Processing speed as measured by the WISC-IV: Age and gender differences in performance and relations with achievement

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**Abstract**
With the most recent revision of the Wechsler Intelligence Scale for Children (WISC-IV; Wechsler, 2003), processing speed has garnered recognition as its own unique construct that plays a significant role in overall intelligence. How processing speed influences intelligence and the degree to which it may affect academic performance is unknown. Previous studies have compared processing speed tasks among different gender and age groups, studying how these demographic variables may influence performance. However, most studies have utilized research-driven tasks as the metric upon which to base their findings as opposed to more commonly used commercial tests. Using the processing speed tasks from the WISC-IV and selected subtests from the Wechsler Individual Achievement Test (WIAT-III; Wechsler, 2009), data were collected from 114 participants. Contrary to previous studies, there were no significant gender performance differences. Processing speed showed a strong relationship with achievement tasks such as the Numerical Operations subtest of the WIAT-III. Verbal abilities measured by the WISC-IV were moderately linked to processing speed, and no significant relationship was found between reading fluency and processing speed. Reservations and limitations are discussed in view of the possible improvement of the representativeness of the sample and other conditions for future studies.

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PROCESSING SPEED AS MEASURED BY THE WISC-IV: AGE AND GENDER DIFFERENCES IN PERFORMANCE AND RELATIONS WITH ACHIEVEMENT

A DISSERTATION
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Abstract

With the most recent revision of the Wechsler Intelligence Scale for Children (WISC-IV; Wechsler, 2003), processing speed has garnered recognition as its own unique construct that plays a significant role in overall intelligence. How processing speed influences intelligence and the degree to which it may affect academic performance is unknown. Previous studies have compared processing speed tasks among different gender and age groups, studying how these demographic variables may influence performance. However, most studies have utilized research-driven tasks as the metric upon which to base their findings as opposed to more commonly used commercial tests. Using the processing speed tasks from the WISC-IV and selected subtests from the Wechsler Individual Achievement Test (WIAT-III; Wechsler, 2009), data were collected from 114 participants. Contrary to previous studies, there were no significant gender performance differences. Processing speed showed a strong relationship with achievement tasks such as the Numerical Operations subtest of the WIAT-III. Verbal abilities measured by the WISC-IV were moderately linked to processing speed, and no significant relationship was found between reading fluency and processing speed. Reservations and limitations are discussed in view of the possible improvement of the representativeness of the sample and other conditions for future studies.
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Processing speed as measured by the WISC-IV: Age and gender differences in performance and its relations with achievement

Child intelligence and achievement testing have become an integral part of educational and clinical evaluations. Within the field of assessment, the most prominent child intelligence measures are the Wechsler scales. The Wechsler Intelligence Scale for Children, fourth edition (WISC-IV, Wechsler, 2003), is the most widely used child intelligence test in the United States. It is also frequently used internationally, and it has been translated and normed in 16 different countries worldwide (Wechsler, 2003). Given this prominence, the WISC is often the subject of clinical and research investigation. The most recent version of the WISC, represents the most substantive revision of the Wechsler child intelligence tests to date (Flanagan & Kaufmann, 2004), with extensive changes from previous editions. Substantive changes include the elimination of the Verbal IQ (VIQ) and Performance IQ (PIQ) and have been substituted for four core indices in order to illustrate a more well-rounded view of intelligence. Four subtests were added, which were adaptations of tests used on other Wechsler tests. Cancellation is a new subtest designed for the WISC-IV. Additionally, scoring and administration instructions were revised and items were reworded in efforts to eliminate cultural bias. (Flanagan & Kaufman, 2004; Wechsler, 2003).

One of the most notable changes in the WISC-IV is the creation of a processing speed index (PSI). Previously, processing speed was considered a minor factor linked to intelligence, whereas in the current conceptualization, the PSI is its own distinct component index and accounts for 20% of the WISC-IV test material (Sattler & Dumont 2008). Although processing speed on the WISC-IV is primarily measured by simple, clerical tasks, efficient processing as an everyday skill is necessary for both routine and complex cognitive
tasks. In Weiss’ (2006) analysis of processing speed, he referred to it as a “key cognitive and individual differences variable” (p. 153), such that its influence is now reflected in most major theories of intelligence.

As an important component of intelligence, processing speed is related to academic success and achievement in various domains such as reading and mathematics, and serves to possibly explain individual differences in children (Weiss, 2006). The culture of our educational system emphasizes the importance of responses that are produced within time constraints. This can cause academic achievement problems for children that are slow processors. Thus, there are important associations between processing speed and academic achievement. The next clear steps for the development of research in this area would be to attempt to directly link processing speed and achievement; however, studies addressing this issue are relatively rare (Dodonova & Dodonov, 2012).

Academic skills and achievement are often measured by tests such as the Wechsler Individual Achievement Test (Wechsler, 2009). The test is specifically designed to complement the WISC-IV and measure eight areas of achievement specified by recent legislation pertaining to special education (Wechsler, 2009). Like the WISC, the WIAT aids in the diagnosis of learning disabilities and can guide educational placement and eligibility for services. Several subtests of the WIAT-III are timed and measure how processing speed may influence academic tasks.

Individual differences in performance on processing speed tasks have been attributed to various personality traits and overall cognitive abilities throughout research studies (Rindermann & Neubauer, 2001; Vartanian, Martindale & Kwiatkowski, 2007). Gender, age, and verbal ability have been shown in other studies to have a significant effect on
processing speed (Alloway, 2009; Camarata & Woodcock, 2006 different date listed in your reference section; Duan, Shi, & Zhou, 2010; Fry & Hale 1996; Kail, 1991; Kail & Ferrer, 2007; Naglieri & Rojahn, 2001; Pascualvaca et al., 1997; Ri ovainen, 2011; Van der Elst, Van Boxtel, Van Breukelen, & Jolles, 2006). However, most studies utilized measures of academic processing speed, or non-standardized measures created for research purposes. While these studies are extremely beneficial in underscoring the importance of academic processing speed or research-analogues and establishing a relationship with academic achievement, these findings may not be as generalizable when considering that most children are evaluated using commercially marketed standardized measures of intelligence such as the WISC-IV. Likewise, these studies also utilized measures that emulate tasks of achievement, such as those featured in the WIAT (WIAT-III; Wechsler, 2009) and Woodcock-Johnson Tests of Achievement (WJ-III; Woodcock, R. (2010) ). This makes the results of the studies and their implications less transferable to real world settings.

Given the lack of research and the recent emergence of speed of processing as a major component of intelligence and its relation to achievement, the goal of this study was to bolster previous findings related to how processing speed is affected by gender, age, and verbal abilities. The current study’s findings will be used to replicate and strengthen the connection between academic achievement and processing speed.

Wechsler became an important figure in the field of assessment in the 1930’s. However, intelligence testing began shortly after the end of the 19th century. In order to better understand the evolving nature of intelligence. The next section reviews historical theories of intelligence and the emergence of the construct of processing speed as considered within these various theories.
History of Processing Speed in Intelligence Test Development and Variance due to Individual Differences

Theories of Intelligence and Processing Speed

Many measures of intelligence contain components relating to processing speed, and some form of what is referred to today in the Wechsler scales as processing speed is included in most modern theories of intelligence. Terminology referring to processing speed varied based on historical influences, theories, and authors. Because the WISC uses the term “processing speed”, when discussing the general concept for the purposes of this paper, the term “processing speed” will be used. However, other authors have used terms including cognitive speed, mental speed, and decision speed. The following section reviews processing speed as a concept featured in several established theories of intelligence and how this construct is conceptualized across several intelligence models.

One theory behind processing speed, sometimes referred to as “mental speed” or “cognitive speed,” purports that speed is a fundamental factor in higher cognitive processes (Brand, 1981). Cognitive speed has been defined as “the ability to perform cognitive tasks automatically, especially under pressure to maintain focus and concentration” (McGrew & Flanagan, 1998, p. 24). Carroll’s empirically supported three-stratum factor analytic theory of cognitive abilities (1993) suggested that there are many distinct cognitive abilities that fall along three different levels. In Carroll’s theory, the three levels consist of Narrow (Stratum I), Broad (Stratum II), and General (Stratum III) strata. Broad level factors (Stratum II) include eight broad factors such as cognitive speediness and processing speed. Processing speed is defined as “an ability involved in tasks or performances that require reaction time and/or decision speed” and broad cognitive speediness, or decision speed is defined as “an
ability involved in tasks or performances that require rapid cognitive processing of information” (Sattler, p. 228) Processing speed is known as well as the more well-known constructs of fluid intelligence and crystallized intelligence (Carroll, 1993). Stratum I includes cognitive constructs such as memory span, visualization, and simple reaction time. Stratum III consists of g, the general factor, or overall intelligence.

An alternative model of intelligence is the Planning, Attention, Simultaneous Processing, and Successive Processing model (PASS; Das, Naglieri, & Kirby, 1994). In this model, successive processing relates to processing speed as it concerns making decisions based on stimuli in a sequence. The brain goes through a series of successive steps as the name of the model implies. Planning involves executive function, control, and organization. Next, the brain focuses attention by maintaining alertness on the stimuli or task at hand. Simultaneous and successive processing processes are responsible for manipulating or encoding the information. (Das, Naglieri, & Kirby 1994). An earlier model of intelligence put forth by Campione and Brown (1978) includes processing speed as a function of a structural component called the architectural system. One subcomponent of the architectural component is efficiency. Efficiency emphasizes selection and storage of information, rate of memory search, duration of alertness, and the speed at which information is encoded. This component includes many of the essential elements of processing speed.

As reviewed, there are many different theories of intelligence that include speed of processing as a component of the model. The model of intelligence and processing utilized in this study is based on Wechsler’s model, theory, and structure of intelligence. The following section begins with a review of the development of the WISC-IV and various
aspects of this test. Next, the different subtests that comprise the processing speed index of
the WISC-IV are discussed in more detail.

**Wechsler Intelligence Scale for Children, 4th Edition (WISC-IV)**

The Wechsler Intelligence Scale for Children, 4th Edition, is the most recently revised
version of the Wechsler children’s intelligence scales (Wechsler, 2003). The first version
was published in 1949 and underwent revisions in 1974 and 1991. The test’s most recent
revision was undertaken to improve theoretical foundations and psychometrics, enhance
clinical utility, and increase user-friendliness (Sattler & Dumont, 2008). The WISC-IV
contains 10 core subtests and 5 supplemental subtests that comprise the following
composites: Verbal Comprehension (VCI), Perceptual Reasoning (PRI), Working Memory
(WMI), and Processing Speed (PSI). The WISC-IV contains approximately 70% of the
same information as its predecessor, the WISC-III (Sattler & Dumont, 2008). Five subtests
were added to the fourth edition including Cancellation, Picture Concepts, Letter-Number
Sequencing, Matrix Reasoning, and Word Reasoning. Three subtests, that all had a motor
component, were deleted (i.e., Picture Arrangement, Object Assembly, and Mazes). The
most recent revisions of the WISC, much closer together than past revisions, reflect the
sentiment that assessment of children’s intelligence is an evolving science. The emphasis on
processing speed in the most recent version of the WISC is an example of how changing
theory and research affects test revision and design.

Although processing speed subtests were featured on the WISC-III; Wechsler, 2005),
processing speed as a major component as represented by the Processing Speed Index (PSI)
was introduced with the WISC-IV, and little research has been conducted relating to its
clinical significance (Calhoun & Mayes, 2005). The PSI has the lowest factor loading on
general intelligence, or $g$, in comparison to other factors. This may indicate that the PSI is more independent and less related to a global “g” construct of IQ than the other factors (Calhoun & Mayes, 2005). PSI is comprised of two core subtests and one supplemental test. Coding and Symbol Search the primary subtests, and are considered fair measures of $g$. In contrast, Cancellation is the supplemental test and it is considered a poor measure of $g$ (Sattler & Dumont, 2008). Cancellation has the lowest loading on Full Scale Intelligence Quotient (FSIQ) than all of the other subtests of the WISC-IV. Coding. The Coding subtest was introduced with the third edition of the WISC (Wechsler, 2003). Coding is used to measure overall visual-motor speed. It also measures dexterity, scanning ability, visual short term memory, visual recall, attention and concentration, visual-perceptual discrimination, and numerical recognition (Sattler & Dumont, 2008).

Coding A is administered to children ages 6-7. Children are shown a sheet that illustrates that each shape, such as a star or square, has its own symbol. The child is given the opportunity to practice and make the correct mark inside an empty shape. There are 5 practice opportunities and 59 empty shapes. The child is given 120 seconds to complete the subtest. Coding B is administered to children 8 and older. The test provides the child with a sample “key” containing boxes numbered 1 to 9 in the lower part and symbols in the upper part. Each number is paired with a symbol. The child is then required to make the correct symbol based on the number provided in the box. The child has 120 seconds to complete as many boxes as possible, with care to avoid errors. Scores are obtained by recording the number of symbols transposed correctly within the time limit.

Motivation has previously been considered as an important factor related to performance on the Coding subtest. Lindley and Smith (1992) conducted a study where
adults were given incentives to improve performance. Regardless of the incentive, no differences in scores were noted. The researchers concluded that processing speed was cognitive and not motivational (Lindley & Smith, 1992). Kamphaus (2001) stated that, since the publication of this study, the overarching consensus is that Coding subtest performance differences are, in fact, due to differences in cognitive ability rather than motivation. However, similar studies have not been conducted with children.

Fine motor skill and manual dexterity, however, may be influential factors in processing speed performance. Processing speed seems to be a construct in which many skills are required to complete timed tasks. The latest WISC removed some subtests that contained manipulatives, decreasing motor involvement and the engagement between examiner and examinee (Flanagan & McGrew, 2004). Other subtests that were considered measures of mixed abilities, such as Picture Arrangement and Picture Completion were deleted or moved to supplemental status (Flanagan & Kaufman, 2004). Feldmann, Kelly, and Diehl (2004) found that motor speed accounted for significant variance for both Coding and Symbol Search subtests. Because of the risk of confounding motor speed and mental speed, strong recommendations have been made to create a conscious distinction between measurement of psychomotor and cognitive abilities (Carroll, 1993). In summary, various skills, both cognitive and motor ability, are required to exhibit high performance on the Coding subtest.

**Symbol Search.** Symbol search is a subtest designed to measure visual-perceptual discrimination and scanning abilities and was modeled after the speed of processing test on the Differential Abilities Scale (Elliot, 2007). This subtest first appeared on the WISC-III (Wechsler, 2003). Symbol Search assesses a variety of skills such as processing speed,
perceptual speed, psychomotor speed, attention, concentration, and visual short-term memory (Sattler & Dumont, 2008). Like Coding and Cancellation, scores are obtained on the basis of accuracy and speed. Final scores are calculated by subtracting the number incorrect from the number of correct responses. Both versions of the Symbol Search subtest have a 120-second time limit. Symbol Search A contains a total of 45 items and is administered to children ages 6-7. Children are shown a target symbol in an array of three others. The child is asked to mark the box labeled YES if the target shape is present in the array and NO if the target shape is not present. Children are provided two demonstration items, exhibited by the test administrator, and two practice opportunities. Symbol Search B is administered to children older than 7 years, 11 months. It is slightly more complicated in that there are two target shapes. Children also must discriminate between five shapes in the array as opposed to three. Symbol Search has positive psychometric properties and appears to reliably measure aspects of a child’s processing speed with average internal consistency ranging from .72-.89 and average test-retest reliability ranging from .74-.87 (Sattler & Dumont 2008). Like Coding, Symbol Search’s required motor capabilities may confound processing speed results (Feldmann, Kelly, and Diehl 2004).

Cancellation. The third subtest of the PSI is Cancellation, which was added to the WISC-IV in 2003. Cancellation tests have are used in the assessment of attentional difficulties and/or visual neglect in stroke and traumatic brain injury patients (Lezak, 2004). There is a long history of cancellation tasks in neuropsychological testing such as the Bells Test (Gauthier, Denault, & Joanette, 1989), used as a popular bedside method to assess special neglect in patients with brain injuries (Azouvi, Louis-Dreyfus, Bemati, Bartolomeo, 2002). Cancellation tasks are paper-and-pencil tests used to measure a person’s ability to
scan for an identifiable target and either cross out or circle such target items in an array. Cancellation tests are used to measure visuospatial functioning, selective and sustained attention, visual discrimination, perceptual speed and scanning, as well as motor perseveration (Na et al., 1999). This subtest was modeled after previous letter cancellation tasks. Cancellation tasks that preceded the WISC-IV consisted of arrays of numbers, letters, or a combination of symbols, in black writing. The WISC’s Cancellation subtest uses color pictures and figures, presumably to appear more interesting to children. The Cancellation subtest assesses a child’s ability to effectively scan and discriminate between targets and distracters. There are two different formats for the Cancellation subtest including both structured and random arrays. The structured format has the stimuli lined up in rows, while the random format has the stimuli appearing at random on the page.

There has been little research on the Cancellation subtest of the WISC-IV since its introduction (Wechsler, 2003). It has been established that this subtest has the lowest loading on g, an overall measure of intellectual functioning, as compared to all other WISC-IV subtests (Keith, Fine, Taub, Reynold, & Kranzler, 2006). However, further research for this particular subtest is scarce. Previous studies of cancellation tasks have not included the new cancellation subtest of the WISC-IV.

Given the emphasis on processing speed in the fourth edition of the WISC and the likelihood that this index will continue in the fifth edition, it is important to consider factors that affect performance on the cancellation task and on processing speed in general. Some of these factors are considered to be individual differences such as gender and age effects, which may lead to changes in the way that processing speed is conceptualized in the future.
Individual Difference Factors Related to Processing Speed

There are number of factors that have been shown to be related to processing speed. In addition to motor speed, other factors such as neurological disorders, gender, and age have been shown to affect processing speed (Camarata & Woodcock, 1996; Duan et al., 2010; Fry & Hale 1996; Kail, 1991; Kail & Miller, 2007; Naglieri & Rojahn, 2001 Pascualvaca et al., 1997; Roivainen, 2011; Van der Elst et al., 2006). In regards to neurological disorders and other diagnoses, Calhoun and Mayes (2005) administered 12 subtests of the WISC-III to nearly 1000 children. Children with disorders such as Attention-Deficit/Hyperactivity Disorder, Bipolar Disorder, and Autism Spectrum Disorder all had PSI scores below the group mean. This pattern was not found in children diagnosed with disorders, such as anxiety, oppositional-defiant disorder, and intellectual disabilities.

Gender and age also have been implicated as important variables related to processing speed. These factors will be more thoroughly discussed in the following sections due to the focus on these constructs in the current study. Given the scant literature on gender and age effects on processing speed, studies on both adults and children will be reviewed.

**Gender.** There is evidence from previous investigations to suggest that girls may perform better on tasks involving attention, planning, and processing speed (Naglieri & Rojahn, 2001; Pascualvaca et al., 1997). In a comparison of WAIS-III composite scores, Longman, Saklofske, and Fung (2007) found that adult women had higher scores on the processing speed index in both American and Canadian samples. Camarata and Woodcock (2006) conducted a study of academic processing speed using normative data across the lifespan from various versions of the Woodcock-Johnson. The sample included nearly 10,000 participants ranging from 2 to 90 years old. There were highly significant gender
effects found in this study for all age cohorts. The difference in scores was most prominent in the adolescent-aged sample. In the adolescent group, females scored more than eight standard score points higher than males overall (Camarata & Woodcock, 2006). The difference in performance was very small in the kindergarten cohort, and became more prominent in each cohort until the high school group, evidencing possible neurological and developmental differences for adolescent males and females. This may mean that processing speed develops at a different rate in males and females. Because overall intelligence scores between males and females are similar, it may also mean that males may be compensating in other areas. An analysis of percentile ranks was also conducted in addition to mean differences to ensure that the differences detected were consistent across the distribution instead of being from large differences between the lowest performing males versus lowest performing females. Males were lower than females at all percentile levels, showing that the effects were not due to the difference between the lowest performing males’ scores and the low performing female scores. Despite these academic processing speed gender differences, no overall differences in general intellectual ability were found (Camarata & Woodcock, 2006).

Rovainen (2011) reviewed several large scale studies on adult gender differences in processing speed, focusing mainly on neurological tasks. Evidence suggested that females outperformed males on tasks involving letters, digits, and rapid naming. For example on the Stroop test, a test of executive functioning developed in the 1930’s, adult females consistently outperformed males in a sample of 1,856 participants on the color naming portion (Van der Elst et al., 2006). In contrast to the notable advantages for females, males
were found to show an advantage on pure motor tasks, such as finger tapping and reaction time tasks (Roivainen, 2011).

Specifically on digit cancellation tasks, girls have been shown to make fewer omission errors and have faster completion times (Naglieri & Rojahn, 2001). This may be due to gender differences in perceptual speed, visual scanning, and attention. Also, girls appear to be better able to discriminate between pertinent and irrelevant stimuli, a skill needed for good performance on a cancellation task.

Age. Information processing in adults greatly differs from how information is processed in children and adolescents. Reaction time is a common metric used to determine processing speed in research studies. Reaction time is defined as the time that elapses between the presentation of a stimulus and a response to the stimulus (Sattler, 2008). Decreased reaction times translate into increased scores on processing speed tests. In an earlier review of the literature, Wickens (1974) found differences, mainly a decrease in reaction time, on speeded tasks from age 3 to adolescence. Since then, it has been widely established that in childhood and adolescence as age increases, reaction times decrease. Decreased reaction times translate into increased scores on processing speed tests. In general, processing speed capabilities increase more rapidly throughout early and middle childhood as they develop. Processing speed continues to grow at a slower rate throughout late childhood and adolescence (Kail, 1991; Kail & Miller, 2007). In most studies regarding developmental processing speed, study findings have indicated that performance improves exponentially on most speeded tasks throughout childhood and adolescence, but the rate of growth and improvement is greatest during childhood (Kail, 1991).
There are differing opinions as to the neurological mechanisms that underlie the developmental rate at which processing speed changes. The global trend hypothesis suggests that all information processing capabilities develop in concert at similar rates (Duan, et al., 2010; Fry & Hale, 1996; Hale, 1990; Kail & Ferrer, 2007). This theory assumes that regardless of the task at hand, there is a biological and developmental ceiling as to how fast information can be processed at certain ages, regardless of the type of task. Older students should fare better on tests of processing speed, with increasingly low reaction times and increased scores.

The local trend hypothesis suggests that different abilities in children develop at different rates depending on the type of task. Kail and Miller (2006) found that language processing abilities may develop before other types of processing. Although the theory is slightly more specific, it is built upon the principle set forth in the local trend hypothesis stating that older children consistently outperform younger children in processing tasks until mid-adolescence when skills seem to plateau (Kail & Miller, 2006).

In the global trend hypothesis, the underlying factor in age-related increases is expected not to be specific to certain tasks, but rather should systematically vary as a child ages (Duan et al., 2010). Fry and Hale (1996) designed a study with students in grades four, five, six, seven, and twelve, along with first and second year college students. The participants completed computerized tasks that measured processing speed, working memory, and fluid intelligence. The measures of processing speed were fairly distinctive in order to support the global trend hypothesis. The children’s groups had longer reaction times on every task when compared to the young adults in high school and college. The differences in speed due to age group were global, with similar effects on each of the tasks,
regardless of task complexity (Fry & Hale, 1996). These findings supported the global trend hypothesis in that a strong direct connection was found between age and speed in a variety of tasks (Fry & Hale, 1996).

In a similar study of gifted students, ages 9, 11, and 13, participants were asked to complete a choice reaction time task and abstract matching task. The choice reaction time task was similar to symbol search, in that it consisted of English numbers and letters and Chinese characters. The participants were required to discern if a target symbol in the first row was contained in a second row with four figures. The 13-year-old participants consistently performed better than the 11-year-old participants and the 9-year-old participants on each task, further showing age-related differences in processing speed (Duan et al., 2010). The study replicated previous findings indicating that older students display quicker reaction times. Other research has been performed to measure processing speed using means other than a paper and pencil test, in order to eliminate potentially confounding motor abilities. Short, rapid eye movements, called, saccades, are typically used in visual processing and daily tasks such as reading. In a study of 245 participants ages 8 to 30, the speed with which saccadic eye movements were initiated was used to measure reaction time on various oculomotor vision tasks. A change point analysis concluded that adult-level performance was reached on most variables by age 14 to 15 (Luna, Garver, Urban, Lazar, & Sweeney, 2004). Although not based upon traditional intelligence testing-type tasks, these findings support the hypothesis that processing speed continues to develop into adolescence and to improve with age even in regards to oculomotor motor tasks used by optometrists.

In contrast to the global trend hypothesis, the local trend hypothesis assumes that information processing changes with age, but different components of information
Kail & Miller’s more recent research (2006) suggests that processing speed may be different for language tasks as opposed to nonlanguage tasks. In this 2006 study, both 9-year-old and 14-year old participants completed 10 speeded tasks based on nonlanguage and language activities. In agreement with previous research findings, the 14-year-olds completed the tasks quicker across all conditions. However, processing speed was faster on language tasks than visual tasks for the younger group, but no differences between tasks were noted at age 14. These findings suggest that language processing may develop more quickly than other forms of processing. Thus, there may be domain specificity in processing speed during childhood (Kail & Ferrer, 2007) supporting the local trend hypothesis and theory.

The current study aims to support and replicate previous studies validating the global trend hypothesis using the subtests of the WISC-IV. Given that the PSI subtest on the WISC are not considered to be distinct and are designed to load on one factor index, they likely use many of the same skills, and therefore, the findings should support the global trend hypothesis. All processing tasks on the WISC are nonlanguage tasks, making it difficult to parse out which specific processing abilities account for the performance on PSI subtests. No studies have used the current version of the WISC to support this theory. Processing abilities affect intelligence scores; however, processing speed translates into academic skills which can affect grades and achievement test scores as well.

**Relations between Processing Speed and Academic Achievement**

Although academic achievement is commonly associated with grades awarded by teachers, academic achievement scores obtained from standardized testing are more highly correlated
with intelligence than grades citation (Dodonova & Dodonov, 2012). This may be due to other factors involved in grades such as motivation, time management, academic support, and other personal traits and skills of the individual (Dodonova & Dodonov, 2012). Psychoeducational and neuropsychological evaluations almost always include elements of academic achievement, due to the fact that difficulties in this area can cause problems in school and in job-related environments. The two most common standardized measures of achievement are the Wechsler Individual Achievement Test (WIAT-III; Wechsler, 2009) and the Woodcock Johnson Tests of Achievement, Normative Update (WJ-III-Woodcock, 2010). Both of these tests are used in clinical, school, and research settings, to assess children’s performance in a variety of academic domains including the broad areas of reading, writing and mathematics. These tests aim to identify academic strengths and weaknesses and are designed to complement tests of intellectual ability such as the WISC-IV and the Woodcock Johnson–Cognitive. Pinpointing areas of difficulty in school has always been a main focus of intelligence assessments for children, ever since the first intelligence test was designed in 1905 (Binet, 1905). The relationship between academic performance and intelligence test scores has been widely studied, and the correlations are typically moderate to strong. As noted previously, speed of processing is an important component of modern ability tests. According to Dodonova and Dodonov (2012), “there is an observed significant unique contribution of processing speed and intelligence to explain the variability in school performance” (p. 170). However, processing speed, as a component of intelligence, is seldom studied as a direct link to school achievement (Dodonova & Dodonov, 2012). Slow processing speed has been associated with reading problems and mathematical learning disabilities in children (Berg & Hutchinson, 2010; Catts, Gillespie, Leonard, Kail, & Miller,
2002). Reading fluency and automaticity, or reading processing speed, as measured by rapid automatic word reading tasks is an integral component of becoming a proficient reader (Benner, Nelson, Allor, Mooney, & Dai, 2008). In a study of over 160 children, Benner et al. (2008) found that academic processing speed, as measured by the Woodcock-Johnson, 3rd edition, mediated the effect of language abilities. The authors found students’ abilities to process information and make correct and timely responses had an influence on academic skills.

**Verbal Abilities and Processing Speed.** Processing speed research that pertains to intelligence testing may also be valuable in the academic setting. Based on Kail’s research, there appears to be an association between performance on verbal tasks and processing speed. Knowledge regarding how processing speed impacts everyday academic skills is an area of investigation that can be useful for implementing teaching techniques and therapeutic intervention for children with reading disabilities. In one study, children who did not perform well on verbal tasks tended to have weaker performance on digit cancellation tasks (Pascualvaca et al., 1997). Leonard et al. (2007) studied 204 14-year-olds diagnosed with language impairment. The participants in that study had language difficulties, not due to hearing problems, brain injury, or intellectual disability. The adolescents were given a battery of tests focused on verbal abilities, such as the Peabody Picture Vocabulary Test (Dunn & Dunn, 2007) and the Clinical Evaluation of Language Fundamentals (Semel, Secord, & Wiig, 2003). Participants were then administered picture matching and reaction time tasks to measure processing speed. Findings confirmed that processing speed deficits exacerbated, and possibly were a determinant of, verbal difficulties. Processing speed and working memory accounted for over 60% of the variance in participants’ composite language
test scores (Leonard et al., 2007). Language skills involve quickly integrating lexical, phonological, grammatical, and semantic knowledge. Moreover, it seems that the positive relationship between language development and processing speed is a rational concept that is gaining popularity given the combination of skills simultaneously required on the verbal tasks. Regardless of the direction of the effects, there appears to be an association between verbal abilities and processing speed.

With the research of achievement, substantial effort has been put forth to better understand the cause of reading disabilities (Catts et al., 2002). However, researchers disagree with regard to what underlies reading disabilities. There are researchers have asserted that reading disabilities occur due to a general disruption in processing (Nicholson & Fawcett, 1994; Wolff, Michaelson & Orvutt, 1990). Some studies have shown that children with poor reading abilities and linguistic processing also showed lower speed of processing (Nicolson & Fawcett, 1994) Other studies claim that specific phonological processing underlies reading disabilities, such as dyslexia, with little impact on other skills that do not involve reading (Tallall, Miller, Jekens, & Orvutt, 1997). When Nicolson and Fawcett (1994) compared children with dyslexia with equally aged peers, there was no difference between the groups on simple reaction time tasks, such as pushing a button at the sound of a certain tone. There were, however, group differences for lexical reaction timed tasks, such as saying yes in response to a real word, and no to a non-existent word. This study suggests a link between cognitive processing speed and language processing.

Although academic achievement is commonly associated with grades awarded by teachers, academic achievement scores obtained from standardized testing are more highly correlated with intelligence than grades (Dodonova & Dodonov, 2012). This may be due to other
factors involved in grades such as motivation, time management, academic support, and other personal traits and skills of the individual (Dodonova & Dodonov, 2012). Psychoeducational and neuropsychological evaluations almost always include elements of academic achievement, due to the fact that difficulties in this area can cause problems in school and in job-related environments. The two most common standardized measures of achievement are the Wechsler Individual Achievement Test (WIAT-III; Wechsler, 2009) and the Woodcock Johnson Tests of Achievement Normative Update (WJ-III-NU; Woodcock, 2010). Both of these tests are used in clinical, school, and research settings, to assess children’s performance in a variety of academic domains including the broad areas of reading, writing and mathematics. These tests aim to identify academic strengths and weaknesses and are designed to complement tests of intellectual ability such as the WISC-IV and the Woodcock Johnson–Cognitive. The next section reviews the WIAT-III in more detail as this test will be used to investigate relations with processing speed in the current study.

**Wechsler Individual Achievement Test, 3rd Edition (WIAT-III, Wechsler, 2009).** The Wechsler Individual Achievement Test, 3rd Edition, was published in 2009. It is used to measure skills in listening, speaking, reading, writing, and mathematics. One of its main purposes is to identify academically-focused strengths and weaknesses in order to better facilitate the delivery of relevant services to school-aged children in the classroom. The test has 16 subtest scores and produces eight standardized composite scores. Due to the lengthy administration time of the test, many examiners have recommended focusing only on necessary subtests (Vaughan-Jensen, Adame, McClean, & Gamez, 2009).
Intelligence and achievement testing has become an integral part of the provision of educational services for children. The WISC and WIAT, specifically, are designed to complement other Wechsler instruments, the No Child Left Behind (NCLB; 2001) policies and administration, Individuals with Disabilities Education Act (IDEA, 2004), and individualized education plans (IEPs). The Individuals with Disabilities Act and No Child Left Behind are both pieces of federal legislation that attempt to comprehensively reform education and create standards based on assessment. The legislation also has a focus on early intervention and identification of students that may need special assistance in educational settings. IDEA addresses the needs of children ages 3 to 21 years of age and increases access to services through school’s special education systems. Once entered into a program, a child and their family participate in the creation of an IEP. An IEP, which specifies how often a child will receive services and specifies accommodations, and progress goals. Most children begin their process of engaging in special education with formal assessment and teacher intervention. Assessment, particularly in the areas of intelligence and achievement, guide children through their entrance into the program and shape learning interventions.

**Achievement, Ability, and Processing Speed**

Pinpointing areas of difficulty in school has always been a main focus of intelligence assessments for children, ever since the first intelligence test was designed in 1905 (Binet, 1905). The relationship between academic performance and intelligence test scores has been widely studied, and the correlations are typically moderate to strong. As noted previously, speed of processing is an important component of modern ability tests. According to Dodonova and Dodonov (2012), “there is an observed significant unique contribution of processing speed and intelligence to explain the variability in school performance” (p. 170).
However, processing speed, as a component of intelligence, is seldom studied as a direct link to school achievement (Dodonova & Dodonov, 2012). Slow processing speed has been associated with reading problems and mathematical learning disabilities in children (Berg & Hutchinson, 2010; Catts, Gillespie, Leonard, Kail, & Miller, 2002). Reading fluency and automaticity, or reading processing speed, as measured by rapid automatic word reading tasks is an integral component of becoming a proficient reader (Benner, Nelson, Allor, Mooney, & Dai, 2008). In a study of over 160 children, Benner et al. (2008) found that academic processing speed, as measured by the Woodcock-Johnson, 3rd edition, mediated the effect of language abilities. The authors found students’ abilities to process information and make correct and timely responses had an influence on academic skills.

Researchers disagree with regard to what underlies reading disabilities. There are researchers who have asserted that reading disabilities occur due to a general disruption in processing, and other studies find that reading is impacted by a very specific deficit in phonological processing, that leaves other areas unaffected ( ). Some studies have shown that children with poor reading abilities and linguistic processing also showed lower speed of processing (Nicolson & Fawcett, 1994). When Nicolson and Fawcett (1994) compared children with dyslexia with equally aged peers, there was no difference between the groups on simple reaction time tasks, such as pushing a button at the sound of a certain tone. There were, however, group differences for lexical reaction timed tasks, such as saying yes in response to a real word, and no to a non-existent word. This study suggests a link between cognitive processing speed and language processing.

Many studies have been conducted to explore how the role of academic fluency and lower order skills is influenced by processing speed. In a study focusing on mental addition
fluency and processing speed, 48 elementary students were classified as at-risk for failing based on their scores falling in the lowest quartile in arithmetic. The participants were administered a version of a digit naming task. Speed of speech was also measured using a number articulation task, where they were asked to repeat a list of single syllable numbers as quickly as possible five times. The study found that working memory, short-term memory, and processing speed influenced performance scores and that these abilities were lower in children identified as having problems in mathematics (Berg & Hutchinson, 2010).

Findings from the preceding studies demonstrate the link between applied academic performance and the construct of speed of processing. The next section reviews the rationale for the present study. The current study will attempt to examine relations between academic achievement as measured by the WIAT-III and speed of processing as measured by the WISC-IV.

**Rationale for the Study**

Processing speed and working memory have been frequently cited as constructs likely to explain individual differences in cognitive ability and academic achievement (Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008; Fry & Hale, 1996). Working memory is defined as the ability to sustain attention, concentrate, and exert mental control (Sattler, 2008). However, processing speed has not received the attention that it deserves, whereas working memory has been more thoroughly researched as a predictor of school achievement (Alloway, 2009). Although there have been a number of studies focused on visual search tasks much like those featured in the PSI, there are scarce independent findings using the three WISC-IV measures of processing speed. The present study will attempt to replicate
previous findings with regard to gender and age differences in performance on the speeded tasks included as indicators of processing speed on the WISC-IV.

Processing speed has become increasingly more important in the most recent version of the WISC, and its significance has not been sufficiently examined in the literature. This is a meaningful issue given the educational, academic, and life decisions. Many children who have cognitive disabilities or demonstrate difficulties in school may have processing speed deficits and become involved with the special education programs within the public school system. Cognitive testing is one of the central steps used to identify students that have learning disabilities and is essential in their placement in schools’ special education programs. Cognitive testing results along with other measures give students access to special assistance and services. Further knowledge about how children process information and the differences therein may also affect the manner in which teachers deliver information and test their students. Greater information regarding the role of processing speed and all factors that could potentially confound or adversely affect scores must be considered to formulate an accurate depiction of the child’s strengths and weaknesses.

The literature supports performance differences in processing speed as a result of multiple variables. Differences in performance on processing speed tasks due to gender, age, and verbal abilities should be studied more thoroughly to provide further insight regarding the construct of processing speed and how it can affect intelligence and achievement. Intelligence test such as the WISC aim to accurately capture an examinee’s general abilities, a construct conceptualized as $g$. The FSIQ is the WISC’s version of a composite measure. Confirmatory factor analysis performed by Keith, Fine, Taub, Reynolds & Kranzler (2006) confirms that the WISC reflects abilities as set forth in the Catell-Horn-Carroll theory. The
FSIQ was built upon a four factor structure of Verbal Comprehension, Perceptual Reasoning, Working Memory, and Processing Speed, and test develops may purport that $g$ and FSIQ are nearly one in the same. At the subtest level however, tests vary in their $g$ loadings, showing that some subtests being factored into the FSIQ are “good” and “poor” measures of $g$ (Sattler, 2008). Even though processing speed loads conservatively on both FSIQ and $g$, it clearly influences a variety of tasks across domains. With a better conceptualization of how children’s individual differences affect processing speed, psychologists may be able to suggest more effective interventions and tests more sensitive to these differences.

Given the preceding literature review regarding the importance of processing speed, the following hypotheses will be investigated in this study:

**General hypotheses:**

1) It is hypothesized that all subtests of the PSI will have a strong relationship with one another. Intercorrelations with the PSI and its subtests range from .10 to .75 (Sattler, 2008). This was performed in order to validate previous findings.

2) It is hypothesized that PSI scores will be positively correlated to WISC-IV Verbal Comprehension (VCI) scores.

3) It is hypothesized that PSI scores will be positively correlated with Academic Achievement as measured by Word Reading, Word Reading fluency, Word Reading Cumulative Percentage, Spelling, and Numerical Operations of the WIAT-III.

4) It is hypothesized that PSI will have a stronger relationship with Word Reading Fluency than with Word Reading, Spelling and Numerical Operations subtests of the WIAT-III.
Demographic hypotheses:

5) It was hypothesized that age would be positively correlated with PSI raw scores on the WISC-IV

5a) It was hypothesized that age would be positively correlated with the Coding subtest raw scores of the WISC-IV.

5b) It was hypothesized that age would be positively correlated with the Symbol Search subtest raw scores of the WISC-IV.

5c) It was hypothesized that age would be positively correlated with the Cancellation subtest raw scores of the WISC-IV.

6) It was hypothesized that females would have higher PSI scores than males.

6a) It was hypothesized that females would have higher Coding subtest scores than males.

6b) It was hypothesized that females would have higher Symbol Search subtest scores than males.

6c) It was hypothesized that females will have higher Cancellation subtest scores than males.

Method

Participants

The sample included 114 children (n=114) ranging in age from 6-16 years living in the Pacific Northwest (M=10.3, SD=3.3). There were 73 females (64%) and 36 males (41%). The majority of the sample was Caucasian (82%); however, 18% came from different ethnic groups including Latino, Native American, African American, Asian, and Pacific Islander.

Procedure
Participants were volunteers from the local community. Each student was responsible for recruiting one participant for the study. No data was collected on methods of recruitment, but many volunteers or their parents were known personally to the student or recruited through emails and other various means. Each participant completed a battery of assessments lasting approximately 3-4 hours. Test administrators were graduate students enrolled in a child assessment class in a doctoral psychology program. All students had completed introductory coursework in intellectual and personality assessment, psychometrics, ethics, clinical skills, and diagnostic interviewing. Test administrators worked with a graduate teaching assistant and were subsequently tested on their knowledge and competency in administering the WISC-IV prior to administering the tests with their community volunteers. Teaching assistants worked to ensure competency to administer the WISC-IV, such as subtest-specific prompts, discontinue rules, and other relevant procedures. Once testing was completed, protocols were reviewed for accuracy by teaching assistants, adding an additional layer of assurance for accuracy and standardization.

Participants were recruited by trained graduate students as a requirement for completion of the course. Administrators and participants were not taped during testing, and testing conditions varied with regard to setting. Prior to administration of the tests, written informed consent was obtained from parents and guardians of all participants, and written assent was obtained from the children themselves. Participants were offered a variety of incentives which were decided upon individually by each administrator, and there were no consequences if participants chose to withdraw. Participants were not permitted to take part in the study more than once. Youth were not allowed to participate if they had been the subject of similar testing within 1 year.
The data were collected between 2002 and 2013. Data collection was ongoing and was approved by the Institutional Review Board at Pacific University. All participants were administered the 1) Wechsler Intelligence Scale for Children-IV (WISC-IV) and all supplemental subtests, 2) the Beery Developmental Test of Visual Motor Integration, Fifth Edition (VMI-5th Edition) and supplemental tests, and 3) selected subtests of the Wechsler Individual Achievement Test, 3rd Edition (WIAT-III). For the purposes of the present study, only data from the WISC-IV and the WIAT-III were utilized.

Measures

**Wechsler Intelligence Scale for Children 4th Edition.** As previously stated, the WISC-IV (Wechsler, 2003) is an intelligence test for children and adolescents ages 6 through 16. The WISC-IV is comprised of 15 subtests, 10 of which are considered to be core subtests, and 5 are supplemental. Scores are reported in terms of cognitive ability (g), which is represented by the FSIQ. The FSIQ is an overall score averaging abilities in different domains. These domains are categorized further into four index scores. The four index scores include the Working Memory Index, the Processing Speed Index (PSI), the Perceptual Reasoning Index, and the Verbal Comprehension Index (VCI). Only the VC and PS Indexes were used in this study along with the Coding, Symbol Search and Cancellation subtests. Coding and Symbol Search are reported to be moderately correlated with Full Scale IQ (r=.57 and .66 respectively) (Wechsler, 2009). As discussed previously, Cancellation is used as a supplemental subtest and is poorly correlated with Full Scale IQ (r=.26).

**Wechsler Individual Achievement Test, 3rd Edition (WIAT-III).** The WIAT-III is an achievement test designed to measure academic strengths and weaknesses. The most recent revision was created to guide specific intervention recommendations and provide more
in-depth analyses of subtests (Burns, 2010). The WIAT-III is comprised of the following eight composite scores: Oral Language, Basic Reading, Total Reading, Reading Comprehension & Fluency, Written Expression, Mathematics, Math Fluency, and Total Achievement.

For the purposes of the current study, participants completed the Word Reading, Numerical Operations, and Spelling subtests. Word Reading fluency was also measured, by using the recommended notation on the Word Reading subtest, noting how many words the child was able to complete in 30 seconds. Due to the fact that testing took place over the course of 11 years, some of the scores were obtained using the WIAT-II. The Word Reading Fluency score was not available in the WIAT-II version of the test. Further, some administrators neglected to indicate the word reading score. Therefore, a subset of 59 participants had complete data for Word Reading Fluency (WRF).

A subset sample was created to explore potential connections between processing speed and WRF as a verbal fluency achievement measure. The WRF sample included 59 participants who had complete scores for Word Reading Fluency as well as Word Reading Cumulative Percentage. The Word Reading Cumulative Percentage is a score derived from the WRF raw score which is then assigned a percentage score based on the normative sample.

Results

Key subtest scores of the WISC-IV, including Coding, Symbol Search, and Cancellation raw and standardized scores were assessed for outliers, as well as normality, including an examination of skewness and kurtosis statistics. Analysis of the skewness and
Kurtosis statistics suggested that scores were normally distributed. Skewness and kurtosis statistics are reported for each subtest score and composite score in Table 1.

Table 1

_Degree of Skewness and Kurtosis Observed for Key Variables (n=114)._  

<table>
<thead>
<tr>
<th>Subtest</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal Comprehension Index</td>
<td>0.26</td>
<td>-0.52</td>
</tr>
<tr>
<td>Processing Speed Index</td>
<td>0.03</td>
<td>-0.32</td>
</tr>
<tr>
<td>Coding</td>
<td>0.28</td>
<td>0.10</td>
</tr>
<tr>
<td>Cancellation</td>
<td>-0.22</td>
<td>-0.29</td>
</tr>
<tr>
<td>Word Reading Speed</td>
<td>-0.38</td>
<td>-0.56</td>
</tr>
<tr>
<td>Numerical Operations</td>
<td>-0.21</td>
<td>-0.22</td>
</tr>
<tr>
<td>Spelling</td>
<td>-0.03</td>
<td>-0.34</td>
</tr>
<tr>
<td>Word Reading</td>
<td>-0.07</td>
<td>-0.80</td>
</tr>
</tbody>
</table>

This study aimed to be as inclusive of normal variability in a sample of community participants as possible to insure the best representation of the population. Given this objective, a decision was made to only exclude participant data from the present study if it dramatically impacted the results due to outlier scores. Although there was variability in scores, it was determined that all data from the participants would be included based on the rationale that this approach would be the most inclusive of normal population variability, and because scores did not affect the potential significance of the results. If outlying scores had been influential outliers, then separate analyses would have been conducted in order to illustrate the differences in findings.

In order to assess for the assumption of linearity inherent in correlation analyses, scatterplots were created using SPSS software, and were visually inspected for the linearity of the distributions. All subtest variables appeared to have adequate linearity.
All analyses were computed using the Statistical Package for the Social Sciences (SPSS, version 21.0) software. Pearson correlation coefficients were computed between the Processing Speed Index and each of the three PSI subtests, as well as with the VCI and selected WIAT subtests. When considering relations with achievement, WIAT-III scores were used, and the sample was reduced to the 59 participant WRF subsample. As noted in the methods section, the sample size reduction was due to the fact that some participants were administered the WIAT-II, which did not yield a word reading fluency or a cumulative percentage score. Other participants were omitted due to the fact that the test administrator failed to note the word reading speed score.

The cumulative percentage aims to provide information about how a raw score is ranked on a scale from 0 to 100 in comparison to scores obtained by other test takers. Due to the nature of the score distributions for the Word Reading Speed score, cumulative percentages were also derived using the WIAT-III’s technical manual. This is an additional supplemental score offered for the WIAT-III. Most scores in the current sample were at or above the maximum score, making it difficult to observe any variance in scores. The WIAT-III’s maximum cumulative percentage is 50; thus, this score is relatively insensitive to higher achieving readers, such as were contained in the sample. Typically, when readers score higher than the score representing 50%, their score is recorded as >50%, which is quite a wide range. Another score of 75 was added if the participant read 7 more words over the requirement for a score of 50. (This particular number of words was chosen as the benchmark due to the fact that the highest difference across categories was seven words). This was done in order to see more variance in abilities. In summary, the cumulative
percentage score in this sample could range from 0 to 75 which is a greater than the typical range of 0 to 50.

**Hypothesis 1**

It was predicted that the composite PSI scores would show a strong relationship with the PSI subtests. Correlation coefficients were calculated among the PSI and its three subtests. The results of the correlational analysis indicated that five of the six correlations were significant and were greater than or equal to .23 (see Table 2). These significant correlations ranged from .23 to .89. However, the correlation between the Coding and Cancellation subtests was not significant. Therefore, Hypothesis 1 was supported for all variables with the exception of the relation between Cancellation and Coding.

Table 2

*Correlation Coefficients for Processing Speed and Processing Speed Subtests of the WISC-IV (n=114).*

<table>
<thead>
<tr>
<th></th>
<th>Processing Speed</th>
<th>Symbol Search</th>
<th>Cancellation</th>
<th>Coding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing Speed</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symbol Search</td>
<td>.794**</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cancellation</td>
<td>.234*</td>
<td>.331**</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Coding</td>
<td>.893**</td>
<td>.460**</td>
<td>.097</td>
<td>1</td>
</tr>
</tbody>
</table>

*Note.* Correlations significant at the .05 level are marked with an *. Correlations significant the .01 level are marked with an **. *p*<.05. **p*<.01.
Hypothesis 2

It was predicted that the PSI scores would show a strong positive relationship with participants’ VCI scores. The correlation between PSI and VCI scores was positive, moderately strong, and statistically significant ($r=.26, p<.01$). Therefore, the hypothesis was supported.

Hypothesis 3

It was predicted that the PSI would be positively correlated with academic achievement as measured by the Word Reading, Word Reading Fluency, Word reading Cumulative Percentage, Spelling, and the Numerical Operations subtests of the WIAT-III. Pearson product-moment correlations were calculated between the PSI and subtests of the WIAT-III. The results of the correlational analysis indicated that only PSI and Numerical Operations (math calculations) were significantly correlated ($r=.42$) (see Table 3). PSI was unrelated to spelling, word reading, word reading fluency, and word reading cumulative percentage. Therefore, hypothesis 3 was only partially supported.
Table 3

*Correlation Coefficients for PSI and Word Reading Speed, Cumulative Percentage, Numerical Operations, and Spelling Subtests of WIAT-III (n=59).*

<table>
<thead>
<tr>
<th></th>
<th>Word Reading Fluency</th>
<th>Cumulative Percentage</th>
<th>Numerical Operations</th>
<th>Spelling</th>
<th>Word Reading</th>
<th>PSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word Reading Fluency</td>
<td>1</td>
<td>.82**</td>
<td>.10</td>
<td>.29*</td>
<td>.34**</td>
<td>.02</td>
</tr>
<tr>
<td>Cumulative Percentage</td>
<td>1</td>
<td>.32*</td>
<td>.39**</td>
<td>.45**</td>
<td>.18</td>
<td></td>
</tr>
<tr>
<td>Numerical Operations</td>
<td>1</td>
<td>.45**</td>
<td>.33**</td>
<td>.42**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spelling</td>
<td>1</td>
<td>.58**</td>
<td>.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Word Reading Processing Speed</td>
<td></td>
<td>1</td>
<td>.22</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* Correlations significant at the .05 level are marked with an *. Correlations significant at the .01 level are marked with an **.

**Hypothesis 4**

It was predicted that the PSI scores would correlate more highly with Word Reading Fluency than with Word Reading, Spelling, and Numerical Operations subtests of the WIAT-III. Given that the PSI score was unrelated to word reading, no further analyses were conducted to further explore this hypothesis.

**Hypothesis 5**

It was predicted that age would be positively correlated with PSI raw scores and raw Coding, Symbol Search, and Cancellation scores. Age was significantly positively correlated with Coding ($r=.67$), Symbol Search ($r=.61$) and Cancellation ($r=.75$) raw scores (see Table
4). As age increased, scores on all three of the PSI subtests also increased. The correlation between age and PSI raw scores was not significant. Therefore, hypothesis 5 was supported for the PSI subtests, but not for the PSI index. This difference is likely due to the measurement scaling for the PSI, and will be addressed in detail in the discussion section.

Table 4

*Correlation Coefficients between Age and Raw scores for WISC-IV Processing Speed Subtests (n=114).*

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Processing Speed</th>
<th>Symbol Search</th>
<th>Cancellation</th>
<th>Coding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>1</td>
<td>.09</td>
<td>.61**</td>
<td>.75**</td>
<td>.67**</td>
</tr>
<tr>
<td>Processing Speed</td>
<td>1</td>
<td>.54**</td>
<td>.06</td>
<td>.46**</td>
<td></td>
</tr>
<tr>
<td>Symbol Search</td>
<td>1</td>
<td>.59**</td>
<td>.70**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cancellation</td>
<td>1</td>
<td>.49**</td>
<td>.70**</td>
<td>.67**</td>
<td></td>
</tr>
</tbody>
</table>

*Note.* Correlations significant at the .05 level would be marked with an *. Correlations significant the .01 level are marked with an **.

**Hypothesis 6**

It was predicted that females would have higher PSI scores than males and would have higher scores on the Coding, Symbol Search, and Cancellation subtests of the WISC-IV. An independent samples *t*-test was conducted to determine whether scores for males and females significantly differed on the variable of processing speed. Equal variances were assumed. An examination of the means revealed than females had slightly higher scores on the PSI (M=103.56, SD=13.22) than males (M=100.95, SD=11.53), but that this difference
was not statistically significant. The mean difference between males’ and females’ mean scores on the PSI was nonsignificant $t(112)=-1.06, p=.29$.

Three more independent samples t-tests were computed to calculate the difference between males’ and females’ scores on the PSI subtests. None of the three independent t-tests was significant. For Coding, females had higher mean scores on the Coding subtest ($M=10.14, SD=2.64$) than males ($M=9.56, SD=2.64$), but the overall test was nonsignificant, $t(112)=-1.06, p=.29$. On the Cancellation subtest, females, on average ($M=10.01, SD=2.63$), fared better than males ($M=9.83, SD=2.59$); however, the results were still nonsignificant, $t(112)=-.37, p=.72$. Further, females also had higher mean scores on the Symbol Search subtest ($M=10.96, SD=2.41$) when compared to males ($M=10.73, SD=2.23$), but again, this test was nonsignificant $t(112)=-.50, p=.62$. Because none of the results was significant, the hypothesis was not supported.

**Discussion**

Processing speed is a construct that has become increasingly more important in recent years. Previous studies have identified that processing speed may be associated with gender, age, and verbal abilities. Further, processing speed has been linked to specific academic skills including language processing (Benner at al., 2008; Catts et al., 2002; Leonard et al., 2007; Pascualvaca et al., 1997) and mathematics (Berg & Hutchinson, 2010). In particular, there is a need for studies that utilize the WISC-IV and link processing speed skills to academic achievement areas as measured by the WIAT-III. Findings on this topic to date have failed to use the WISC or most other commercially marketed tests of intelligence and have instead relied on speeded tasks created for individual research studies.
The purpose of the current study was to generalize the results of studies conducted using specific tasks developed for research purposes to the processing speed subtests of the WISC-IV by demonstrating similar findings. Findings utilizing the WISC-IV would add to the generalizability of previous findings that purport that processing speed is a construct influenced by multiple characteristics, including gender, age, and verbal abilities. Additionally, the study’s purpose was to link processing speed capabilities with areas of achievement, both basic achievement and achievement fluency, as measured by the WIAT-III.

In general, this study established some relationships with processing speed, gender, age, and verbal abilities. The WISC-IV subtests were constructed upon the assumption that all subtests would be related to one another. The findings of the first hypothesis supported that most of the processing speed subtests were related to one another; however, the relationship between Cancellation and Coding in this sample was nonsignificant. This finding of a lack of relation between these subtests is potentially problematic because the three subtests that measure the processing speed construct are thought to measure the same skill. As Cancellation has the lowest loading on \( g \), it has been criticized for its low psychometric properties and is seen as a weakness in the overall quality of the WISC-IV (Sattler, 2008). This finding also raises the possibility that the PSI subtests tap into different capabilities and may not be measuring the same construct. This is a weakness of the WISC given that Cancellation is sometimes used as a supplemental or substitution subtest in place of Coding. Although it is not surprising that Cancellation was unrelated, an alternative explanation is that there are specific characteristics of this sample that may account for the findings. This explanation will be further explored in the limitations section.
Processing speed has been linked to verbal abilities in previous studies (Pascualvaca, 1997; Leonard et al., 2007). This finding was replicated in this study. Processing speed and verbal abilities, as measured by the VCI scores of the WISC-IV, showed a moderately strong relationship with one another within this sample. Thus, it appears that children who possess strong verbal skills also have the ability to process information efficiently in a time-limited setting. Tasks such as reading require both strong verbal and processing skills (Leonard et al., 2007)

Another aim of the current study was to replicate previous findings that have supported researchers’ global trend hypothesis as addressed in Hypothesis 5 (Fry & Hale, 1996; Hale, 1990), which purports that processing speed has a strong relationship with age into late adolescence. In this sample, age had a significant positive relationship with the individual subtests of the PSI, but had a weak negative relationship with the composite PSI directly. As noted previously, the composite PSI includes two of the three subtests and is calculated using scaled scores, thus the age effect has already been adjusted for in the use of the scaled scores. Therefore, there was little remaining effect to be accounted for by the age variable.

It was hypothesized that amongst the academic skills, processing speed would more strongly relate to measures of academic fluency as this task requires quick processing and previous studies have linked processing speed to academic fluency. In this study, participants’ PSI scores were not significantly correlated with word reading fluency. The reduced sample size necessary for this analysis may have led to the nonsignificance of this finding. Thus, significant effects may have been detected with a larger sample. Other reasons for the lack of effects may be due to the nature of the academic fluency measure used
in this study. This study utilized the word reading fluency score which is a supplemental score and is perceived by many examiners as optional. In this study, data for this variable was missing as some test administrators simply forgot to enter the word reading fluency score. This type of administration mistake is relatively common as the examiners were relatively new test administrators. Finally, the conversions used in the calculation of the word reading fluency measure percentage appeared to be problematic. For these reasons, this may not have been the best test of the relation between processing speed and academic fluency.

Despite the small sample, Numerical Operations and PSI were significantly linked, showing that accuracy in completing numerical calculations may be significantly related to processing speed. No other selected subtests of the WIAT-III were significantly correlated to PSI. There were not significant relations between word reading and spelling with processing speed.

Previous studies have consistently found that females perform better than males in tasks of attention and planning across all age groups (Naglieri & Rojahn, 2001; Pascualvaca et al., 1997). The findings in this study related to gender did not suggest significant gender differences in this group. Although females consistently outperformed males on the processing speed tasks; the mean differences were nonsignificant. With a larger sample size, the gender differences in performance may have reached statistical significance. However, there may also be developmental effects in gender differences such that males and females are more divergent in adolescence and early adulthood. This sample included children from ages 6 to 16 with the majority of children around age 10 ($M=10.2$); thus, younger children may not show the same gender differences that are prominent in adolescence.
Limitations

The current study had limitations with regard to the sample characteristics. The study was conducted with participants who were predominantly of Caucasian ethnicity and largely from the Northwestern region of the United States. The sample was approximately 80% Caucasian, which is in contrast to the norming group for the WISC-IV, which was roughly 60% Caucasian (Wechsler, 2009). Participants were mostly female, which may have affected some of the results pertaining to gender due to unequal sample sizes. Sample sizes varied for certain analyses, and it is possible that some relationships may have been significant if a larger sample was used, with an equivalent number of males and females. The sample was also limited by the confines of the original study, which did not allow for participants with considerable cognitive deficits or pathology to engage in testing. These exclusion criteria and sample characteristics likely restricted the range of the scores. Furthermore, the sample mostly consisted of children with average to high average abilities, as those children were more likely to volunteer for testing. This limitation did not provide the sample with a wide range of abilities that would naturally occur within the normal population.

Finally, testing administrators and testing settings varied across participants, which contributed to differences in testing conditions. Although numerous checks and safeguards were put into place regarding testing administrator training and checking the protocols after the measures were scored, most administrators were graduate students administering the WISC-IV for the first time. This may have contributed to unforeseen and unknown errors in administration and scoring.
The aspects of the study that involved school achievement and word reading fluency were conducted using a restricted sample of only 59 participants. This is due to the inclusion of the Word Reading Speed and Cumulative Percentage scores that were additions to the WIAT-III. Some of the participants were tested before the creation of the WIAT-III, so their scores could not be used in the analysis, as this score was not included on the WIAT-II. Additionally, some test administrators failed to note this score on the protocol as it is regarded as a supplemental score. The cumulative percentage scores are also problematic, in that the ceiling is very low. The cumulative percentage maximum score is 50%, and therefore, does not reflect variability in the sample for readers who had very high Word Reading Fluency scores. Attempts were made to make the score potentially more sensitive, but nonetheless, the maximum score was 75% even with the modifications made in the current study.

**Future Directions**

There are a number of future directions that would improve our understanding of the role of processing speed in academic achievement and overall intelligence as well as factors affecting processing speed. Future directions should include further testing and investigation of processing speed and how it relates to other constructs of intelligence. Researchers may want to consider using commercially marketed and widely used tests, such as the Stanford Binet-5 or the processing speed subtests of the Woodcock-Johnson Tests of Cognitive Ability as these tests are most commonly used in clinical and educational decision-making.

Because some of the hypotheses that were not supported were well-founded in the literature, it may be beneficial to use a larger, more diverse sample of participants. Grouping participants by gender and age may build upon previous studies using other measures of
processing speed. Future studies may also benefit from further examining the link between processing speed and school achievement, looking at specific academic subjects with timed and untimed components, such as reading fluency and reading comprehension, as well as math calculation and math fluency would aid in the understanding of how processing speed impacts academic performance.

Most tests of processing speed contain a component of motor skill and/or dexterity; however the level of motor involvement in processing speed is still unclear. The WISC-IV has been scrutinized for the importance of motor skills in the PSI subtests. Future studies may want to utilize other commercially marketed tests that measure processing speed, but that have subtests which are less reliant on motor speed in the assessment of processing speed. The degree to which motor speed, attention, motivation, and other skills relate to processing speed is unknown. Currently, all four core subtest scores from the Working Memory Index and Processing Speed Index are calculated as part of the Full Scale IQ. However, on the WISC-III, only two of these subtests were combined to form a score. Because of the many skills confounding processing speed, it is possible that children with problems such as motor difficulties, low motivation or ADHD, could yield lower scores on the WISC-IV than the WISC-III (Calhoun & Mayes, 2005). These are important issues to consider given the educational, academic, and life decisions that are made based upon assessment results. All factors that could potentially confound or adversely affect scores must be examined to formulate an accurate depiction of the child’s strengths and weaknesses.

**Conclusion**

Clinical practitioners and educational specialists do not always administer measures with the purpose of estimating processing speed. However, processing speed may be helpful,
particularly in diagnosing learning disorders and behavioral problems in children. The existing literature supports the conclusion that the construct of processing speed is beginning to be considered an entity in and of itself, as illustrated by the most recent version of the WISC-IV.

In summary, developmental and individual differences play a role in processing speed and in the broader domain of general cognitive ability. However, without further research, it is unknown to what extent processing speed overlaps with other abilities. It is also relatively unknown to what extent these abilities directly impact academic achievement.

Overall, the current study provides general information and insight into factors that may be related to processing speed. The study’s findings indicated significant correlations amongst all PSI subtests, with the exception of Cancellation and Coding. Processing speed and verbal skills also showed a strong relationship. Interestingly, PSI was not correlated with the verbal academic skills of word reading, spelling, and word reading fluency as measured by the WIAT-III. However, Numerical Operations and PSI showed a significant relationship. Contrary to expectation, no significant gender effects were found in the current study; however, females slightly outperformed males on all PSI subtests of the WISC-IV. Additionally, age was related to all subtests of the PSI, which is consistent with literature supporting a clear and methodological link in connection to age. Limitations with regard to the sample size and homogeneity were discussed in order to lay the foundation for future studies that will further investigate factors affecting processing speed more thoroughly.

In conclusion, processing speed influences human thinking, decision-making, and overall intellectual functioning. When the construct is measured and matched with overall achievement and individual academic skills, it provides professionals with more information
with which to predict success, risk factors, and provide more individualized education and therapeutic interventions.

References


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