001) in combination with the *Dean Woodcock Sensory Motor Battery* (Dean & Woodcock, 2003) lateral preference scale, a continuous measure of handedness. Polynomial multiple regression analyses indicated curvilinear relationships between handedness and reading comprehension and basic reading skills, along with handedness and auditory working memory. Individuals towards the extremes of the handedness continuum performed lower on the reading related tasks. Therefore, just knowing a general classification of right, left

or mixed handed will not provide significant knowledge regarding lateralization or potential cognitive and academic costs and benefits. One overarching implication of these findings is that laterality is an important predictor variable of reading skills and related reading processes, hence knowledge of an individual's hand preference on a continuum may well be useful for evaluative purposes.

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A Dissertation

Presented in Partial Fulfillment of Requirements for the
Degree of
Doctor of Philosophy
in
School Psychology
in
the Department of Counseling and Psychological Services
in
the College of Education
Georgia State University

Atlanta, Georgia
2007

ACKNOWLEDGMENTS

I would like to thank my committee members, Dr. Scott Decker, Dr. Joel Meyers, Dr. Chris Oshima and Dr. Catherine Cadenhead, for all of their input and support. I am also grateful for the enormous amount of support I received from my cohort, Jasolyn Henderson, Jana Ladner, Sharon Thompson, and Karen Lopp, who have helped motivate me throughout the program.

I am especially thankful to have such a wonderful husband, Jerome, without whose love and support I would not have been able to do this while working and raising our precious daughter Kyra. I am also grateful for my parents for their love and encouragement to challenge myself throughout life and nourish my intellectual curiosity. Thank you to many others who have supported me throughout this project and my journey through this program.

TABLE OF CONTENTS

Page

LIST OF TABLES

CHAPTER ONE

PREDICTING READING PROCESSES AND ACHIEVEMENT ACROSS THE LIFESPAN THROUGH HANDEDNESS MEASUREMENT: A REVIEW OF RESEARCH WITH IMPLICATIONS FOR ASSESSMENT PRACTICES

Introduction

As early as 1937 when Orton reported that children with reading difficulties had strephosymbolia, or twisted symbols, research in the area of reading was initiated only to proliferate further throughout the next seventy years. Simultaneously, research began to consider hemispheric lateralization through the work of Broca and Dax (Bishop, 1990) concerning speech and lesions in the left cerebral hemisphere. Since that time, the knowledge base concerning reading and laterality and the relationship between the two has come a long way, yet questions continue to remain unanswered due to inconsistencies of the research results. One of the most popular measures of hemispheric lateralization is handedness which is important because it provides insight into brain lateralization that would otherwise not be readily available for study. Furthermore it can give us possible clues to behavior. For example, handedness has a history of being associated with various mental illnesses and diseases, as well as neurodevelopmental disorders such as dyslexia. As with research in reading, the research findings have been inconsistent and therefore not as informative about brain functioning and human behavior as desired. It is the goal of this review to address the literature in terms of specific reading processes and reading related skills and its relationship with handedness as a measurement of laterality as the purpose of this paper is to help inform School Psychologists about this relationship as it relates to current practices in the schools, particularly screening and observational processes. Additionally, the review will address the limitations of the research that may explain these inconsistencies and suggest guidelines for future research and clinical assessment practices in the schools. This is important as early identification and treatment for reading problems is key for future reading success.

Review

Reading Processes and Reading Related Skills

As reading is likely the most important academic skill necessary for school completion and enhanced quality of life, it is crucial to investigate the underlying processes contributing to its development. Researchers have demonstrated that the type of orthography influences phonological awareness development. Torgesen and Wagner (1994) noted “phonological awareness is generally defined as one’s sensitivity to, or explicit awareness of, the phonological structure of the words in one’s language” (p. 276). Exposure to transparent languages, those with clear connections of sounds to letters, expands consciousness at the phoneme level. In contrast, contact with languages that focus on the onset-rime levels, the initial consonant, vowel and subsequent consonant level, advances phonological awareness at the initial consonant point, rather than the phoneme level (Ellis & Hooper, 2001; Wimmer, Landerly, & Schneider, 1994). The phoneme level rather than the rime or vowel and subsequent consonant level has been suggested to have the most impact on learning to read (Hulme, et al., 2002; Nation & Hulme, 1997).

Research related to phonological awareness and reading has noted a significant relationship between phonological awareness and basic reading skills which then can impact reading fluency and comprehension (Adams, 1990; Carroll & Snowling, 2004; Chiappe & Siegel, 1999; Chiappe, Chiappe, & Gottardo, 2004; Chiappe, Siegel, & Gottardo, 2002; Durgunoglu, Nagy, & Hancin-Bhatt, 1993; Gottardo, 2002; Muter & Diethelm, 2001; Oakhill, Cain, & Bryant, 2003; Thompkins & Binder, 2003; Tunmer, Herriman, & Nesdale., 1988; Wagner & Torgesen, 1987; Wagner, Torgeson & Rashotte, 1994; Morris, et al., 1998; Van Alphen, et al., 2004; Vukovic, Wilson, & Nash, 2004). Phonological awareness is just one aspect of phonological processing which is defined as "mental operations that are involved when the phonological, or sound structure, of oral language is utilized in decoding written language" (Torgesen, et al., 1997, p. 162). The inclusion of awareness of phonology, phonological short-term memory and rate of access to phonologically coded information in long-term memory is typically implied as part of phonological processing (Adams, 1990). Phonological processing explained the primary percentage of variance towards reading in English (Gottardo, 2002; Hulme, et al., 2002), more so than oral language proficiency and onset-rime awareness.

Additional research has tried to separate out different parts of phonological processing, such as phonological memory and rhyme awareness. According to Gathercole, Willis, and Baddeley (1991), phonological memory and rhyme awareness did share a common phonological processing component, but other analyses established that the types of phonological processing tasks were nonetheless differentially linked with reading and vocabulary development. One of the skills typically housed under the term phonological processing, naming speed or rapid naming, has been found to be crucial for reading (Bowey, Storey, Ferguson, 2004; Manis, Seidenberg, & Doi, 1999; Morris, et al., 1998; Parrila, Kirby, & McQuarrie, 2004; Vukovic, Wilson, & Nash, 2004). Naming speed and phonological awareness were both noted as key factors in reading as set out in the double deficit hypothesis of dyslexia formed by Wolf and Bowers (1999). According to this hypothesis, deficits in phonological skills are different than deficits connected with the speed of reading-related cognitive processes associated with the identification of letters and the sequential scanning of print. Rapid naming tasks require some of these nonphonological processes. However, there has been debate about whether naming speed is an independent variable or is part of phonological processing. Research has suggested that phonological measures contribute more of the variance to reading decoding tasks; while rapid naming measures are more involved in word identification skills (Wolf, et al., 2002). Findings were equally supportive of the independence of the two deficits despite correlations between the two (Manis, et al.; 1999; Swanson, Trainin, Necoechea, & Hammill, 2003; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Wolf, et al., 2002; Wolf, 1999; Wolf & Bowers, 1999) although according to Vukovic and Siegel’s recent review of literature (2006), there is not support for a separate deficit of naming speed.

In addition, researchers have conveyed that while phonological reading processes are crucial for the development of good reading skills, there is more to reading than phonological processing (Parrila, et al, 2004; Share & Stanovich, 1995; Van Alphen, et al., 2004; Vukovic, et al., 2004). A number of studies have shown that there is unexplained variability in orthographic reading skills in children and adults even after controlling for intelligence, phonological processing, and exposure to print (Barker, Torgesen, & Wagner, 1992; Cunningham & Stanovich, 1991; Stanovich & West, 1989). Torgesen, et al. (1997) suggested that the unexplained variability can be accounted for by unreliable assessment of reading experience and skills, or possibly an additional processing variable that directly impacts the rate at which orthographic representations are formed. Many other variables are important for reading skills, including knowledge of the alphabet and letter names (Foy & Mann, 2003; Muter & Diethelm, 2001; Siegel, 1993; Treiman & Rodriguez, 1999), verbal short term memory (Chiappe, et al., 2004; Morris, et al., 1998; Swanson, 1993, 1994), context (Thompkins & Binder, 2003), and semantics, lexical access and skill (Comeau, Cormier, Grandmaison, & Lacroix, 1999; Morris et al., 1998; Nation & Snowling, 1998; Unsworth & Pexman, 2003).

Another significant variable related to reading skills is verbal working memory (Chiappe, Hasher, & Siegel, 2000; Comeau, et al., 1999; Gottardo, Stanovich, & Siegel, 1996; Jeffries & Everatt, 2004; Kibby, Marks, Morgan, & Long, 2004; Swanson, 1993, 1994). According to Baddeley’s model of working memory, there are three components; the first being the central executive which chooses and directs processes, including coordination between the other two components: the articulatory loop which has a role in storage of verbal information and the visuospatial scratch pad which stores imagery and spatial information (Baddeley, 1992). In general, studies examining particular working memory components have indicated that the articulatory or phonological loop is often impaired in children with reading decoding problems, but also the executive processing and long term memory processes run by the central executive component of working memory may impair reading comprehension (Swanson, 1999). Investigators have indicated that verbal working memory relates to reading, with results mixed as to which type of reading skill. Unique variance for verbal working memory has been found for word reading and reading comprehension tasks (Gottardo, et al., 1996; Swanson, 1993), with an even larger proportion of unique variance on the reading comprehension measure (Gottardo, et al., 1996). In contrast, Oakhill, Cain, and Bryant (2003) found that working memory was predictive of reading comprehension but not the ability to read words. This would be supportive of the model suggesting that there are two independent types of reading, comprehension and accuracy (Oakhill, Cain & Bryant, 2003).

In summary, there are many processes that are crucial to reading skills such as phonological awareness, rapid naming, auditory working memory and other aspects of language. As the goal of this article is to help clarify the relationship of these reading processes with handedness, the question then becomes how do these reading processes and skills relate to the brain and lateralization in particular? In order to answer this question, a review of basic hemispheric laterality is necessary.

Hemispheric Laterality

Each hemisphere of the brain has its own unique way of processing information. In general, the left hemisphere is typically responsible for speech, language, hearing, and verbal memory, while the right hemisphere is in charge of processing tactile information, visual-spatial data, and emotions (see reviews in Dean, 1984; Hellige, 1990; Nass, 2002). That being said, we are constantly learning about shared functions of both hemispheres. Both hemispheres are responsible for motor information. The corpus callosum sits between the two hemispheres and is the primary structure responsible for interhemispheric interaction. Although there is some evidence that infants' brains are extremely plastic and brain development is altered through modifications of neural circuitry and the creation of novel circuitry, researchers also believe that the two cerebral hemispheres are innately specialized to a degree at birth (Nass, 2002; Segalowitz & Hiscock, 2002). Research suggesting the key pathways from the motor cortex in the brain to the muscles throughout the body are crossed contralaterally has led to the assumption that right hand functions are principally controlled by the left hemisphere, while left hand functions are controlled by the right hemisphere (Bishop, 1990). Past research on laterality has generally indicated that most people prefer the right side (e.g. are right-handed, right-footed) with this preference being influenced by left hemisphere (Annett, 1975; Dean & Woodcock, 2003). Research with infants has noted that there are consistent laterality asymmetries that can be linked to lateral hand preference and the right handed bias of the population (Corbetta & Thelen, 2002).

More recent research has purported that the left hemisphere also influences left-handedness, possibly through interhemispheric interconnections as evidenced in manual tasks and bilateral fingertapping tasks (Harrington & Haaland, 1991; Njiokiktjien, et al., 1997). For example, Njiokiktjien, et al. (1997) found that for left handers regularity in a bilateral fingertapping study increased with age, with the exception of the older children, but it did not increase in right handers. Furthermore, they found better coordination between the two hands at older ages attributable to an increase in control of the left-hand. The authors explained this as potentially due to sequential movements being controlled by the left hemisphere in both dextrals (right-handers) and sinistrals (left-handers) and the degree of handedness also being primarily controlled by the left hemisphere.

It is widely accepted that the left hemisphere is dominant for language, particularly in the right-handed. A review of hemispheric specialization neuroimaging studies of functional and structural asymmetries found that left-handers have an increased likelihood over right-handers to have an uncharacteristic pattern of hemispheric specialization for language (Josse & Tzourio-Mazoyer, 2004). Additionally, handedness and footedness have been found to be significant predictors of language laterality (Strauss & Wada, 1983; Watson, Pusakulich, Ward, & Hermann, 1998), with results suggesting higher numbers of left-handers and left-footers in those with right language dominance.

Measurements of hemispheric laterality and reading. In order to assess each hemisphere's functionality, laterality has been studied through use of many techniques, with the oldest being observation of patients following an injury in a single hemisphere of the brain (Hellige, 1990). In addition, a wide range of techniques has been utilized to measure hemispheric specialization in a normal population. One popular noninvasive strategy to study reading and laterality has been dichotic listening, where stimuli are presented simultaneously to both ears so researchers can determine function through the stimulation of one hemisphere. The accuracy of identification of stimuli is then used to infer cerebral lateralization of function (Hellige, 1990; Kraft, Harper, & Nickel, 1995; Reiss, Tymnik, Kogler, Kogler, & Reiss, 1999). Research on earness, or the preference for which ear, has suggested that it can be reliable for children as young as three years of age (Kraft, et al., 1995) and that in right-handers, there is a tendency toward left ear dominance (Papousek & Schulter, 1999). Additionally, the mean duration of right-ear hearing is longer than that for the left-ear in right-handed participants, and mean duration of left-ear hearing is longer than that for the right-ear in left-hande participants (Dane & Bayirli, 1998). A reduced left hemisphere language dominance has been implicated in groups with simultaneous reading and language impairments (Asbjornsen, Helland, Obrzut, & Bolike, 2003). When presented with a writing condition during which children with dyslexia had to write their dichotic listening responses rather than verbalize them, those with less lateralization (or less right ear advantage) were relatively poorer in single-word decoding, which has implications for the left hemisphere (Kershner

& Stringer, 1991). Kershner and Micallef (1991) found that weak hemispheric lateralization was related specifically to word decoding skills. A separate dichotic listening task yielded equal performance from normal and dyslexic readers; but normal readers demonstrated more asymmetrical auditory evoked potentials in the left temporal regions than the dyslexic participants. In essence, the more symmetrical the activation bilaterally, the poorer the phonological processing, particularly with ending sounds as opposed to beginning or middle sounds (Brunswick & Rippon, 1994).

Dual task laterality methods have also been utilized to assess reading and its relationship with hemispheric specialization (Hiscock, Antoniuk, Prisciak, & Von Hessert, 1985; Van Hoof & Van Strien, 1997). Hiscock, et al. (1985) used reading and simultaneous fingertapping with children and found that silent reading causes asymmetric interference (i.e. disturbing concurrent right-hand tapping more so than left-hand tapping). Vocalizing was noted to increase the level of bilateral interference dramatically. Van Hoof and Van Strien (1997) also utilized a word reading and fingertapping task with university students and found that consistent right-handers evidenced increased interference during fingertapping with their right hand, whereas, consistent left-handers showed interference with both hands. The authors hypothesized that the bilateral hand interference in left-handers reflect a more capricious pattern of speech lateralization in right-handers. An additional sentence-reading paradigm revealed a gender difference, with a more discerning right-handed interference pattern in men than women for which the authors implied a more precise lateralization of language pattern.

Imaging techniques have recently become useful for studying hemispheric differences and reading. Shaywitz, et al. (2003) found impaired left hemisphere posterior brain processing for nonsense words in two different groups of poor readers, a group that was consistently poor and a group that demonstrated poor reading in elementary school but not in high school. Furthermore, when reading real words, there were no differences noted between the nonimpaired readers and consistently poor readers in the temporoparietal area. In contrast, the consistently poor readers increased their activation compared to the nonimpaired readers in the occipitotemporal region even though the nonimpaired readers had higher reading scores. The authors explained that while both nonimpaired readers and consistently poor readers use the occipitotemporal system for reading real words, they in fact do not process them the same. The authors hypothesized that nonimpaired readers use the phonology system and the impaired readers using rote memory for real word recognition. Similarly, Shaywitz, et al. (1998) found dysfunction in the left hemisphere posterior brain during reading tasks in participants with dyslexia. Following a year-long phonology intervention neuroimaging results showed more activation was present in the inferior frontal gyrus and middle temporal gyrus than prior to the intervention (Shaywitz, et al. 2004). Furthermore, a year after the intervention, development had continued in the left superior temporal and occipitotemporal regions, as well as in both sides of the inferior frontal gyri. This suggests that a phonologically based remediation intervention may assist in the development of the neural processes related to phonologically based reading and more globally suggests that interventions can change neural systems, not just surface skills.

Another behavioral method of assessing laterality and reading has been to investigate visual fields, which are expected to represent the opposite hemisphere (Chiarello, Hasbrooke, & Maxfield, 1999; Lavidor & Ellis, 2003; Scott & Hellige, 1998). Right visual fields/left hemisphere processing has been implicated for phonological priming, while left visual field/right hemispheric word processing has been noted for activation of orthography (Chiarello, et al., 1985; Lavidor & Ellis, 2003). In contrast, Chiarello et al. (1999) found that when no attention was paid to phonological or orthographic similarity of words, this information is processed by either the right or left hemisphere. Pronunciation of words has also been investigated through visual field measures. Scott and Hellige (1988) found no advantage for the left hemisphere/right visual field associated with regularity or with the orientation of the words but did note an advantage for both accuracy and reaction time independent of word regularity and frequency as processed by the left hemisphere/right visual field.

Footedness, or preference for the right or left foot, has also been investigated but more in the area of language processes related to reading, than reading itself. It was found to be a predictor of language lateralization, even stronger than handedness in several studies (Elias & Bryden, 1998; Watson, Pusakulich, Ward, & Hermann, 1998). But in another study, footedness was not as strong as handedness (Polemikos & Papaeliou, 2000).

Hand skill, typically measured by peg moving speed, has been another primary measure of the interrelationship between reading skills, cognitive processes and laterality. Brunswick and Rippon (1994) found no differences in hand skill in a group of dyslexics versus normal controls. Similarly in a group of normals and reading impaired siblings, no relationship was found between lateralization of hand skill and reading or cognitive abilities (Francks, et al., 2002; Francks, et al., 2003), although a later study by many of the same researchers (Francks, et al., 2003) found correlations between reading ability and fine hand motor skill in general with poor reading performance associated with slower peg moving. Annett (1992) found that left handers were poorer than all other hand skill groups in phonological processing, a significant processing area for reading. Smythe and Annett (2006) noted that sinistrals demonstrated weaker phonological skills but results were not statistically significant as a whole when all groups were clumped together. However, when children were chosen for good performance on other measures, including reading, there was a significant increase in the prevalence of left-handedness in those with poor phonological processing. In contrast, there was no relation between reading and hand preference but left and right hand skill correlated with reading in another study (Palmer & Corballis, 1996). Crow, Crow, Done, and Leask (1998) found that the worst cognitive deficits were evidenced towards the middle of the hand skill continuum, whereas less pronounced deficits that were dependent upon sex and ability were noted at both ends of the continuum. For reading comprehension in particular, Crow, et al. (1998) found a minor deficit towards the dextral end with females performing worse than males except at the equal hand skill point where the trend reversed. The authors also noted a global development delay in children who did not ascertain dominance indisputably in one of the hemispheres by age 11.

One way that researchers have tried to synthesize the research regarding hemispheric laterality and reading or other cognitive abilities is to test various theories regarding handedness and its relationship to hemispheric lateralization. These theories have also attempted to explain various impairments and disorders related to reading. An explanation of these theories is necessary for readers to understand possible reasons for handedness and why it may be related to reading skills and processes.

Handedness Theories

Theories range from Annett's right shift theory to Yeo and Gangestad's developmental instability model. Perhaps the best-known theory is Annett's right shift theory.

Right shift theory. Right shift theory suggests that there is one gene that influences human handedness; this RS+ gene causes an asymmetrical bias for the growth of the brain towards the direction of the left hemisphere in utero (Annett, 2002). This right shift factor induces a speech bias to the left hemisphere, rather than the right hemisphere, with the shift in handedness due to incidental left hand weakening. When the RS + factor is missing, there is an element of chance that lateralizes right, left and bilateral speech with many different plausible combinations.

Annett explains phonological reading through her theory as well. She noted that the increase in mixed and lefthanders among dyslexics is due to the lack of the RS+ gene, or an R -- genotype, rather than the bias towards left hemisphere speech, and the shift in handedness towards dextrality. When explaining the small effect of handedness on dyslexia, Annett and colleagues (Eglington & Annett, 1994; Annett, 2002) attributed it to the presence of some strong dextrals that are likely of a different genotype, the RS ++ genotype, rather than the genotype seen in the most common form of dyslexics, those with phonological difficulties. In order to explain why not all individuals with the RS-- genotype would have difficulties with phonological processing, Annett (2002) noted that chance would lead the lateralization to one side or the other in at least half of the cases. For those that chance resulted in more negative consequences such as using both hemispheres for speech processing, the greater load on production and storage may lead to an increased risk of problems (Annett, 2002). Additionally, Annett proposed that there are risks to reading toward the right of the spectrum that might be due to “over-typical”, rather than atypical, cerebral dominance. This implies that the right hemisphere has been weakened so errors in visual word memory, for example, could be a characteristic of this group.

Developmental instability model. In contrast, Yeo and Gangestad have formulated the developmental instability model, which is a polygenetic model rather than a single gene model like the right shift theory. According to Gangestad and Yeo (1994), developmental instability, the inability to express the forechosen developmental design for our species as specified, is caused by arbitrary environmental effects such as pathogens, toxins, and mutations (Gangestad & Yeo, 1994; Yeo, Thoma, & Gangestad, 2002). This instability can cause handedness consequences such as left-handedness or extreme right-handedness (Yeo, Gangestad, & Daniel, 1993). Yeo, et al. (1993) suggest that a vulnerability towards developmental disturbances may be a link between handedness and various neurodevelopmental disorders. This could lead to various configurations of language (Natsopoulos, Kiosseoglou, Xeromeritou, & Alevriadou, 1998).

Genetic plus environment model. Geschwind's genetic plus environment model has also been introduced to explain handedness. Geschwind and Galaburda (1985a, 1985b) claim that sinistrality is only somewhat genetic and to some extent it is a result of intrauterine influences, such as too much testosterone. They noted that testosterone could cause fast development in the right hemisphere, which in turn increases functions typically mediated there, such as visual spatial skills. When there are excessive impediments of growth or early puberty, full development does not occur therefore increasing the likelihood of learning disabilities or inferior overall functioning (Geschwind & Galaburda, 1985a). One study's findings that "pure" left-handers reported the highest number of speech disorders (Cornish, 1996) has provided support for part of the theory, but the same study did not support the superior right hemisphere functions.

Prevalence of Handedness

It is important to now review the research regarding the prevalence of handedness to aid in the understanding of how the incidence of certain classifications of handedness, measurement and demographics may contribute to differences in the research. Handedness incidence figures fluctuate, depending on the study, the sample demographics, and the definitions. According to Annett (1998), when evaluating samples of children, military personnel and college undergraduates, the proportions of left-handedness were consistent. Approximately 3 to 4% of the participants were consistent left-handers, while 60 to 70% were consistent right-handers. Mixed-handers represented 25 to 33% of the samples. Results of Annett's 2004 study were somewhat different when she changed the definitions. In this study, Annett utilized a questionnaire and evaluated the difference in prevalence by changing the definitions of mixed, right and left handedness. For example, when any combination of left, right and equal responses were denoted as mixed handedness, only 48% of the participants were consistent right-handers, while 49% were mixed. But, when the definition of mixed handedness was limited to definite preferences for left and right-handedness, as in her earlier study, there were only 36% mixed-handers (Annett, 2004).

Handedness by country. Recent studies have sought to clarify differences due to geographical and cultural variations. In an international study of 17 different countries, left-handedness while writing was reported to vary from 2.5 % in Mexico to 12.8% in Canada. The participants from the United States reported a 12.2% incidence of left-handedness. The average percentages of left-handedness, right-handedness, and mixed handedness were 9.5%, 89.6%, and .9% respectively (Perelle & Ehrman, 1994). Raymond and Pontier's (2004) review of studies that focused on throwing objects and using a hammer found approximately 7 to 20% of the throwers in the United States to be left-handed depending upon the dataset, while in France it varied from 15 to 21%. In contrast, Annett (2003) found no difference in the handedness between participants in France and the United Kingdom universities. Studies reflecting incidence representations from other countries tend to reflect the same pattern of handedness, but at different percentages with ambidextrousness and left-handedness varying the most. Right-handedness is the most prevalent in Germany (Dittmar, 2002), Columbia (Ardila, Rosselli, & GENECO, 2001), and China (Li, Zhu, & Nuttall, 2003).

Handedness by gender. Following along the same line, the incidence reports of handedness vary by gender. The exact incidence levels are made even more ambiguous when you consider that the same researchers find a certain incidence level in one study but another in a different study. For example, according to Annett in 1999, the shift to dextrality was stronger in females than males by about 20% (Annett, 1999), but no differences were found for sex in 2004 (Annett, 2004). Brito and Santos-Morales (1999) found that the frequency of left-handedness ranged from 7% to 26% depending upon the task with boys, and 5% to 20% depending upon the task with girls. Additionally, they found that girls were more right-handed and less mixed handed (67.6% and 30.1% respectively) as compared to boys (54.8% and 42.2% respectively). When looking at young children’s handedness, Ozturk, et al. (1999) found a 9.4% incidence rate of left-handedness in children five to six and a half years old that did not differ between boys and girls. In conclusion, the gender and handedness research suggests a range from no statistical significant between genders to significantly more left-handers in the males than females.

Handedness by age. The pattern of age and handedness also varies per study. According to many studies, the younger you are, the less right-handed (Brito & Santo-Morales, 1999; De Agostini & Dellatolas, 2001; Dittmar, 2002; Galobardes, Bernstein, & Morabia, 1999; Porac, 1993). This trend has been attributed to the effects of birth cohorts and related social pressures, decreased population of left handers, as well as the vulnerability of the right hemisphere during aging (Brito & Santo-Morales, 1999; Dittmar, 2002). However, other studies have found no link between age and handedness (Ardila, et al., 2001). As previously mentioned, handedness prevalence rates vary depending upon the study. This pattern appears to hold true whether the aspect being investigated is age, gender or country.

Relationship of Handedness and Cognitive Abilities Related to Reading

Language in general. Investigators reviewing language and cerebral lateralization research (Josse & Tzourio-Mazoyer, 2004) found it to be multidimensional. Manaut, Gomez, Vaquero, and Rodriguez (2002) noted that hemispheric specialization of language is not finished until adolescence, particularly in boys, which suggests an earlier maturation period for girls. Additionally, they noted that family history of handedness on the left side of the continuum is a factor that may delay the age of language lateralization. Josse and Tzourio-Maqzoyer (2004) noted that the size of the left planum temporale explained part of the relationship between left hemispheric specialization and language comprehension. Additionally, the authors noted that a higher chance of an atypical hemispheric specialization pattern for language is more likely in left-handers than right-handers. Foundas, Leonard and Hanna-Pladdy (2002) found that the size of the left planar was the best predictor of handedness degree. Furthermore, they noted that a larger left planum temporal and more distinguished leftward planar asymmetries were more frequent in consistent right-handers than consistent left-handers. Moreover the extent of the planar asymmetry was smaller in the left-handers as compared to the right-handers.

Kolk and Talvik (2002) found that there was not a significant difference between right and left-handers on language tests, including receptive language, verbal fluency and phonological processing tests. In general though, left-handers performed better on a small number of the language comprehension tasks, as well as demonstrated stronger short term memory functioning than right-handers. Additionally, there has been no evidence of a significant relationship between hand preference and vocabulary or word fluency (Cerone & McKeever, 1999).

Phonological processing. One of the most important aspects of language for the development of reading skills is phonological processing. Much of the research suggests that individuals at the left end of the continuum are at risk for poor phonological processing (Annett, 1992; Annett, 2002). For example, more difficulty with rhyme awareness (Annett, 1992), phonological awareness (Brunswick & Rippon, 1994) and phonological fluency (De Agostini & Dellatolas, 2001) has been evident. Smythe and Annett (2006) found poor phonological awareness with sinistrals but results were not statistically significant. In contrast, Kolk & Talkvik (2002) found no relationship between handedness and phonological processing.

Tremblay, Monetta, and Joanette (2004) found that while the left and right hemispheres may be equal in terms of phonological processing speed when the orthography –phoneme match is more transparent for both right- and left-handers, more errors were made when participants used their right hemisphere to process words than when using left hemisphere processes. This is consistent with Annett's (1991) findings of more errors towards the left end of the continuum than the right. Additionally, when the demands for processing phonological information increase, there is more evidence of the superiority of the left hemisphere (Chiarello, Hasbrooke & Maxfield, 1999).

Memory. A review of the research revealed no studies conducted regarding working memory and handedness in particular, however investigations using Positron Emission Tomography (PET) imaging procedures has indicated that working memory is composed of a verbal subsystem, which is lateralized to the left hemisphere, and a spatial subsystem which is lateralized to the right hemisphere (Smith, Jonides, & Koeppe, 1996). Verbal working memory has been associated with the frontal lobes, as well as Broca's area (Reuter-Lorenz, et al., 2000; Smith, et al., 1996). Smith, et al. (1996) also found evidence of activity in the parietal lobe, prefrontal cortex and supplemental motor cortex, all within the left hemisphere. Reuter-Lorenz, et al. (2000) noted that a left lateralization pattern for verbal working memory and right lateralization for spatial working memory has been implicated in younger adults, but older adults activate bilaterally.

Research has been conducted relevant to more general memory processes and handedness. The results of three studies (Jones & Martin, 1997; McKelvie & Aikins, 1993; Martin & Jones, 1997) similarly note that there was a significant difference in verbal recall between right and left-handed groups. In all three studies, the frequency of correctly recalling the left-facing orientation of a head on a coin was greater for the left-handed groups than for right-handed groups suggesting a general contralateral effect of handedness on memory. Martin & Jones (1997) suggested the results might imply processing with the visuospatial sketchpad component of working memory. Another study indicated this pattern also occurs when people recall the orientation of a person on a road sign from their everyday memory (Martin & Jones, 1998). Additionally, Annett (1992) found that word order memory was sacrificed in children who were at the left end of the handedness continuum.

Laterality and Reading

In order to comprehensively discuss handedness as it relates to reading skills and related processes, a review of the literature regarding reading and brain lateralization is necessary as handedness is ultimately considered a measure of lateralization.

Neurological measures. Much of the latest research on reading has focused on anatomical sites. A recent metanalysis of 35 imaging studies was conducted by Jobard, Crivelo, and Tzourio-Mazoyer (2003) that focused on word reading and ranged from the years 1992 to 2002. According to Jobard, et al. (2003), brain areas activated during reading tasks vary depending upon the type of route they use. The phonological route typically utilizes the left superior temporal gyrus, but also gets assistance from regions specializing in working memory (e.g., opercular part of Broca's area and supramarginal gyrus). If the route is direct, this is accomplished through the occipitotemporal junction for tasks like prelexical processing but also to areas for the processing of meaning, such as the basal temporal language area, the triangular portion of Broca's area, as well as the posterior middle temporal region. Planar asymmetry in phonological abilities and reading skills have been implicated in other studies (Eckert, Lombardino, & Leonard, 2001).

In terms of dyslexia, neuroimaging studies have shown mixed results. In a review of neuroimaging research looking at developmental language disorders, including reading impairments, Lane, Foundas, and Leonard (2001) noted a pattern of discrepant results which they suggested were due to an interaction effect of variables such as gender, age, SES, and intelligence that interfere with presentation on a behavioral level, differences in structural development and processing difficulties noted through functional imaging studies. While Best and Demb (1999) found a lack of deviation from the normal leftward planum temporale asymmetry in five participants, many studies have shown that dyslexic children have smaller left planum temporale areas than normal or even symmetrical planum temporale areas since there was not an increased right planum (Hynd, Semrud-Clikeman, Lorys, Novey, & Eliopulos, 1990; Larsen, Hoien, Lundberg, & Odegaard, 1990; Stein, 1994). According to Leonard, et al. (1993) measurements of the parietal and temporal banks of the planum temporale revealed that a group of participants with dyslexia had a higher level of bilateral abnormalities when compared to the control group. In particular, in the right hemisphere, there was a significant transfer of right planar tissues from the temporal to parietal bank, which caused larger asymmetries. Leonard, et al. (1996) found the horizontal planum was connected to the prediction of phonological awareness in dyslexic participants; particularly increased leftward asymmetry was accounted for mainly by variance in the right, rather than the left, planum.

There has also been some support for the involvement of other anatomic variables in dyslexia, rather than just the planum temporale (Eckert & Leonard, 2000). Dyslexics have been found to have symmetrical cerebellar grey matter whereas the control groups have greater matter on the right side than the left (Rae, et al., 2002). A magnetic resonance spectroscopy study revealed that there were biochemical disparities between a group of men with dyslexia and control counterparts in the temporo-parietal lobe and the right cerebellum (Rae, et al., 1998). Similarly to the research on normals, in an MRI study the total superior temporal lobe surface, not the planum temporale, showed symmetry in dyslexic participants, but leftward asymmetry in the controls (Kusch, et al., 1993). The dyslexics also revealed a significant association between reading comprehension and posterior superior temporal lobe surface asymmetry, such that those with higher skills had more leftward asymmetry, which may suggest the direction of the asymmetry may serve as an indicator for possible reading comprehension difficulties (Kushch, et al., 1993). This same pattern was also noted by Leonard, et al. (1993).

Behavioral measures of handedness and reading. In addition to direct measures of laterality, there are numerous indirect measures. Despite the voluminous amount of research regarding laterality and reading skills, there has been no agreement about the relationship between the two. One popular indirect measure of laterality is handedness as defined by hand skill and/or hand preference. The majority of the handedness studies have focused on developmental dyslexia, as it’s easier to find relationships with groups that are deficient in reading, than in normals (Annett, 2002).

There are only a few studies with normals, including those looking at hand skill, rather than just hand preference. For example, Palmer and Corballis (1996) investigated a group of children from middle school in New Zealand and found that right and left hand skill was related to reading with the correlations higher for boys than girls. Using Annett’s genetic model, the authors explained this to be a result of different hemispheric development patterns and activities chosen by boys and girls. Annett (2002) reported that undergraduates whose performance was good on lexical processing tasks, fell within the center of the laterality distribution. De Agostini and Dellatolas (2001) used a handedness scale to find that left-handers did not perform as well as right-handers on a task of pseudoword reading but there was no difference when required to read real words. Eckert, Lombardino, and Leonard (2001) assessed thirty-nine sixth graders on various measures of reading and processing, as well as through an MRI and found better reading skills in non-right-handers but noted a larger familial history of reading disorders and low SES in the dextral group.

Bishop (1990) reviewed 25 studies dating from 1932 until 1972 and could not confirm Orton's (1937) theory that there is an over-representation of non-right handedness in individuals with dyslexia. However, a more recent meta-analysis of the same studies indicated a significant over-representation of left-handers and of mixed-handers further on the left side of the continuum (Eglington & Annett, 1994) suggesting that a relationship is likely. In more recent years, individuals with dyslexia were shown to be much less right handed, ranging from pure to modest levels of right-handedness, but strong left hand tendencies (Brunswick & Rippon, 1994). Two other studies have not found a relationship between handedness (either preference or hand skill) and reading (Everatt, Steffert, & Smythe, 1999; Francks, et al., 2003) although Everatt, et al. (1999) did note that those without dyslexia were more dextral. Rae, et al. (2002) did not find a significant difference when using a handedness questionnaire but did find one when using a peg test. The control group moved the pegs at a significantly faster rate with their right hand than the group of dyslexic participants. While not all studies have found clinical significance in terms of handedness and reading skills, the majority appear to have demonstrated some link.

Measurement of Handedness

Measurement techniques are important for understanding the literature regarding handedness and reading skills and related processes, as findings may change depending upon the particular measurement technique. Handedness has typically been measured through questionnaires, observations and more recently, a reaching task. In a study by Steenhuis and Bryden (1999) a distribution of handedness for proficiency and preference was dependent upon the number and type of questions and tasks, but overall hand preference, as measured by a questionnaire, related best to observed hand use for manipulating articles, especially in persons right-handers (Steenhuis & Bryden, 1999).

Questionnaires have been one of the most frequently used measurement techniques for handedness. Questionnaires have been found to be reliable and stable (Coren & Porac, 1978; McMeekan & Lishman, 1975; Woodward, Ridenour, Dean, & Woodcock, 2002). Additionally, questionnaires can be as effective as performance-based measurements (Caville & Bryden, 2003). It has been established that the best source of information may be the client however, rather than a close relative (Jason & Lantz, 1995).

Discussion

Directions for Future Research

As aforementioned, much of the research regarding the relationship between handedness and reading processes or skills has been mixed. Future investigators need to clarify this link and address the inconsistencies. Additionally, investigators need to address the relevance to today's assessment practices.

Methodological Limitations of the Research

The inconsistencies in the research findings can be explained by many factors. For example, one of the problems revolves around the measures used for handedness. Research has suggested that handedness is continuous and the degree of handedness is important (Bishop, Ross, Daniels & Bright, 1996; Isaacs, Barr, Nelson, & Devinsky, 2006; Dean, 1982). While that is the case, many of the measures classify only right or left-handed and are not continuous (Annett, 1972; Bishop, 1990; Dean & Reynolds, 1997) and may therefore minimize or exclude significance between the degree of handedness and reading processes and reading related skills. Although Annett (2002) purports that handedness is continuous, her handedness research questionnaire has 12 items and it has only three options for answering each question, right, left or either although she does note that the questionnaire allows for the identification of subgroups based upon an association analyses due to differing hand preference for diverse actions with varying frequency and related hand skill. A more continuous measure such as the Lateral Preference Scale, allows answers to vary from always right, mostly right, both equally, mostly left to always left for each item (Dean & Woodcock, 2003). The Edinburgh Handedness Inventory, another popular measure, includes only three categories (Bishop, 1990; Oldfield, 1971), either right, left, or mixed and has participants put in up to two crosses in each of the right or left categories which may be more confusing than a Likert scale. Others measure only one manual task preference or include a superfluous amount of items measuring numerous unimanual preferences. According to Curt, Mesbah, Lellouch and Dellatolas (1997), a handedness scale with 12 items has nearly the same or even better reliability than other scales with more items. For children 8 items is reliable.

Another limitation of the research regarding handedness and reading is the limited sample size. Because the overall sample size is small in many cases (some as low as 36), the incidence of left and mixed handedness is also small. With a larger sample size, differences may become clearer.

Available data offer little evidence for lateralized motor impairment or an increase in left-handedness in children with learning disorders said to be due to an abnormal development of the left hemisphere but it could be due to methodology. For instance, Hill and Bishop (1998) found that when they used a questionnaire and observed handedness behaviors, there were differences between groups in the degree of handedness that were not detected by a conventional handedness inventory.

Content of the Research

The purpose of this paper was to review the research regarding reading and handedness in order to help delineate the relationship between the two. As noted numerous times in the body of this manuscript, findings are mixed, leaving questions regarding whether there is a relationship. In order to fully investigate plausible relationships between reading and handedness, the known processes involved in reading also need to be addressed. While researchers have investigated a link between phonological processing, albeit with mixed results, one particular area of relevance that has yet to be investigated is that of auditory working memory. While it has been found to be of significant importance for the development of reading skills (Chiappe, Hasher, & Siegel, 2000; Comeau, et al., 1999; Gottardo, Stanovich, & Siegel, 1996; Jeffries & Everatt, 2004; Kibby, Marks, Morgan, & Long, 2004; Swanson, 1993, 1994) there has been no research investigating its possible link with hand laterality.

Relevance of the Research

As School Psychologists, the most traditional role is to conduct psycho-educational evaluations, whether it is in a school system or private practice. Similar to that established in an earlier survey (Hutton & Dubes, 1992), a 1995 study suggested that 50 to 75% of a practitioner’s time is devoted to psychological assessment. Many of the assessments are to determine whether a student has a learning disability, and more often than not, the area of concern is reading. In order to address this role, numerous measures have been created, but observations still remain important (Reschly & Wilson, 1995). For example, Wilson and Reschly (1996) surveyed 251 practicing school psychologists nationally and found that a structured observation was the top measurement technique used by practitioners. This was reported to be an increase from six years earlier when it was ranked number seven. According to Stinnett, Havey and Oehler-Stinnett (1994) and Shapiro and Heick (2004), one of the most frequently used assessment measures in the social/emotional and behavioral domains is behavioral observation.

One observation that psychologists are trained to make during assessments is that of handedness (Groth-Marnat, 2000; Sattler, 2001).

Interestingly, while we have many well defined measures of achievement and cognitive processes, most school psychologists do not have any standard measures of laterality, or handedness in particular, although the research findings suggest that handedness is continuous, therefore a note about whether children are right, left or mixed handed would not sufficiently classify their handedness (Bryden, 1978; Dean, 1982). Given the research suggesting a relationship between language and laterality, and the supplementary research suggesting a possible relationship between language based reading processes and laterality, albeit an unclear relationship, should psychologists add this type of measure to their standard battery, particularly when assessing children with possible reading learning disabilities? To go even further, even though psychologists note handedness, there appears to be a lack of knowledge about what to do with this information. For example, one of the most widely used textbooks for psychological assessment in the schools notes that mixed handedness is relevant to include in psychological reports but does not ascertain why and how to assimilate that data with other collected assessment data (Sattler, 2001). Why would psychologists note mixed handedness, or any other classification of handedness when observing him/her? Is this information germane to advanced learning processes or to learning disabilities, in particular reading processes and reading related skills? Do we need to be measuring handedness as part of screening processes in the schools or in clinical practice? One possible implication of a relationship between handedness and reading processes is early identification and intervention. Early intervention can be effective and may be prudent to future reading success (Elbaum, Vaughn, Hughes, & Moody, 2000; Foorman, Francis, Fletcher, Schatschneider, & Metha, 1998; Pinell, Lyons, DeFord, Bryk, & Seltzer, 1994; Torgesen, et al., 2001). If the research suggests there is a relationship between handedness and reading processes or skills, then it may be prudent to measure the degree of handedness and utilize this information as part of a screening process, as well as during the psycho-educational evaluation.

Co*nclusions*

In conclusion, future researchers need to take into account both the content of the research as well as the methodological issues. In order to improve the field of school psychology practice, the science behind it needs to be improved. To do this in the area of handedness and reading processes and reading related skills, future researchers should address methodology through sample size, representative samples (as most studies were conducted outside the United States), as well as measurement instruments. Additionally, it is recommended that future investigations include good, poor and average readers to address the continuum of skills, not just those of poor readers or normals. Furthermore, as cognitive processing is becoming more and more important in assessments linked to reading skills, research, as well as psychological evaluations, should be comprehensive and not only focus on the primary reading skill areas, but also on processing capabilities such as phonological awareness and working memory that have typically been associated with reading. It is this author’s opinion that if we address content and methodology, the assessment practices of school psychologists, or psychologists in general, may be changed and better tailored to address the individual needs of the child. In the meantime, school psychologists currently practicing can be investigating potential measures of handedness and their usefulness during the screening and evaluation process.

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CHAPTER 2

DOES A CONTINUOUS MEASURE OF HANDEDNESS PREDICT READING RELATED PROCESSES AND READING SKILLS THROUGH THE LIFESPAN?

Introduction

The research results with regard to handedness, specific reading skills and reading processes are ambiguous at best. The method in which handedness is measured contributes to the diverse research results in studies regarding reading or other cognitive abilities. Previous researchers have measured handedness using observations, questionnaires, hand skill and reaching tasks. Interestingly, while questionnaires are the most frequent measurement technique and have adequate technical properties (Coren & Porac, 1978; McMeekan & Lishman, 1975; Woodward, Ridenour, Dean & Woodcock, 2002), inconsistent findings are still prominent. One significant limitation of previous research using handedness questionnaires is a lack of measurement on a continuum. The present investigation addresses this limitation through an investigation of the relationship between handedness, as measured by a continuous lateral preference scale, reading processes and reading skills. In particular, the researcher attempted to address a gap in the literature regarding handedness and verbal working memory as related to reading. Additionally, the researcher investigated both reading processes (phonological processing and working memory) and a variety of reading skills (basic reading, reading comprehension and reading fluency) as its related to a continuum of laterality in one study, rather than separate studies and over a wider range of ages than previous studies.

Most people demonstrate a preference for the right side of their body, for example, their right hand or leg, and this preference generally implicates left hemisphere processes (Annett, 1975; Dean & Woodcock, 2003). Infant research has indicated lateral asymmetries that are linked to handedness and the right hand bias of the population (Corbetta & Thelen, 2002). A great deal of research suggests that language is primarily controlled by the left hemisphere, especially in individuals with a dextral bias. Josse & Tzourio-Mazoyer (2004) conducted a review of relevant hemispheric specialization neuroimaging studies that revealed individuals whose handedness is towards the sinistral end of the continuum are more likely to have an atypical hemispheric specialization for language than those on the dextral side. Furthermore, both footedness and handedness have predicted more left-handers and left-footers in individuals with right language dominance (Strauss & Wada, 1983; Watson, Pusakulich, Ward, & Hermann, 1998).

Much of the research suggests that left-handedness is less prevalent in the older ages of life. For example, Gilbert and Wysocki (1992) found that left handedness for both writing and throwing combined was less prevalent in the elderly than in the younger ages per questionnaire report of over a million persons ages 10 to 86 years old. They also found that those with a left hand writing preference and right hand throwing preference decreased as well with age. Similarly, Davis and Annett (1994) found that the percentage of left-handedness decreased from the age group of 18-30 to the age group of above 81 years of age from 11.2% to 2.0% respectively with reductions occurring each decade. Porac (1993) found that the mixed–right handedness group was overrepresented and the always right group was underrepresented in the under 30 group with a reverse pattern in the over 60 group. This pattern was not significant in the always left and mixed left handedness groups but the author reported this to be likely a cause of the small sample size of left handers (Porac, 1993). In an investigation similar to Porac (1993), Coren (1995) found further support of reductions in consistent left handers and mixed left handers with a much larger sample size of 12,030 subjects ages 8 to 99 years old (Coren, 1995).

Handedness has been measured using observations, questionnaires, hand skill and reaching tasks, each of which contribute to discrepant results in studies regarding reading or other cognitive abilities. For example, the incidence of hand preference and the distribution of the proficiency of hand skill have been found to vary depending upon the number and quality of questions or specified manual tasks (Steenhuis & Bryden, 1999). Questionnaires are by far the most frequent measurement technique and have been found to be stable and reliable (Coren & Porac, 1978; McMeekan & Lishman, 1975; Woodward, Ridenour, Dean & Woodcock, 2002). Furthermore, it has been established that questionnaires can be as successful as observing manual skills even with the very young (Caville & Bryden, 2003).

Why are the research findings on handedness based on questionnaires inconsistent if they have adequate technical properties? One possible reason is that handedness is now considered to be continuous and includes many points among a spectrum of behavior, rather than being separate classifications (Bryden, 1978; Dean, 1982). But while that is the case, many of the measures allow for classification of only right- or left-handedness (Annett, 1972; Bishop, 1990; Dean & Reynolds, 1997), which doesn't permit the measurement of degree of handedness. Additionally, it reduces the amount of data available with which to detect trends. Both Annett's and Oldfield's handedness inventories (Annett, 1972, 2002; Bishop, 1990; Oldfield, 1971) include three or less categories of handedness as choices for the informant for each item although each has their own way of determining subgroups of mixed handedness. On the other hand, the Lateral Preference Scale from the *Dean Woodcock Sensory-Motor Battery*, is a continuous measure that allows five answer choices ranging from always right to always left (Dean & Woodcock, 2003) based upon answers on a Likert scale. This may be less confusing than providing zero, one or two plus marks in right or left handed categories to indicate the strength of the preference as needed in the Edinburgh Handedness Inventory (Oldfield, 1971). Another problem in existing scales is the number of items included. Adequate or above reliability has been established for scales with only 12 items for adults and 8 items for children (Curt, Mesbah, Lellouch, & Dellatolas, 1997) but some scales have only one item such as "What hand do you write with?" or have more items than needed or desirable.

In fact, Curt, Mesbah, Lellouch, and Dellatolas (1997) found that a scale with 21 items or more had lower reliability than a scale with 12 items.

Various studies have suggested a link between handedness and different clinical populations, including mental retardation (Mandal, Pandey, Das, & Bryden, 1998), schizophrenia spectrum disorders (Ortuno, Lopez, Landecho, & Bonelli, 2005; Rowe, Rudkin, & Crawford, 2000), autism (Escalante-Mead, Minshew, & Sweeney, 2003; Hauck & Dewey, 2001), post-traumatic stress disorder (Saltzman, Weems, Reiss & Carrion, 2006) and attention deficit hyperactivity disorder (Niederhofer, 2005) to name a few. Additionally, many investigators have reported relationships with dyslexia (Annett, 2002) and more specifically processes related to dyslexia. For example, researchers have indicated that left-handedness is a risk factor for poor phonological processing (Annett, 1992, 2002; Smythe & Annett, 2006), This includes awareness of phonemes and rhymes (Annett, 1992; Brunswick & Rippon), as well as phonological fluency (De Agostini & Dellatolas, 2001). This is important in that phonological processing has been continually demonstrated to be vital for reading development and skills (Adams, 1990; Carroll & Snowling, 2004; Chiappe & Siegel, 1999; Chiappe, Chiappe, & Gottardo, 2004; Chiappe, Siegel, & Gottardo, 2002; Durgunoglu, Nagy, & Hancin-Bhatt, 1993; Gottardo, 2002; Morris, et al., 1998; Muter & Diethelm, 2001; Oakhill, Cain, & Bryant, 2003; Thompkins & Binder, 2003; Tunmer, Herriman, & Nesdale, 1988; Wagner & Torgesen, 1987; Wagner, Torgeson, & Rashotte, 1994; Van Alphen, et al., 2004; Vukovic, Wilson, & Nash, 2004).

Other researchers have demonstrated no statistically significant relationship between phonological processing and handedness (Kolk & Talvik, 2002; Smythe & Annett, 2006) although the general direction of the relationship remains the same with poorer performance on phonological processing towards the left handed side of the continuum. The farther left on the handedness continuum, the more reading errors are made (Annett, 1991; Tremblay, Monetta, & Joanette, 2004). Moreover, it has been established that the left hemisphere is superior to the right hemisphere when phonological processing complexities increase (Chiarello, Hasbrooke, & Maxfield, 1999).

An important area that has not been investigated in terms of its relationship with hand preference despite its previously established importance to reading skills is verbal working memory (Chiappe, Hasher, & Siegel, 2000; Comeau, Cormier, Grandmaison, & Lacroix, 1999; Gottardo, Stanovich, & Siegel, 1996; Jeffries & Everatt, 2004; Kibby, Marks, Morgan, & Long, 2004; Swanson, 1993, 1994). As both working memory and handedness are related to reading, it would make sense to investigate prediction models of reading with both working memory and handedness measures. Therefore, a possible relationship between working memory and reading will be addressed in the current study.

The research results with regard to handedness and specific reading skills are ambiguous at best and indicate a need for further clarification. For example, while Bishop's (1990) review of relevant studies did not find an over-representation of left-handedness and ambidexterity in individuals with dyslexia, a later meta-analysis of the same studies did find more sinistrals and mixed handers throughout the dyslexia population (Eglington & Annett, 1994) suggesting that a relationship is probable. Evidence of a significant relationship between reading and laterality has been supported in normals through the use of hand skill measures (Crow, Crow, Done & Leask, 1998; De Agostini & Dellatolas, 2001; Palmer & Corballis, 1996) and reading tasks. For example, De Agostini & Dellatolas (2001) found left-handers performed poorer when required to read pseudowords than right handers but not when required to read real words. Annett & Manning (1989) noted that those at the extreme right hand side of the continuum of handedness have poorer reading/English skills than others but the same authors have also noted difficulties with reading on either extreme of the spectrum when compared to the more central points on the continuum (Annett & Manning, 1990) supporting Annett's notion of the heterozygote advantage. Additionally, performance on tests of word processing was also related to placement on the hand skill distribution, with those performing better on lexical processing tasks centered in the distribution (Annett, 2002). On the other hand, other studies on a normal population have found no relationship between reading and handedness (Everatt, Steffert, & Smythe, 1999; Natsopoulos, Kiosseoglou, Xeromeritou, & Alevriadou, 1998).

Results of the previous studies may have been limited by the restricted range of participant ages utilized in the research. For example, some of the findings are based on younger children such as the 3 to 8 year old children in De Agostini & Dellatolas's study (2001), or the 5 to 11 year olds that participated in Annett & Manning's research (1989) and Annett's research in 1992. The next age group tested was that of 11-13 year olds by Palmer & Corballis (1996), 13-18 year olds in one study and 12 to 13 year olds in another study both by Williams (2001). University or college students have also been used (Everatt, Steffert & Smythe, 1999). There is a remarkable absence of research over a wide range of ages that can account for any age differences in the relationship between handedness and reading skills or processes.

In addition to the aforementioned measurement limitations, sample size is another methodological issue that limits the research regarding handedness and reading. The smaller sample sizes used in many of the relevant studies are problematic, particularly when studying left and mixed handedness as their incidence rates are small at the start. The present study will address this issue by using a large normative sample.

The present investigation is designed to shed some light on the ambiguity of the handedness and reading research. By using a large normative sample with a wide range of ages, this study will investigate any relationship that might exist between reading skills and related reading related processes. Additionally, unlike much of the prior relevant research, the sample is representative of the United States population. As previously noted, there is a gap in the research regarding handedness and working memory and reading processes. This study will attempt to address that gap and it will examine phonological awareness and reading skills simultaneously in one study. The following research questions will be asked:

1. Does handedness, as measured on a continuum, relate to phonological processing?

2. Does handedness, as measured on a continuum, relate to working memory?

3. Does handedness, as measured on a continuum, relate to basic reading skills?

4. Does handedness, as measured on a continuum, relate to reading comprehension skills?

5. Does handedness, as measured on a continuum, relate to reading fluency?

6. Does the relationship between handedness, reading skills, and related cognitive reading processes change by age?

The author hypothesizes that the continuous measurement of handedness will predict phonological processing, basic reading skills, reading comprehension, reading fluency, as well as auditory working memory with more difficulties in these areas the further the participants are along the handedness continuum towards the left side. The author hypothesizes that the relationship between handedness and phonological processing, basic reading skills and auditory working memory will be the strongest. Additionally, the author hypothesizes that the handedness measure will be more predictive of reading at the earlier ages than older ages.

Method

Participants

The data were collected from participants as part of a normative sample for the *Dean-Woodcock Sensory-Motor Battery* (Dean & Woodcock, 2003), the *Woodcock Johnson Psycho-Educational Battery-Revised (WJ-R)* (Woodcock & Johnson, 1989a, 1989b) and *Woodcock Johnson Psycho-Educational Battery-Third Edition (WJ III)* (Woodcock, McGrew, & Mather, 2001). Data were collected from ages 3 to 94 years, with the majority falling between the ages of 4 to 80. Only participants that were administered both the *DWSMB* and one of the two *WJ* batteries will be included in the study. The authors of the *WJ-III* transformed the scores from the *WJ-R* into comparable *WJ-III* scores through the use of a regression technique (K. McGrew, personal communication 9-14-06). Selection of participants met the following criteria: "1) no evidence of psychiatric symptoms, diagnosis or past treatment; 2) no evidence, diagnosis or treatment of a neurological disorder, 3) no evidence, diagnosis, or treatment of an orthopedic condition; 4) no diagnosis or treatment of a medical defect, learning disability, or sensory-motor impairment with the exception of corrective lenses; 5) no reported history of a head injury with loss of consciousness, diagnosis of a concussion, or present evidence of an active disease process" (Dean & Woodcock, 2003, p. 38).

Instruments

In order to assess various reading skills, as well as cognitive processes related to reading, subtests from the *WJ-R* and *WJ-III* were chosen for analytical purposes due to available norming data and adequate reliability and validity.

Participants were given either the *WJ-R* subtests or the *WJ-III* subtests depending upon date of administration. A few of the subtests (Reading Vocabulary, Auditory Working Memory, Understanding Directions, Reading Fluency, and Sound Awareness) did not exist in the *WJ-R* but were developed for the *WJ-III* and subsequently administered to those taking that version of the *WJ*, therefore the sample size was subsequently smaller for those subtests. Please see Table 1 for a description of the subtests and the abilities measured (Schrank, McGrew, & Woodcock, 2001).

Woodcock Johnson Psycho-Educational Battery-Revised. The Letter Word Identification, Word Attack, and Passage Comprehension subtests were chosen to represent relevant reading skills. Numbers Reversed was administered to assess working memory. Sound Blending and Incomplete Words subtests were also given as measures of phonological processing.

Internal reliability coefficients for achievement subtests in the *WJ-R* ranged from the high .80s to low .90s (McGrew, Werder, & Woodcock, 1991). Split-half reliabilities on the cognitive battery ranged from the mid .70s to low .90s. Content validity was established through the use of confirmatory and exploratory factor analyses. Adequate construct validity was also reported. Concurrent validity was established through comparisons with the *WJ* to known cognitive and achievement tests.

Woodcock Johnson Psycho-Educational Battery-Third Edition (WJ III). The Letter Word Identification, Word Attack, Passage Comprehension, Reading Vocabulary and Reading Fluency subtests were administered to sample reading

Table 1

Summary of Woodcock-Johnson Psycho-Educational Battery Subtests

	Test requirement	Abilities required
LWI	Read single words or letters	Rdg decoding
Rdg Fluency	Read statements & answer yes/no while timed	Rdg speed
PC	Read passages & identify missing word	Rdg comprehension
Word Attack	Read nonsense words	Rdg decoding Phonetic coding
Rdg Vocabulary	Read words & provide meanings	Printed language comprehension
Sound Awareness	Provide rhyming words; Remove, substitute & reverse parts of words	Phonetic coding
Numbers Reversed	Reverse number sequence	WM; STM
Sound Blending	Blend sounds to form a word	Phonetic coding
Auditory WM	Reorder words & numbers in immediate awareness	WM; STM
Understanding Directions	Listen & follow sequential directions	Listening ability Auditory WM
Incomplete Words	Name spoken words missing a phoneme	Auditory processing Phonetic coding

**Note*. Rdg = reading. WM = working memory. STM = short-term memory. PC= passage comprehension. LWI=letter-word identification.

skills. A Basic Reading Skills Composite was also obtained and included the Letter Word Identification and Word Attack subtests. A Reading Comprehension Composite was obtained that contained the Reading Vocabulary and Passage Comprehension subtests. Working memory subtests (Auditory Working Memory, Numbers Reversed and Understanding Directions) were administered. Each of these except Understanding Directions was included in the Working Memory Composite. Phonological processing subtests were also given (Sound Blending, Sound Awareness and Incomplete Words). All three subtests make up the Phonemic Awareness/Phonological Awareness composite score.

Overall, the subtests of the *WJ III* showed adequate to above reliability. The split-half reliability coefficients for the Letter Word Identification subtest scores ranged from .88 to .99, yielding a median coefficient of .94. The internal consistency reliability coefficients for reading fluency ranged from .87 to a .94, with a median coefficient of .90. The split-half reliability coefficients for the Passage Comprehension subtest obtained scores that ranged from .73 to .96, with a median coefficient of .88. The Word Attack median reliability coefficient was a .87, with a range from .78 to .94, while the median coefficient for Reading Vocabulary was a .90, with a range of .82 to .94. The split-half internal consistency reliability coefficients for Sound Awareness ranged from .67 to .92, with a median coefficient of .81. The median reliability coefficient for Numbers Reversed was .87, with a range from .84 to .93 depending upon the age. The median test reliability for the Sound Blending subtest was .89. Its range was from .81 to .94. Auditory Working Memory reliability coefficients ranged from .80 to

.96, generating a median of .87. The median split-half coefficient for Understanding Directions was .83, with a range from .62 to .93.

Composite/cluster scores also demonstrated adequate to above reliability with all median coefficients in the .90's. The Basic Reading Skills Composite median reliability coefficient was .95 with a range from .90 to .98. The split-half reliability coefficients for the Reading Comprehension composite varied from .89 to .96 with a median coefficient of .92. The median coefficient for Working Memory Composite was a .91 with a range from .89 to .96, whereas the Phonemic Awareness composite ranged from .84 to .96 with a median coefficient of .90.

Concurrent validity studies were conducted with the *WJ-III Achievement* and two other achievement batteries. According to McGrew and Woodcock (2001) reading comprehension correlated with other reading comprehension measures at .62 to .79; while basic reading skills correlated with reading decoding at .66 to .82. Working memory was most strongly related to the *Stanford-Binet Intelligence Scale- Fourth Edition* Short Term Memory composite (correlation of .64), as well as the *Wechsler Adult Intelligence Scale Third Edition* Working Memory Index (.67). The authors reported that no concurrent validity correlations could be conducted for phonological awareness measures due to the lack of this cognitive ability being measured in other intelligence tests and referred the readers to other structural, content and developmental evidence of validity (McGrew & Woodcock, 2001).

Dean-Woodcock Sensory-Motor Battery (DWSMB). The Lateral Preference Scale from the *DWSMB* was previously administered to each participant included in this study. The data were collected from participants as part of the compilation of normative data for the whole battery. Collected data included 1383 participants ages 4 to 80 years, with 200 participants from the age 4 to 10 group, 346 participants from ages 11 to 24, 412 from ages 25-49 and 425 from ages 50 to 80. Only data from participants co-co-administered with either the *WJ-R* or *WJ-III* subtests were included in this study.

The Lateral Preference Scale provides a measurement of handedness using questions involving fine motor activities performed by the arms and hands such as Which arm would you use to pet a dog? For each question, a score of 1 to 5 is given by the participant that indicates which hand or arm is used. The scores stand for the variations in hand, with 1 = Left Always, 2 = Left Mostly, 3 = Both Equally, 4 = Right Mostly, and 5 = Right Always.

Split-half reliability coefficients ranged from .86 for ages 4 to 10, to .97 for ages 50 and older. The authors purport that the *DWSMB* has adequate validity due to “chosen and refined well-accepted and researched tests of sensory and motor functioning” (Dean & Woodcock, 2003, p. 49). Additionally, they note that that the battery has adequate content validity of sensory and motor constructs, as noted through support from previous investigations regarding the CHC theory and the *WJ-R*.

Statistical Analysis

All statistical analyses were conducted through the use of the SPSS statistical software, version 14.0. Analysis was performed on W scores, a transformed Rasch score that transforms the data into equal intervals that allow for better comparison of scores (Dean & Woodcock, 2003). Linear and curvilinear associations between the dependent variables and age and/or the lateral preference scale were examined with polynomial regression analyses using the Holm's procedure for multiple comparison testing to control for experimentalwise error (Holm, 1979). The lateral preference scale and/or age in chronological months served as the independent variable(s) for the pre-specified research questions, but the lateral preference scale served as a dependent variable when looking at the relationship between age and lateral preference when conducting preliminary analyses. The independent variables and their squares were included in the regression equations to account for linear and quadratic (curvilinear) relationships (Pedhazer, 1997). The quadratic equation was selected instead of the more parsimonious linear equation when two conditions were met: the R^2 for the quadratic equation was statistically significant and the additional increase in the proportion of variance explained by the quadratic equation (the R^2 Δ) was statistically significant.

Results

Preliminary Analyses

Prior to answering the research questions, some preliminary investigations were needed, in particular descriptive statistics, the relationship of age and hand preference, and the relationship between age and reading skills and reading processes.

Descriptive statistics. Means and standard deviations of the W scores on the standardized reading skills and cognitive reading processes measures are summarized in Table 2 along with the sample size for each variable. One limitation that should be noted is that the composite scores were obtained by averaging the subtest W scores. When a missing value was present, the composite was then composed of the remaining subtests in that composite.

Effects of age on hand preference. Linear and curvilinear associations between age and the lateral preference scale were examined with polynomial regression analyses with the lateral preference scale served as the dependent variable. The age in months and the square of age in months served as the independent variables to account for linear and quadratic relationships. Both linear ($R^2 = .033$, $F(1, 1381) = 47.087$, $p<.001$) and quadratic models ($R^2 = .047$, $F(2, 1380) = 34.381$, $p<.001$) were found to be significant with the proportion of variance accounted for by the second-degree polynomial statistically significant ($R^2\ \Delta=.014$, $p<.001$). This suggests a quadratic relationship between lateral preference and age. A visual inspection of the scatterplot suggests that at the younger and older ages, right hand preference is higher than in the middle ages.

Relation between age, reading processes and reading skills. To assess the relationship between age and reading skills and related cognitive processes, tests of linearity and nonlinearity were utilized. The dependent variables included the eleven reading, phonological processing and auditory working memory

Table 2

Means, Standard Deviations and Pearson Correlation Coefficients of Reading Skills and Processes Measures and Lateral Preference Scale

Subtests	N	Mean	SD	Pearson r with LPS
Letter Word Identification	1260	529.45	47.17	.03
Word Attack	291	512.62	21.50	.03
Passage Comprehension	1077	511.17	26.94	-.04
Reading Fluency	296	536.51	56.47	.02
Reading Vocabulary	277	532.90	21.81	-.05
Sound Blending	1245	507.88	19.54	-.08**
Incomplete Words	1352	511.85	12.07	-.05
Sound Awareness	266	506.08	16.46	.02
Auditory Working Memory	598	509.87	22.49	-.12**
Numbers Reversed	610	505.73	30.33	-.07
Understanding Directions	301	500.34	11.78	-.09
Basic Reading Skills Composite	1261	525.42	45.14	.05
Reading Comprehension Composite	1079	512.58	27.60	-.05
Phonological Awareness Composite	1364	509.35	13.83	-.08**
Auditory Working Memory Composite	627	507.68	24.90	-.10*
Lateral Preference Scale	1383	504.54	17.08	1.00

Note. LPS = Lateral Preference Scale

* R significant at $p < .05$. **R significant at $p < .01$.

subtests, as well as composites for the three target areas. The age in months and the square of age in months served as the independent variables to account for linear and quadratic relationships. For all dependent variables, linear relationships and quadratic relationships were found with reading processes and reading skills in all cases ($p < .001$) except sound blending for which only a quadratic relationship was found (linear $p = .965$; quadratic $p < .001$). Please see Table 3 for the linear and quadratic F and p values. An analysis of the R^2 change between the two different regression equations revealed that the quadratic relationship better accounted for the variance in all dependent variables ($R^2\ \Delta$ $p < .003$ for all cases). Also represented in Table 3 are the R^2 values. The combination of age and its squared variable accounted for 26% to 47% of the variance in the different reading skills and 19% to 43% in reading processes variables. A visual inspection of scatterplots suggests that for all reading skills and cognitive reading processes, the younger ages and older ages demonstrate lower reading skills than the middle ages.

Research Questions One through Five: Relationship between Hand Preference, Reading Skills, and Reading Processes

Correlational analyses. A correlational analysis was initially conducted between the Lateral Preference Scale (LPS) and *Woodcock Johnson Psycho-Educational Battery-Revised* and *Woodcock Johnson Psycho-Educational Battery-Third Edition* reading skills and processes subtests and related composites. Significant negative correlations with lateral preference were found for the sound blending and auditory working memory subtests, as well as the

Table 3

Regression Statistics for Age, Reading Processes, and Reading Skills: Linear versus Quadratic Relationship

DV's	Linear			Quadratic			Change Stats	
	R^2	F	Sig.F	R^2	F	Sig.F	R^2 Δ	Sig.
LWI	.28	1543.88	.000*	.47	1765.40	.000*	.19	.000*
WA	.15	432.29	.000*	.26	427.14	.000*	.11	.000*
PC	.21	991.50	.000*	.42	1378.87	.000*	.21	.000*
RF	.18	307.64	.000*	.32	332.15	.000*	.14	.000*
RV	.31	874.65	.000*	.45	769.43	.000*	.13	.000*
SB	.00	.00	.965	.19	511.73	.000*	.19	.000*
IW	.05	233.11	.000*	.25	717.54	.000*	.20	.000*
SA	.10	92.36	.000*	.22	115.18	.000*	.12	.000*
AWM	.04	69.13	.000*	.26	290.19	.000*	.22	.000*
NR	.09	246.72	.000*	.23	391.02	.000*	.14	.000*
UD	.08	94.80	.000*	.21	153.16	.000*	.13	.000*
BRS-C	.27	1481.16	.000*	.43	1514.90	.000*	.16	.000*
RC-C	.21	1022.18	.000*	.43	1451.13	.000*	.22	.000*
PA-C	.02	71.38	.000*	.24	734.82	.000*	.22	.000*
AWM-C	.09	273.22	.000*	.26	471.46	.000*	.17	.000*

*R significant according to Holm's procedure.

phonological awareness and auditory working memory composite scores. See Table 2 for correlational analyses results.

Regression analyses. In order to further assess the relationship of the reading processes and reading related skills variables with lateral preference, linear and curvilinear associations between the LPS and dependent variables were examined with polynomial regression analyses. The dependent variables included the eleven reading, phonological processing and auditory working memory subtests, as well as composites for the three target areas. The LPS and the square of the LPS served as the independent variables to account for linear and quadratic (curvilinear) relationships. Please see Table 4 for results including F and p values. The following discussion is broken down by composites and their related subtests.

In terms of basic reading skills, results suggested that neither linear or quadratic relationships significantly described the data (linear p= .067, quadratic p=.056). When broken down into the different basic reading skills subtests, neither letter-word identification (linear p=.282; quadratic p=.086) or word attack were found to be significantly related to lateral preference (linear p = .665; quadratic p= .513).

Global reading comprehension skills were found to have a quadratic relationship with lateral preference (p<.001). Subtest differentiation yielded a quadratic relationship with lateral preference and passage comprehension (p<.001) but no relationship between reading vocabulary and lateral preference (linear p=.425; quadratic p= .653). Also noted in Table 4 are R^2 and R^2 change

Table 4

Regression Statistics for Lateral Preference Scale on Reading Processes and Reading Skills: Linear versus Quadratic Relationship

DV's	Linear			Quadratic			Change Stats	
	R^2	F	Sig. F	R^2	F	Sig.F	R^2 Δ	Sig.
LWI	.00	1.16	.282	.00	2.46	.086	.00	.053
WA	.00	.19	.665	.01	.67	.513	.00	.285
PC	.00	1.75	.187	.02	8.48	.000*	.01	.000*
RF	.00	.09	.769	.02	2.60	.076	.02	.025
RV	.00	.64	.425	.00	.43	.653	.00	.640
SB	.01	8.38	.004	.01	8.66	.000*	.01	.003*
IW	.00	3.55	.060	.01	3.30	.037	.00	.081
SA	.00	.06	.809	.01	.93	.395	.01	.181
AWM	.01	7.94	.005	.07	21.33	.000*	.05	.000*
NR	.01	3.22	.073	.03	10.12	.000*	.03	.000*
UD	.01	2.40	.122	.04	6.64	.002*	.04	.001*
BRS-C	.00	3.36	.067	.01	2.89	.056	.00	.121
RC-C	.00	2.75	.098	.02	8.65	.000*	.01	.000*
PA-C	.01	7.84	.005	.01	8.93	.000*	.00	.002*
AWM-C	.01	6.01	.015	.05	17.33	.000*	.04	.000*

*R significant according to Holm's procedure.

statistics. Lateral preference and its squared variable accounted for 2% of both general reading comprehension skills and passage comprehension. A visual inspection of the scatterplot suggests that the extremes of laterality performed lower in the area of global reading comprehension and passage comprehension than those closer to the middle. The regression analysis found no relationship between reading fluency and lateral preference (linear p=.769, quadratic p= .076).

A second degree polynomial was found to explain a greater proportion of variance between the overall phonological awareness composite and lateral preference (p=.002) than a linear model. About 1% of the variance in lateral preference is accounted for by both the linear and the quadratic terms. A subtest encompassed in that composite, sound blending, had a significant quadratic relationship with lateral preference, with a significantly greater proportion of variance accounted for by the second-degree polynomial ($R_2 \Delta p = .003$). Lateral preference and its quadratic term accounted for 1% of the variance of sound blending. A qualitative analysis of the scatterplot suggests that the extremes of laterality performed lower in the area of sound blending than those closer to the middle. No significant relationship was between incomplete words and lateral preference (linear p=.060, quadratic p=.037) or sound awareness and lateral preference (linear p=.809, quadratic p=.395). A qualitative analysis of the scatterplot suggests that the extremes of laterality performed lower in the area of phonological awareness than those closer to the middle.

The combined auditory working memory composite was found to have a quadratic relationship with lateral preference ($p<.001$). The inclusion of the linear and quadratic terms of lateral preference accounted for 5% of the variance in the auditory working memory composite. When broken down by subtest, again a quadratic relationship was noted with the quadratic equation being more significant than a linear relationship for the auditory working memory subtest ($p<.001$). Seven percent of the variance in the auditory working memory subtest was accounted for by lateral preference and its squared term. A significant quadratic relationship, but not linear, was found between lateral preference and the numbers reversed subtest ($p=.004$), as well as with an additional auditory working memory subtest not included in the composite, understanding directions, and lateral preference (quadratic $p=.002$) with the R^2 change test suggesting the second degree polynomial explained a greater proportion of variance for both dependent variables ($p<.001$, $p=.001$). The linear and quadratic lateral preference terms explained approximately 3% and 4% of the variance in these reading cognitive processes respectively. Results suggest that an advantage in auditory working memory may lie in the middle of the lateral preference spectrum when compared to those at the extremes of lateral preference.

Research Question Six: Relationship between Hand Preference, Age, and Reading Skills and Reading Processes

Regression analyses. To determine whether the regression of the dependent variables on lateral preference and age was linear or curvilinear, hierarchical polynomial multiple regression analyses was conducted. The increment in proportion of variance accounted for by the interaction between lateral preference and age, and the square of age and lateral preference was tested (per Pedhauzer, 1997). The multiple regression model with both predictors indicated a significant curvilinear relationship between lateral preference, age and all dependent variables ($R^2\Delta$ $p \leq .027$ for all subtests). See Table 5 for more specific results. The addition of the squares of age and lateral preference, along with their interaction term, explained 7% to 41% of the variance in reading skills and 6% to 40% of cognitive processes related to reading.

As the previous analyses included the interaction term in the quadratic model the next step of the regression analyses was to determine whether the squares of age and lateral preference added significantly to the proportion of variance accounted for by age, lateral preference, the interaction between the two independent variables and their squared terms for all dependent variables. Results suggested that the square of lateral preference and the square of age added to the proportion of variance ($R^2\Delta$ $p \leq .017$ for all tests). See Table 6 for R^2, $R^2\Delta$, F & p values. The addition of the squares of age and lateral preference explained 7% to 41% of the variance in reading skills and 6% to 40% of cognitive processes related to reading.

To investigate further, another polynomial regression analyses was conducted to see if the interaction between age and lateral preference added significantly to the proportion of variance accounted for by age and lateral preference and their squared terms. The interaction did not add significantly to the regression equation on any variables. Please see Table 7 for R^2, F and

Table 5

Regression Statistics for Lateral Preference, Age, Reading Processes and Reading Skills: Linear versus Quadratic Relationship

DV's	Linear			Quadratic			Change Stats	
	R^2	F	Sig.F	R^2	F	Sig.F	R^2 Δ	Sig.
LWI	.23	183.58	.000*	.41	170.69	.000*	.18	.000*
WA	.03	5.12	.007*	.07	3.95	.002*	.03	.027*
PC	.13	77.93	.000*	.38	130.06	.000*	.25	.000*
RF	.07	10.42	.000*	.13	8.48	.000*	.06	.000*
RV	.18	29.13	.000*	.21	14.01	.000*	.03	.018*
SB	.05	34.20	.000*	.22	68.24	.000*	.16	.000*
IW	.00	2.90	.055	.17	53.20	.000*	.16	.000*
SA	.01	1.13	.326	.06	3.21	.008*	.05	.004*
AWM	.01	4.34	.013	.21	30.49	.000*	.19	.000*
NR	.04	12.28	.000*	.17	24.66	.000*	.13	.000*
UD	.01	1.20	.302	.07	4.61	.000*	.06	.000*
BRS-C	.21	169.66	.000*	.36	139.11	.000*	.14	.000*
RC-C	.13	82.46	.000*	.40	141.05	.000*	.26	.000*
PA-C	.02	13.03	.000*	.20	68.78	.000*	.18	.000*
AWM-C	.03	9.74	.000*	.21	33.59	.000*	.18	.000*

*R significant according to Holm's procedure.

Table 6

Regression Statistics for Lateral Preference, Age, Reading Processes and Reading Skills: Testing the Squared Terms

DV's	No Squared Terms			Squared Terms			Change Stats	
	R^2	F	Sig.F	R^2	F	Sig.F	R^2 Δ	Sig.
LWI	.24	128.43	.000*	.41	170.69	.000*	.17	.000*
WA	.04	3.77	.011*	.07	3.95	.002*	.03	.017*
PC	.14	59.67	.000*	.38	130.06	.000*	.24	.000*
RF	.07	7.57	.000*	.13	8.48	.000*	.06	.000*
RV	.18	19.99	.000*	.21	14.01	.000*	.03	.015*
SB	.06	25.53	.000*	.22	68.24	.000*	.16	.000*
IW	.02	6.71	.000*	.17	53.20	.000*	.15	.000*
SA	.01	.97	.407	.06	3.21	.008*	.05	.002*
AWM	.05	10.42	.000*	.21	30.49	.000*	.16	.000*
NR	.05	11.51	.000*	.17	24.66	.000*	.12	.000*
UD	.01	.81	.491	.07	4.61	.000*	.06	.000*
BRS-C	.22	116.97	.000*	.36	139.11	.000*	.14	.000*
RC-C	.15	63.75	.000*	.40	141.05	.000*	.25	.000*
PA-C	.03	12.80	.000*	.20	68.78	.000*	.18	.000*
AWM-C	.05	10.93	.000*	.21	33.59	.000*	.16	.000*

*R significant according to Holm's procedure.

Table 7

Regression Statistics for Lateral Preference, Age, Reading Processes and Reading Skills: Testing the Interaction

DV's	No Interaction			Interaction			Change Stats	
	R^2	F	Sig.F	R^2	F	Sig.F	R^2 Δ	Sig.
LWI	.41	213.33	.000*	.41	170.69	.000*	.00	.491
WA	.06	4.73	.001*	.07	3.95	.002*	.00	.355
PC	.38	160.611	.000*	.38	130.06	.000*	.00	.022
RF	.12	10.08	.000*	.13	8.48	.000*	.01	.161
RV	.20	16.9	.000*	.21	14.01	.000*	.01	.176
SB	.22	85.37	.000*	.22	68.24	.000*	.00	.954
IW	.17	66.41	.000*	.17	53.20	.000*	.17	.498
SA	.06	3.79	.005*	.06	3.21	.008*	.00	.342
AWM	.21	38.15	.000*	.21	30.49	.000*	.00	.774
NR	.17	30.87	.000*	.17	24.66	.000*	.00	.911
UD	.07	5.78	.000*	.07	4.61	.000*	.00	.989
BRS-C	.36	173.70	.000*	.36	139.11	.000*	.00	.355
RC-C	.39	173.80	.000*	.40	141.05	.000*	.00	.011
PA-C	.20	86.03	.000*	.20	68.78	.000*	.00	.864
AWM-C	.21	42.04	.000*	.21	33.59	.000*	.00	.782

*R significant according to Holm's procedure.

significant testing results. This suggests that the relationship between lateral preference and the different reading skills and cognitive processes does not depend upon age.

A regression analysis was also conducted to determine whether the addition of lateral preference and the square of lateral preference in order to account for curvilinear relationships added anything above and beyond the linear and quadratic age terms to the regression equation. Significant testing of the R^2 change indicates that lateral preference increased the proportion of variance accounted for in the letter word identification, passage comprehension, auditory working memory, numbers reversed, understanding directions, basic reading skills composite, reading comprehension composite, and auditory working memory composite variables ($R^2\Delta$ $p \leq .002$ for all variables). Please see Table 8 for R^2, F and significant testing results. Two percent of the variance in passage comprehension, 1% of variance in letter word identification, and 2% of the various in global reading comprehension was accounted for by the linear and quadratic lateral preference terms. The addition of the linear and quadratic lateral preference terms accounted for 2%, 4% and 3% of the variance in numbers reversed, auditory working memory and the auditory working memory composite respectively.

Discussion

The purpose of this study was to examine the relationship between hand preference and reading skills and their related cognitive processes. Specifically, this study investigated the relationship between hand preference and basic

Table 8

Regression Statistics for Lateral Preference, Age, Reading Processes and Reading Skills: Testing the Effect of Lateral Preference over and beyond Age

DV's	Age			Age and Lateral Preference			Change Stats	
	R^2	F	Sig.F	R^2	F	Sig.F	R^2 Δ	Sig.
LWI	.40	414.20	.000*	.41	213.33	.000*	.01	.000*
WA	.06	9.10	.000*	.06	4.73	.001*	.00	.670
PC	.36	298.49	.000*	.38	160.611	.000*	.02	.000*
RF	.10	15.69	.000*	.12	10.08	.000*	.03	.017
RV	.19	33.03	.000*	.20	16.99	.000*	.01	.382
SB	.22	170.04	.000*	.22	85.37	.000*	.00	.468
IW	.16	132.18	.000*	.17	66.41	.000*	.00	.493
SA	.05	6.18	.002*	.06	3.79	.005*	.01	.252
AWM	.17	59.49	.000*	.21	38.15	.000*	.04	.000*
NR	.15	52.25	.000*	.17	30.87	.000*	.02	.000*
UD	.02	3.65	.027*	.07	5.78	.000*	.05	.001*
BRS-C	.35	338.53	.000*	.36	173.70	.000*	.01	.002*
RC-C	.38	323.87	.000*	.39	173.80	.000*	.02	.000*
PA-C	.20	170.26	.000*	.20	86.03	.000*	.00	.194
AWM-C	.18	67.88	.000*	.21	42.04	.000*	.03	.000*

*R significant according to Holm's procedure.

reading, reading comprehension and reading fluency skills, as well as phonological processing and auditory working memory. The current study expands upon the previous lateral preference research by using a large population from the United States. Thereby it increases the chance of predicting an existing relationship while simultaneously being more representative of the United States population. Additionally, previous research findings were limited in terms of the age range of its participants. By using a population that ranged from ages 4 to 80, the author was able to examine the relationships between hand preference, reading skills and reading related processes across the entire lifespan.

Conclusions

Multiple polynomial regression analyses were performed to determine whether hand preference was related to reading processes and/or reading achievement and whether this relationship varied by age. Regression analyses indicated that lateral preference was related to many of the dependent variables, including reading comprehension, phonological awareness and auditory working memory as noted on composite variables and many of the individual subtests. The relationship between hand preference, reading skills and reading processes is better described by a curvilinear relationship rather than a linear relationship. In other words, individuals towards the middle of the handedness continuum performed higher on the reading related tasks than those in the extremes. This suggests that the relationship between hand preference, reading skills and reading processes is a complex model that simple correlational or linear statistical methodology may not adequately address.

Additionally, results suggest that lateral preference does significantly add to the regression model in predicting reading skills and reading processes. Taking into account age, individuals with the more extreme handedness, either right or left, may have a disadvantage related to basic reading skills, global reading comprehension and auditory working memory as noted by performance on composite variables. This pattern of relationship with reading skills and handedness has been demonstrated in the past (Annett, 2002; Annett & Kilshaw, 1984; Annett & Manning, 1990; Palmer & Corballis, 1996) using either hand preference or hand skill measures, but as previously noted, this relationship has not always been supported (Crow, Crow, Done, & Leask, 1998; Mayringer & Wimmer, 2002). Age and hand preference together predicted 36% of the variance in basic reading skills, 39% of the variance in reading comprehension and 21% of the variance in auditory working memory, with hand preference adding a statistically significant amount of predictive power to the equation although handedness only added a maximum of 4% in the variation accounted for in the aforementioned skills so practical significance must be questioned. Hand preference did not add anything significant above age in relation to phonological processing skills, reading fluency, reading vocabulary, or word attack skills. The relationship between lateral preference and reading related tasks did not change by age for any of the variables.

Results do not support past research findings suggesting that phonological processing deficits are more common in left-handers (Annett 1991, 1992) or that those on the left side of the continuum are more likely than those elsewhere on the continuum to have more difficulty with reading skills (Annett, 1992; Brunswick & Rippon, 1994) but does support more recent results suggesting an absence of a relationship between phonological processing and handedness in children either by using hand skill or handedness questionnaires (Kolk & Talvik, 2002; Smythe & Annett, 2006). This study further supplements their results by adding a larger age range, through age 80.

An important part of this study is that it synthesizes the research concerning the relationship between lateral preference and reading skills with the research that indicates that auditory working memory and reading are connected (Chiappe, Hasher, & Siegel, 2000; Comeau, Cormier, Grandmaison, & Lacroix, 1999; Gottardo, Stanovich, & Siegel, 1996; Jeffries & Everatt, 2004; Kibby, Marks, Morgan, & Long, 2004; Swanson, 1993, 1994). To the knowledge of this author, the relationship between auditory working memory and handedness has not been previously investigated. As predicted, the results of this study indicate that there is indeed a relationship between auditory working memory and hand preference. The fact that with those individuals whose handedness falls more to the middle of the continuum did better on auditory working memory tasks than those at either extreme was unexpected based on the evidence of auditory working memory being associated with the left hemisphere (Reuter-Lorenz, et al., 2000; Smith, Jonides, & Koeppe, 1996).

Limitations of the Research

One limitation of the study is the lower sample size of the youngest age group in various subtests. The small sample size may have hindered the ability to detect statistical significance in general, but also decreased the chances of finding an interaction between age and lateral preference on those tasks if present. Additionally, the participants were not all given the same achievement measure, rather some had the *WJ-R* and others had the *WJ-III* although scores were transformed statistically to be equivalent. The results may have been influenced by the particular transformation method utilized and therefore a different statistical transformation may yield different findings. Therefore, a future replication of this study using a single achievement measure is recommended. A third limitation is that in some cases not all subtests of a composite were administered thus making the composite score less valid. Additionally, achievement composite scores were calculated according to the test publisher's guidelines but in fact, there may be alternative ways to combine subtests to get a more valid picture of the various skills.

Implications for Further Research

The broad implication of the current findings is that the presence of mixed or left handedness is not a predictor for a reading related deficit as many findings have suggested but rather it is the handedness at either extreme that would suggest a cost to reading related skills and cognitive processes. Therefore, just knowing a general classification of right, left or mixed handed will not provide significant knowledge regarding lateralization or potential cognitive and academic costs and benefits. A more continuous measurement of laterality would be more helpful, particularly in screening or evaluation processes. This is evidenced by the curvilinear relationship evidenced between handedness and the reading skills and related processes, rather than a linear relationship. The current research findings would suggest a need for further investigation of auditory working memory and hand preference, in order to substantiate the current findings, as well as to explore the relationship between laterality and visual working memory and the differences between both visual and auditory modes. Researchers should continue to investigate quadratic relationships, as well as linear relationships, as these findings demonstrated that while a linear relationship may be significant, a curvilinear relationship might be an even better explanation. This may account for some of the differences in the findings throughout the laterality and reading literature.

Additional research should include a larger number of participants in the lower ages, as these ages had the lowest number of participants in the current study, particularly when compared to the oldest group. This may yield any statistical differences that may not have been discovered in the current study between the age groups in terms of their relationship between hand preference and reading skills and related cognitive processes. A targeted longitudinal study of laterality of children throughout the developmental pre-reading to reading stages may provide useful information about how the relationship changes during crucial years. Further research may also wish to look at clinical groups, in particular those with learning disabilities, as the findings suggested being a strong right-hander or left-hander may be more indicative of a possible disorder.

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