THE TEST OF AUDITORY PROCESSING SKILLS – THIRD EDITION (TAPS-3): VALIDITY ANALYSES AND RECONCEPTUALIZATION BASED ON THE CATTELL-HORN-CARROLL MODEL OF COGNITIVE ABILITIES

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Kellie Murphy Edwards

Certificate of Approval

Barry Burkhart
Professor
Psychology

Steven K. Shapiro, Chair
Associate Professor
Psychology

Philip Lewis
Professor
Psychology

Frank Weathers
Associate Professor
Psychology

Joe Pittman
Interim Dean
Graduate School

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Kellie Murphy Edwards

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Kellie Murphy Edwards

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Signature of Author

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Date of Graduation

DISSERTATION ABSTRACT

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Kellie Murphy Edwards

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(M.S., Auburn University, 1998)
(B.A., Western Kentucky University, 1993)

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The purpose of the present study was to examine relationships between subtests from a recently revised measure of auditory processing, The Test of Auditory Processing Skills – Third Edition (TAPS-3) (Martin & Brownell, 2005) and subtests from other commonly used measures of cognitive and academic skills, the Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV) (Wechsler, 2003), Wechsler Individual Achievement Test – Second Edition (WIAT-II) (Wechsler, 2001), and Test of Visual Perceptual Skills – Revised and Upper Level – Revised (TVPS-R, TVPS-UL-R) (Gardener, 1996, 1997). Using the Cattell-Horn-Carroll (CHC) model of cognitive abilities as a theoretical guide and the multitrait-multimethod matrix methodology of Campbell and Fiske (1959), hypotheses were generated about these relationships. Data for this study came from 40 psychoeducational evaluations of children referred due to academic difficulties. Results revealed significant relationships between TAPS-3 subtests and the CHC abilities of Auditory Processing (G*a*), Short-Term Memory (G*sm*), and Crystallized Intelligence (G*c*), as measured by subtests of the WISC-IV and WIAT-II, providing some evidence of convergent validity of the TAPS-3. Discriminant validity was also demonstrated with measures of Visual Processing (G*v*), Quantitative Knowledge (Q*q*), and to lesser degrees, Fluid Intelligence (G*f*) and Processing Speed (G*s*). Findings suggest that the TAPS-3 measures multiple cognitive abilities and may not be a pure measure of auditory processing.

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INTRODUCTION

Measures of auditory processing have received far less attention from researchers comparable to intelligence and achievement testing, despite their inclusion in psychoeducational evaluations of children. Psychoeducational evaluations are common for children experiencing school-based learning problems. These evaluations have traditionally included an intelligence test and individualized achievement test. They may also include other measures of cognitive and perceptual processing, including auditory processing, based on research suggesting associations between learning problems and these skills (National Center for Learning Disabilities [NCLD], n.d.a). Tests of auditory processing may be administered by an audiologist, speech-language pathologist, psychologist, or other clinician trained to understand the role of auditory processing in the development of learning disorders (Martin & Brownell, 2005). Depending on the results of the evaluation, parents and teachers may be encouraged to consider, in addition to any intellectual and academic deficits, possible underlying problems in a child's auditory processing system as obstacles to learning. More comprehensive audiological and auditory processing evaluations might be indicated, and interventions designed to improve aspects of auditory processing might be recommended for children with learning problems, in cases where results on measures of auditory processing suggest weaknesses.

In the past, the psychometric soundness of auditory processing measures was not always well established, and the skills measured by these tests have not always been linked to well-established theories (Cacade & McFarland, 1998). One recently revised measure, the Test of Auditory Processing Skills - Third Edition (TAPS-3) (Martin & Brownwell, 2005) was reportedly developed to reflect current research and conceptualizations of auditory processing. The TAPS-3 has nine subtests, “designed to provide the types of information necessary to assess the processing of auditory information that pertain to the cognitive and communicative aspects of language” (Martin & Brownell, 2005, p. 9). Through factor analysis, three broad index areas were derived and are assessed with the TAPS-3: (1) Phonologic Skills, (2) Auditory Memory, and (3) Auditory Cohesion. A subtest designed to screen for problems with auditory attention was also included. The TAPS-3 is marketed to a wide range of professionals for use in evaluations of individuals ages 4 to 18 years (Martin & Brownwell, 2005). Results might be used to help in diagnosis and guide the development of interventions for children with auditory processing or learning problems. Because of its potential to affect educational and treatment decisions, such a measure should be both psychometrically sound and consistent with the current conceptualization of auditory processing. The proposed study is designed to shed light on these essential aspects of instrument validity.

The standardization of the TAPS-3 was based on a sample of over 2,000 students and was nationally stratified to match United States census data regarding gender, ethnicity, location, and parent education level (Martin & Brownell, 2005). At the time of test development, test-retest reliability of the TAPS-3 was reported to be high, with coefficients ranging from 0.72 to 0.96 for the entire standardization sample. Internal consistency coefficients were moderate to high. Cronbach’s coefficient alpha and Spearman-Brown coefficients ranged from 0.49 to 0.96 for individual subtests across all age groups, with median coefficients of 0.69 to 0.94 for the entire standardization sample. The concurrent validity of the TAPS-3 was examined with IQ scores from the Wechsler Intelligence Scale for Children-Third Edition (WISC-III) (Wechsler, 1991). The overall score from the TAPS-3 showed a moderate relationship to the WISC-III Full Scale IQ score ($r = 0.57$). Other TAPS-3 index scores were moderately related to WISC-III Verbal IQs, Performance (nonverbal) IQs, and Full Scale IQs ($r = 0.37$ to 0.58). However, more specific analyses were needed to examine the relationships between the index scores of the TAPS-3 and other well-established measures of related constructs. In addition, a more critical theoretical and practical examination of auditory processing assessment, especially the TAPS-3 was needed.

The present study further evaluated the validity of the TAPS-3 by examining the relationships between the subtest scores from the TAPS-3 and subtest scores from two widely used measures of childhood intelligence and academic achievement—the Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV) (Wechsler, 2003) and the Wechsler Individualized Achievement Test-Second Edition (WIAT-II) (Wechsler, 2001). A selected subtest included in both the Test of Visual-Perceptual Skills-Revised (TVPS-R) (Gardener, 1996) and Test of Visual-Perceptual Skills-Upper Level-Revised (TVPS-UL-R) (Gardener, 1997) was also included in the analyses. The multitrait-multimethod matrix as first described by Campbell and Fiske (1959) served as the guiding strategy for analyzing the validity of the TAPS-3. Specific traits common across the TAPS-3 and other measures were drawn from a well-validated theory, the Cattell-Horn-Carroll (CHC) model of cognitive abilities (Flanagan & Ortiz, 2001; McGrew & Flanagan, 1998). Methods for assessing these traits vary across subtests.

Interrelationships among the four primary measures were examined, with hypotheses related to both the size and pattern of correlations in the matrix. Some CHC abilities measured by the WISC-IV, WIAT-II, and TVPS such as Short-Term Memory (G*sm*), Crystallized Intelligence (G*c*), and Reading/Writing Ability (G*rw*) were expected to relate positively with the TAPS-3 scores, providing evidence of convergent validity. Other CHC abilities such as Fluid Intelligence (G*f*), Visual Processing (G*v*), Processing Speed (G*s*), and Quantitative Knowledge (G*q*), as measured by other subtests were expected to be less related to TAPS-3 scores, indicating discriminant validity. Before providing an explicit theoretical basis for and outline of specific hypotheses, a review of the conceptualization of auditory processing that guided the development of the TAPS-3 is offered.

Auditory Processing and its Components

The TAPS-3 is based on a fairly simple definition of auditory processing—"what we do with what we hear" (Katz, Stecker, & Henderson, 1992b). More specifically, auditory processing involves the receipt of an auditory signal and the performing of some cognitive operation related to that signal. The components of auditory processing are the various operations that can be performed with auditory information. Many books and articles have been written over the past decade describing various components of auditory processing and disorders characterized by component deficits (Bellis, 2002; 2003; Chermack & Musiek, 1997; Katz, Stecker, & Henderson, 1992a; Kelly, 1995; Masters, Stecker, & Katz, 1999). Some of these aspects of auditory processing are assessed with the TAPS-3. They are described below.

Auditory attention

The capacity to attend to information is important for all other aspects of auditory processing. In clinical settings, sustained attention has often been evaluated with the use of a continuous performance test (CPT). The use of CPTs is common in assessment batteries for Attention-Deficit/Hyperactivity Disorder (ADHD), and CPT formats for ADHD evaluations may be auditory, visual, or a combination of these. Auditory attention for school-aged and older individuals can be assessed by an auditory CPT, and the most widely used and empirically validated auditory CPT was designed by Keith (1994). For this test, individuals listen to single words and raise their hands when they hear a specific word. Errors of omission (i.e., failures to respond) as well as commission (i.e., responses when no appropriate stimulus is presented) are calculated and relate to problems with auditory inattention or impulsivity respectively. Children with auditory processing deficits have shown difficulties with Keith's auditory CPT, regardless of whether they also have ADHD (Riccio, Cohen, Hynd, & Keith, 1996). This suggests that this auditory CPT in particular may measure both auditory processing and sustained attention abilities.

The TAPS-3 includes a screening test of auditory attention problems, the Optional Figure-Ground subtest, that follows the format of Keith's auditory CPT. Individuals listen to words played on a CD player and raise their hand when specific words are said. Errors are recorded, but these are not converted to standard scores or used in the calculation of any factor scores. Individuals without auditory attention problems are not expected to have more than one error on this subtest. This was the case during standardization with a sample of children without attention problems, as 95% of them had only one or no errors (Martin & Brownell, 2005). According to the authors, referral for further assessment of attention and/or audiological problems may be appropriate for individuals having two or more errors. However, no data were provided on the use of this subtest with populations of children with either ADHD or hearing impairments.

Auditory discrimination

The ability to recognize and discriminate differences in phonemes (speech sounds) is referred to as auditory discrimination (Bellis, 2002; NCLD, n.d.b). The Auditory Discrimination Test-Second Edition (ADT) (Wepman & Reynolds, 1987) and the Goldman-Fristoe-Woodcock Test of Auditory Discrimination (GFW) (Goldman, Fristoe, & Woodcock, 1976) are two widely used tests of this ability. The TAPS-3 also contains an auditory discrimination task, the Word Discrimination subtest, and it is similar to the ADT. Individuals are asked to listen, with their backs turned or eyes closed, to pairs of words spoken by the examiner. The words in each pair are of equal length but differ on one phoneme (e.g., dog – log, compute – commute, eliminate - illuminate). Individuals then indicate whether they heard the same word twice by saying, “same,” or two different words by saying, “different.” In contrast, the GFW requires individuals to touch pictures of objects that correspond with orally presented words, with backgrounds of both quiet and noise. Although the GFW was designed as a measure of auditory discrimination, it has also been described as a measure of auditory selective attention (Glass, Franks, & Potter, 1986), and a similar task is included in the Woodcock-Johnson III: Tests of Cognitive Abilities (WJ-III Cognitive Abilities) as the subtest, Auditory Attention (Woodcock, McGrew, & Mather, 2001a). This may result in some confusion in the use of the terms, auditory discrimination and auditory attention.

In general, tests of auditory discrimination have not received support from researchers in the fields of education and learning disabilities. The ADT was first developed in 1958 and was later revised, yet criticisms have remained, such as being biased against Black-English speaking children and bilingual Mexican-American children (Lombard & Harney, 1977; Smith & Brewer, 1987). Koenke (1978) suggested that the ADT results in a large number of overreferrals while the GFW has a large number of "misses." Simpson, Haynes, and Haynes (1984) found little more than a "random relationship" between the ADT and reading achievement when intelligence was controlled. Webster (1985) found that the ADT did not significantly contribute to the variance in reading ability when included in a larger battery of academic achievement, visual-motor integration, and learning aptitude tests. Similarly, the GFW showed only a low correlation with reading achievement and was only modestly related to another measure of auditory selective attention (Finkenbinder, 1973; Glass et al., 1986). Thus, there are reasons to question the use of an auditory discrimination test in psychoeducational evaluations of children. Yet, measures of auditory discrimination continue to be used in clinical settings, and low scores may be used to guide diagnosis and recommendations.

During test development, the Word Discrimination subtest of the TAPS-3 loaded onto the Phonologic Skills factor when three factors were specified in the Principle Components Analysis for ages 4 through 7, 8 through 10, and 14 through 18. For this reason, the authors included it with the Phonological Segmentation and Phonological Blending subtests as a measure of "elementary phonological abilities" (Martin & Brownell, 2005, p. 66). However, for ages 11 through 13, it loaded alone, on a separate factor. It also loaded alone, on a separate factor when four factors were specified for the factor analysis, and this occurred for all age groups. Word Discrimination also had the lowest correlation to the TAPS-3 total scaled scores compared to all other TAPS-3 subtests (r = 0.47), indicating that this subtest is the only modestly related to all other aspects of auditory processing measured by the TAPS-3. Considering these results as well as previous research failing to show a relationship between auditory discrimination and academic skills, the inclusion of the Word Discrimination subtest in the TAPS-3 and specifically as a contributor to the Phonologic Skills index, is questionable.

Phonological awareness

The knowledge of the sound structure or phonological structure of a spoken word is referred to as phonological awareness. It includes the understanding that words can be divided into syllables, ability to rhyme words and discriminate rhyming from non-rhyming words, and awareness of phonemes or sounds made by individual letters and letter blends (Gillon, 2004). These skills help children map sounds to symbols and break words into their component sounds; both of these are crucial in learning to read. Children with high levels of phonological awareness are often the better readers in the first and second grades, and a deficit in phonological awareness is highly predictive of both reading and spelling problems (Bhat, Griffin, & Sindelar, 2003; Gillon, 2004; Vellutino, Fletcher, Snowling, & Scanlon, 2004). The relationship between phonological awareness and word recognition is one of the few well-established individual differences among children with reading disabilities, and a causal link has been proposed. This has been termed the phonological deficit hypothesis for dyslexia (Gillon, 2004; Vellutino et al., 2004). Evidence for this hypothesis comes from studies showing life-long deficits in phonological awareness and analysis for poor readers as well as improvements in reading for individuals who receive training in phonological awareness (Vellutino et al., 2004).

The TAPS-3 contains two subtests that measure phonological awareness—Phonological Segmentation and Phonological Blending. Phonological Segmentation requires individuals to correctly delete specific syllables or sounds from words. The examiner says a target word, asks the examinee to repeat it, and then asks the examinee to repeat it again while deleting one of the sounds. There are 35 items of increasing difficulty, and individuals are required to delete either an initial, medial, or final sound in the target words. The authors of the TAPS-3 reported that students "top out" by age 9 on this subtest, making few errors; this is likely due to them becoming "proficient with decoding" (Martin & Brownell, 2005, p. 62). The Phonological Blending subtest requires individuals to listen to a series of phonemes and then blend these sounds into a word. The examiner presents the phonemes at the rate of approximately two sounds per second (e.g., c – a – t). The examinee must then say the word. The difficulty of the items increases as the words become longer, requiring increased auditory closure abilities. According to the authors, this subtest, "…requires both memory and vocabulary—skills that continue to develop through adolescence" (Martin & Brownell, 2005, p. 62). Scaled scores from these subtests, as well as the Word Discrimination subtest, are used to determine the TAPS-3 Phonologic Skills index score (Martin & Brownell, 2005).

Auditory memory

Tests of auditory memory are primarily measures of immediate and/or delayed recall of stimuli presented in an auditory format. Auditory memory is often evaluated by presenting individuals with sequences of digits and/or letters, lists of words, or sentences of increasing length to repeat, either immediately after oral presentation by the examiner or after a delay. Auditory memory skills may be considered to be a specific subset of memory span or working memory skills, although these broader terms allow for the use of non-auditory memory tasks as well. Tests of auditory memory skills can be found on multiple cognitive and memory batteries including the Wechsler intelligence scales (Wechsler, 1997a, 2002, 2003), Wechsler Memory Scales-Third Edition (WMS) (Wechsler, 1997b), WJ-III Cognitive Abilities (Woodcock et al., 2001a), Clinical Evaluation of Language Fundamentals (CELF) (Semel, Wiig, & Secord, 1995), and Wide Range Assessment of Memory and Learning-Second Edition (WRAML2) (Sheslow & Adams, 2003). These skills, in combination with phonological awareness, were found to be predictive of early learning success in school, based on teacher ratings (Alloway et al., 2005). Poor auditory working memory as measured by the CELF was also found for boys who experienced significant behavior problems resulting in school expulsion (Ripley &Yuil, 2005). One of the most frequently used measures of auditory working memory is the Digit Span subtest of the Wechsler intelligence batteries. Low scores on this test have been associated with attention problems in children (Mayes, Calhoun, & Crowell, 1998).

The TAPS-3 has four auditory memory subtests. These are Number Memory Forward, Number Memory Reversed, Word Memory, and Sentence Memory. The Number Memory Forward and Reversed tasks are similar in format to the Digit Span subtest of the Wechsler intelligence tests. Individuals are required to listen to a series of digits presented orally by the examiner, at a rate of one digit per second. The Forward task requires individuals to repeat these sequences verbatim while the Reversed task requires them to say the sequences in backward order. Unlike the Wechsler batteries that present these tasks as a single subtest, the TAPS-3 allows for two separate subtest scores for Number Memory Forward and Number Memory Reversed. The TAPS-3 Word Memory subtest is a list-learning task. It presents individuals with increasingly longer sequences of meaningfully unrelated words said by the examiner, again at a rate of one per second. Once the list has been presented, individuals are required to repeat the words in the same order. The final TAPS-3 auditory memory subtest is Sentence Memory. This task requires individuals to listen to increasingly longer sentences said by the examiner and repeat these verbatim.

Auditory cohesion

The term auditory cohesion was introduced by prominent speech-language pathologist and audiologist Dorothy Kelly in a 1999 interview about auditory processing. The authors of the TAPS-3 chose to apply this term to summarize the skills required by two subtests, Auditory Comprehension and Auditory Reasoning. According to Kelly (1999), "auditory cohesion is a higher-order linguistic processing skill. It relates to such skills as complicated conversations as well as understanding jokes, riddles, inferences, and abstractions." Based on this description, auditory cohesion would require attention, language processing, and reasoning skills. Thus, it could be difficult to differentiate specific deficits in auditory cohesion from broader cognitive deficits or speech and language impairments.

The Auditory Comprehension subtest of the TAPS-3 requires individuals to listen to short stories and demonstrate understanding of those stories by answering brief questions. The answers to the questions are found directly in the content of the stories.

This task requires attention, short-term memory, and comprehension skills in order to correctly answer questions. The task is similar to the Story Recall subtest of the Woodcock-Johnson III: Tests of Achievement (WJ-III Tests of Achievement) (Woodcock, McGrew, & Mather, 2001b), a subtest used to measure the broader area of Listening Comprehension within that battery.

The Auditory Reasoning subtest also requires individuals to listen to short stories and demonstrate understanding by answering questions about them. However, the examinee must use information contained within the story as well as some common-sense and social knowledge in order to answer the questions. The answers to the questions are not found directly in the stories but can be inferred from the information given (Martin & Brownell, 2005). Therefore, in addition to attention, memory, and comprehension, this task requires some logic and reasoning abilities.

Other Components and Measures of Auditory Processing

In addition to those previously mentioned, there are other aspects of auditory processing not assessed by the TAPS-3. The authors of the TAPS-3 acknowledge that not all aspects of auditory processing are evaluated by their measure but reportedly tried to include those aspects that were practical and convenient to assess in a school or clinical setting without specialized equipment (Martin, 2005). In addition to the type of tests included in the TAPS-3, there are traditional auditory measures that focus on receipt of auditory stimuli and basic brain responses. These include electrophysiologic tests such as aural reflex testing and auditory brainstem response (ABR) (Jerger & Musiek, 2000; Willeford, 1985). The TAPS-3 authors commented that these tests were beyond the scope of the TAPS-3 and should only be conducted by an audiologist (Martin &

Brownell, 2005). Other tests are designed to evaluate individuals' recognition or recall of auditory stimuli presented in various formats. There are behavioral tests that present auditory stimuli to each ear separately (i.e., monotic), the same stimulus to both ears simultaneously (i.e., diotic), or different stimuli to the two ears simultaneously (i.e., dichotic). These may require the interpretation of filtered, distorted, or compressed/accelerated speech or the recall and reproduction of sequences of pitches, digits, words, or sentences. These tests were not discussed by the authors of the TAPS.

The Cattell-Horn-Carroll (CHC) Model of Cognitive Abilities

The various abilities assessed with measures of auditory processing have yet to be integrated into an empirically-validated model of this construct. However, these same components have been identified as broad and narrow abilities within a large, empirically-validated cognitive theory, the Cattell-Horn-Carroll (CHC) model of cognitive abilities (Flanagan & Ortiz, 2001; McGrew & Flanagan, 1998). Many abilities measured by tests of intelligence, academic achievement, and visual processing are also included in the CHC model. Because the current study will examine relationships between TAPS-3 factors and abilities measured by the WISC-IV, WIAT-II, and TVPS, the CHC model provides a useful organizing framework for the development of hypotheses about these relationships.

The CHC model is a prominent structural theory that supposes multiple intelligences and interrelated broad and narrow cognitive abilities (Flanagan & Ortiz, 2001; McGrew & Flanagan, 1998). The theory began as a two-factor model of intelligence (i.e., Fluid and Crystallized Intelligence) (Cattell, 1941). It has been expanded to include ten different areas of broad cognitive abilities that can further be divided into 70 narrow cognitive abilities (McGrew, 1997). The current CHC model is a synthesis of two earlier prominent models of intelligence and cognitive abilities, the G*f*-G*c* model (Horn, 1994; Horn & Noll, 1997) and the Three-Stratum model (Carroll, 1993). The two models were in general agreement about the inclusion of eight broad cognitive abilities. However, the Three-Stratum model included a general intelligence component (g), based on the work of Spearman (1904), while the G*f*-G*c* model contained no g. The models also differed on the placement of two cognitive abilities, Quantitative Knowledge (G*q*) and Reading/Writing Ability (G*rw*). The G*f*-G*c* model included these as broad abilities while the Three Stratum model listed them as narrow abilities contained within Fluid Intelligence (G*f*) and Crystallized Intelligence (G*c*).

McGrew (1997) used confirmatory factor analysis and other validity evidence to integrate these two models into the current CHC model. He found some support for the Three Stratum model, with the integrated CHC model containing narrow cognitive abilities (stratum I), broad cognitive abilities (stratum II), and a general intelligence component (g) (stratum III). However, consistent with the G*f*-G*c* model, G*q* and G*rw* were included as broad abilities, and the ten broad cognitive abilities were named primarily according to the G*f*-G*c* model. The CHC broad abilities are: Fluid Intelligence (G*f*), Crystallized Intelligence (G*c*), Short-Term Memory (G*sm*), Visual Processing (G*v*), Auditory Processing (G*a*), Long-Term Storage and Retrieval (G*lr*), Processing Speed (G*s*), Correct Decision Speed (*CDS*), Quantitative Knowledge (G*q*), and Reading/Writing Ability (G*rw*). Further analyses were done to clarify placement of narrow abilities subsumed under the ten broad cognitive abilities (McGrew and Flanagan, 1998). An expanded description of each of these broad abilities and their component narrow abilities is beyond the scope of this proposal, and readers are referred to Flanagan and Ortiz (2001) or McGrew and Flanagan (1998) for further discussion.

The CHC model has become recognized as one of the most well-validated conceptualizations of cognitive abilities, and it has been applied in the development of multiple tests of intelligence, cognitive abilities, and achievement (Flanagan & Ortiz, 2001; McGrew & Flanagan, 1998). These include the Kaufman Assessment Battery for Children-Second Edition (K-ABC-II) (Kaufman & Kaufman, 2004), Stanford Binet-Fifth Edition (SB5) (Roid, 2003), WJ-III: Cognitive Abilities, and WJ-III: Tests of Achievement (Woodcock et al., 2001a, 2001b). Other tests have also been reconceptualized as measuring various CHC abilities and are suggested as appropriate in cross-battery evaluations based on the CHC model (Flanagan, 2000; Flanagan & Ortiz, 2001, Phelps, McGrew, Knopik, & Ford, 2005; Tusing & Ford, 2004). These have included the Wechsler intelligence tests (Wechsler, 1997a, 1997b, 2001, 2002, 2003) and Differential Ability Scales (DAS) (Elliott, 1990). Empirical studies have also related CHC abilities to academic achievement in both reading and mathematics (Evans, Floyd, McGrew, & Leforgee, 2002; Floyd, Evans, & McGrew, 2003).

As previously noted, the development of TAPS-3 was not based on the CHC model but rather on the work of various experts in auditory processing and its associated disorders (Martin & Brownell, 2005). Presently, there is no widely accepted and empirically validated theory of auditory processing that could have guided the development of the TAPS-3. However, the skills required by each of the TAPS-3 subtests closely match with descriptions of some of the narrow cognitive abilities included in the CHC model. The next section will discuss specific subtests of the TAPS-3 and the CHC abilities that are likely measured by them.

The TAPS-3 and the CHC Model

Table 1 provides a summary of the TAPS-3 subtests, factors to which they contribute according to the factor analysis conducted by the test developers, tasks required by the subtests, and the broad and narrow CHC abilities with which they are likely associated. While three of the TAPS-3 subtests seem to correspond to narrow abilities listed under the broad category of Auditory Processing (G*a*), others appear to fall under other broad CHC abilities such as Short-Term Memory (G*sm*), Long-Term Storage and Retrieval (G*lr*), and Crystallized Intelligence (G*c*). In addition, the CHC model has 13 different narrow abilities listed under the broad ability of Auditory Processing (G*a*). Only Phonetic Coding (PC), which is further subdivided into analysis and synthesis abilities (PC:A, PC:S), and speech sound discrimination (US), appear to be measured by the TAPS-3. Thus, it is appropriate at this point to question whether the TAPS-3 is truly a measure of auditory processing, or primarily assessing other cognitive abilities.

Relevance of the Current Study to Practice Guidelines

Because the TAPS-3 may be used to guide diagnoses and recommendations for children with learning problems, any indication that it is not a valid measure of auditory processing could have serious implications for clinical practice. This includes possible misdiagnoses and inappropriate interventions (e.g., interventions designed to improve auditory skills for children who actually exhibit memory deficits). Specifically, low scores on the TAPS-3 may be used to support diagnoses of Auditory Processing Disorder

(APD) or learning disabilities. The next sections will provide a review of these disorders and the role of auditory processing assessment in these diagnoses.

Auditory Processing Disorder (APD)

Use of auditory processing measures, such as the TAPS-3, has grown over the past decade with the relatively new and still evolving diagnosis of APD (Cacade & McFarland, 1998; Emanuel, 2002). The American Speech-Language Hearing Association (ASHA) defined central auditory processes and Central Auditory Processing Disorder (CAPD) in a statement released in 1996. Central auditory processes were described as auditory system mechanisms responsible for sound localization and lateralization, auditory discrimination, auditory pattern recognition, temporal aspects of audition, and auditory performance when there are competing acoustic signals or degraded acoustic signals (ASHA, 1996). CAPD was then defined as a deficiency in one or more of these areas. However, research on CAPD often failed to differentiate deficits in specific auditory processes from either a generalized perceptual deficit or problems in other related areas such as language processing and attention (Cacade and MacFarland, 1998).

Some of the most significant problems in research on CAPD have included the reliance on a single battery of auditory processing tests (i.e., a battery with only auditory tasks) and the lack of control groups for comparison purposes. For example, various tests of auditory processing have been used to argue an underlying auditory basis for dyslexia. Cacade and MacFarland (1998) criticized these studies for the use of poorly standardized instruments and the lack of a more comprehensive assessment battery that could discriminate deficits in auditory processing from deficits in other areas including visual perception and memory. While Dagenais, Cox, Southwood, and Smith (1997) included visual stimuli in their examination of reaction times for children with CAPD by requiring them to respond vocally to printed words, their study was criticized because of the lack of non-language based tasks. The group of children with CAPD in this study demonstrated significantly longer reaction times when responding to printed words than children in the nondisordered control group, but because all of the stimuli were language-based, it was possible that language dysfunctions explained these results rather than auditory processing deficits (Condouris & Smith, 1998).

The overlap of CAPD and Attention-Deficit/Hyperactivity Disorder (ADHD) in children is also well-documented and demonstrates the lack of consensus and specificity in diagnosis (Riccio & Hynd, 1996; Riccio, Hynd, Cohen, Hall, & Molt, 1994). In a study of children diagnosed with CAPD based on linguistic and nonlinguistic auditory tasks, 60% also met DSM-IV criteria for ADHD based on structured diagnostic interviews (Riccio et al., 1994). It has been suggested that the diagnosis of ADHD or CAPD may depend on whether a child is evaluated by a psychologist or an audiologist (Keller, 1992). However, there may be some real differences between attention deficits and auditory processing deficits, in terms of treatment response. In a double-blind, placebo-controlled study of the effects of stimulant medication on the sustained attention and auditory processing skills of children with ADHD, only sustained attention was significantly improved with medication (Tillery, Katz, & Keller, 2000). The authors inferred from this that CAPD and ADHD are independent but often co-occur.

To discuss the many problems with the diagnosis of CAPD in school-aged children, a consensus conference was held with senior scientists and clinicians (Jerger &

Musiek, 2000). One resulting recommendation was that the term CAPD be replaced with Auditory Processing Disorder (APD) because this term was considered a more appropriate operational definition, did not attribute the disorder to any specific anatomical localization, and more accurately emphasized the interaction of the peripheral and central sites. Children with auditory processing deficits were said to be, "…uncertain about what they hear, have difficulty listening in the presence of background noise, have difficulty following oral instructions, or have difficulty understanding rapid or degraded speech" (Jerger & Musiek, 2000, p. 467). Because children with other related disorders may also show these difficulties, guidelines for differential diagnosis were provided. Specific diagnoses to consider included ADHD, language impairment, learning disabilities, an autism spectrum disorder, and reduced intellectual functioning. In order to effectively differentiate APD from other disorders of similar symptomatology, clinicians were advised to, "…consider the following listener variables: attention, auditory neuropathy, fatigue, hearing sensitivity, intellectual and developmental age, medications, motivation, motor skills, native language, language experience, language age, response strategies and decision-making style, and visual acuity" (Jerger & Musiek, 2000, p. 470). Methods for APD screening and follow-up assessment by audiologists were discussed, including questionnaires, behavioral measures, and electroacoustical and electrophysiologic measures.

Despite these recommendations, a study in 2002 revealed that of 192 audiologists surveyed across the United States, none were following the previously outlined minimum standard battery recommendation for the assessment of APD. Thus, there is a considerable lack of uniformity and comprehensiveness in the assessment and diagnosis of APD among audiologists. Reasons given for this included that some recommended tests are not commercially available, and some provide little supportive documentation for administration and interpretation. Tests of some auditory processing abilities, such as auditory memory skills, were typically not used by audiologists because they tended to be used instead by speech-language pathologists and psychologists, an indication of the growing role of auditory processing assessment in both speech-language and psychoeducational evaluations. Some school systems lacked the funding to purchase specialized equipment. Finally some professionals preferred to choose their own measures based on clinical experience and the literature, rather than be guided by the consensus statement (Emanuel, 2002).

APD is a relatively new diagnostic term with criteria that continue to evolve. While the lack of standardization across APD assessments in practice is concerning, acceptance of this label in both research and clinical practice is growing (Emanuel, 2002). At this time, fully satisfying the assessment requirements for the diagnosis of APD as described by the consensus conference would require a comprehensive evaluation with tests of intelligence, achievement, linguistic skills, auditory processing, visual processing, and socio-emotional and behavioral functioning. Psychoeducational evaluations often involve this comprehensive type of test battery. The inclusion of measures of auditory processing skills in these evaluations could improve differential diagnosis and allow for appropriate referrals to audiologists for follow-up electrophysiologic and other specialist measures, provided that the measures of auditory processing are valid.

Auditory Processing and Learning Disabilities

Even in cases where APD is not suspected, an assessment of auditory processing abilities may be relevant to the psychoeducational evaluation process for children with suspected learning disabilities. Researchers studying perceptual and cognitive abilities have been examining auditory processing for over half a century, and deficits in auditory perceptual processes have long been considered important factors in the development of learning problems (Cacace & McFarland, 1998; Katz & Wilde, 1985; Mylkebust, 1954; Pinheiro, 1977). While deficits in auditory processing are not included as a specific learning disorder in the current Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) (American Psychiatric Association, 1994), they are listed as "Information Processing Disorders" by the NCLD (2005). Within the field of learning disabilities, there is a recent trend towards comprehensive evaluations that include tests of various cognitive and perceptual abilities, including auditory processing (Harwell, 2001; McGrew and Flanagan, 1998).

In 1997, the Individuals With Disabilities Education Act (IDEA) was amended to clarify the criteria for diagnosis of learning disabilities and eligibility for special education accommodations. In addition to showing a significant discrepancy between intellectual functioning and academic achievement, a psychoeducational evaluation for learning disabilities had to determine that the discrepancy was not due to a visual, hearing, or motor impairment, mental retardation, emotional disturbance, or economic or environmental disadvantage. The Individuals with Disabilities Education Improvement Act (2004) reformed the IDEA to allow local educational agencies to eliminate discrepancies between intelligence and achievement in the determination of learning disabilities. The law gives no further specifics on the means for determining specific learning disabilities, allowing local and state agencies wide latitude in making eligibility determinations (Committee on Education and the Workforce – 108th Congress, 2004). In the state of Georgia, where the current study will be conducted, criteria for the determination of eligibility for specific learning disability accommodations are as follows:

> The documentation of a numerical severe discrepancy between achievement and intellectual ability may be considered as part of the determination of eligibility but is not required. Still central to the state definition of specific learning disability is the documentation of a deficit in one or more basic psychological processes. (Georgia Department of Education, 2005).

These basic psychological processes, as listed on the Georgia state form for special education eligibility, include attention, organization, discrimination and perception, sequencing, memory, and conceptualization and reasoning skills (Georgia Department of Education, n.d.). Within this context, the assessment of auditory processing may be considered central to the determination of a specific learning disability in cases where deficits in auditory processing are revealed, even in the absence of any intellectual-achievement discrepancy.

In some cases, the diagnosis of a specific learning disability based on a cognitive processing deficit may be appropriate. For example, there is a strong empirical relationship between underlying phonological processing and reading problems in children. Thus, a specific reading disability diagnosis based on a deficit in phonological awareness seems reasonable based on current research. However, the contribution of auditory processing to the development of a specific learning disability does not have the same support in the literature. In some cases, causal hypotheses have been put forth, suggesting that children who have dyslexia, a specific type of reading disability, have underlying low level auditory processing deficits. Other researchers have found children with dyslexia to have some difficulties with speech perception that may present as auditory deficits on various tests, but these children did not always have pervasive auditory deficits (Vellutino et al., 2004). For these reasons, the diagnosis of a learning disorder based solely on deficits in auditory processing is concerning.

Currently, learning disabilities are thought to have multiple causes and behavioral manifestations. Perceptual deficits, including auditory processing deficits, are included in the current understanding of learning disabilities, in addition to other factors such as attention, basic cognitive processing and speed of processing, problem solving, social cognition, self-concept, neurological correlates, and genetic influences (Swanson, Graham, and Harris, 2003). To address these factors, a growing number of measures are being included in psychoeducational evaluations. Clinicians must then meaningfully synthesize the results and determine the most appropriate diagnoses and recommendations. The TAPS-3 is one such test that may have a great influence on the diagnoses given and services provided to children with learning problems.

Purpose and Hypotheses

The current study was developed to evaluate the validity of the TAPS-3 for children with academic problems who were receiving psychoeducational evaluations. The goals of the study were to determine the relationships between the abilities measured by the TAPS-3 and other abilities measured in psychoeducational evaluations, including both cognitive and academic abilities. This study was designed to shed light on the utility of this test as a measure of auditory processing as well and about the degree of overlap in measured abilities across tests used in psychoeducational batteries. This study is relevant to current practices in psychoeducational assessment and diagnosis of both APD and learning disabilities.

Based on the results of previous research, commonalities in measured abilities according to the CHC model, and similarities in subtest task demands/methodologies, a correlation matrix with hypothesized results was created for the current study. The matrix included all subtests of the TAPS-3 as well as selected subtests from the WISC-IV, WIAT-II, and the TVPS Visual Sequential Memory subtest. Multiple hypotheses about statistical relationships between measures were generated for the current study. Some of these hypotheses suggest positive relationships between subtests of the TAPS-3 and subtests from other measures. They are described as hypothesized high, moderate, or modest correlations depending on the degree to which two subtests measure the same broad or narrow cognitive abilities, the similarity of the task demands/methodology, and the presence of previous empirical support for the relationship. Results supporting these hypotheses would provide evidence of convergent validity. In cases where there is no common cognitive ability or common task demand/methodology across two subtests, no significant relationship was anticipated. Confirmation in these cases would provide evidence of discriminant validity (Campbell & Fiske, 1959). The convergent validity hypotheses are grouped according to the TAPS-3 factors. They are listed below.

Phonologic Skills Hypotheses

1. The Phonological Segmentation and Phonological Blending subtests of the TAPS-3 were expected to have high positive correlations with the Word Reading, Phonological Decoding, and Spelling subtests of the WIAT-II. This is based on the relationship between phonologic awareness and these academic skills as demonstrated in previous studies (Bhat, Griffin, & Sindelar, 2003; Gillon, 2004; Vellutino, Fletcher, Snowling, & Scanlon, 2004).

2. The Phonological Segmentation and Phonological Blending subtests of the TAPS-3 were expected to have modest positive correlations with the Reading Comprehension subtest of the WIAT-II. While phonological awareness is necessary for reading comprehension, it may not be sufficient. This may be especially true for children ages nine and older who have mastered the skills necessary for the Phonological Segmentation subtest and thus make few errors (Martin & Brownell, 2005). This would result in a slightly lower positive correlation than is expected for the other WIAT-II reading and spelling subtests.

3. The Word Discrimination subtest was not expected to relate significantly to reading or spelling abilities as measured by subtests of the WIAT-II, despite the inclusion of the Word Discrimination subtest as a contributing subtest to the Phonologic Skills index. The possible interpretation of Word Discrimination as measuring an additional factor on the TAPS-3 as well as previous research failing to demonstrate a relationship between auditory discrimination and academic skills supports this hypothesis (Koenke, 1978; Simpson, Haynes, & Haynes, 1984; Webster, 1985). The Word Discrimination subtest of the TAPS-3 is also a likely measure of speech-sound discrimination (UA), a

narrow ability contained within Auditory Processing (G*a*) (Flanagan & Ortiz, 2001). No subtests of the WISC-IV, WIAT-II, or TVPS have been shown to measure this ability. The methodology of the Word Discrimination subtest also differs significantly from the task demands of all other included subtests.

Auditory Memory Hypotheses

4. The Number Memory Forward and Word Memory subtests of the TAPS-3 were expected to have high positive correlations with the Digit Span subtest of the WISC-IV, based on their similar method of presenting meaningfully-unrelated auditory information in a sequential manner as well as their likely common measurement of the narrow cognitive ability, Memory Span (MS) within the broad ability of Short-Term Memory (G*sm*) (Flanagan & Kaufman, 2004).

5. The Number Memory Reversed subtest of the TAPS-3 was expected to have a high positive correlation with the Letter-Number Sequencing subtest of the WISC-IV, based on their likely common measurement of the narrow cognitive ability, Working Memory (WM) within the broad ability of Short-Term Memory (G*sm*) (Flanagan & Kaufman, 2004). These subtests also share a similar methodology, in that they both require individuals to recall meaningfully-unrelated numbers or letters in an order that differs from the initial presentation of the sequence.

6. The Number Memory Reversed subtest of the TAPS-3 was expected to have a moderate positive correlation with the Digit Span subtest of the WISC-IV, based on their likely common measurement of Short-Term Memory (G*sm*) as well as similar task demands (Flanagan & Kaufman, 2004).

7. The Number Memory Forward and Word Memory subtests of the TAPS-3 was expected to have moderate positive relationships with the Letter-Number Sequencing subtest of the WISC-IV, based on their likely common measurement of Short-Term Memory (G*sm*) (Flanagan & Kaufman, 2004). They also have some methodological similarities. All three subtests present meaningfully-unrelated information to be recalled and present items of increasing length in order to increase task difficulty.

8. The Sentence Memory subtest of the TAPS-3 was expected to have lower positive correlations with the Digit Span and Letter-Number Sequencing subtests of the WISC-IV, compared to the other three TAPS-3 Auditory Memory subtests. This is because the Sentence Memory task more closely matches the description of Long-Term Storage and Retrieval (G*lr*) than Short-Term Memory (G*sm*). However, similar to the Digit Span and Letter-Number Sequencing subtests of the WISC-IV, the Sentence Memory subtest presents items of increasing length. This common task demand may result in low positive correlations between these subtests.

9. Low positive correlations were expected between the Number Memory Forward, Number Memory Reversed, and Word Memory subtests of the TAPS-3 and the Visual Sequential Memory subtest of the TVPS. All of these tests likely require Short-Term Memory (G*sm*) and present items of increasing length. A higher positive correlation would indicate that the tests primarily measure memory and not auditory or visual processing skills respectively.

Auditory Cohesion Hypotheses

10. The Auditory Comprehension and Auditory Reasoning subtests of the TAPS-3 were expected to be moderately correlated with the WISC-IV subtests

Similarities and Comprehension. These subtests all likely measure the narrow CHC ability, Language Development (LD) that is contained within Crystallized Intelligence (G*c*) (Flanagan & Kaufman, 2004). However, the Auditory Comprehension and Auditory Reasoning subtests also seem to fit with descriptions of Listening Ability (LS), a narrow ability under Crystallized Intelligence (G*c*) and meaningful memory (MM), a narrow ability of Long-Term Storage and Retrieval (G*lr*). The methodology used to evaluate Language Development (LD) also differs across these three subtests.

11. The Auditory Comprehension and Auditory Reasoning subtests of the TAPS-3 were expected to have positive correlations with three other WISC-IV subtests measuring Crystallized Intelligence (G*c*), Vocabulary, Information, and Word Reasoning (Flanagan & Kaufman, 2004). However, the task demands of these subtests are quite different, and these correlations are expected to be low.

12. A moderate positive correlation between the Auditory Comprehension and Auditory Reasoning subtests and the Listening Comprehension subtest of the WIAT-II was hypothesized. These all require Crystallized Intelligence (G*c*) and specifically the narrow abilities, Language Development (LD) and Listening Ability (LS). However, they are quite different in methodology. Listening Comprehension on the WIAT-II requires individuals to match pictures with orally presented words and sentences as well as provide single words that match orally presented definitions and pictures.

13. The Auditory Comprehension and Auditory Reasoning subtests of the TAPS-3 were expected to correlate moderately with the Reading Comprehension subtest of the WIAT-II based on commonalities in the task demands. All three of these subtests require individuals to answer questions about short passages. The two Auditory Cohesion

subtests require individuals to listen to orally presented passages while Reading Comprehension requires individuals to read passages.

Discriminant Hypothesis

Subtests measuring the broad abilities of Fluid Intelligence (G*f*), Visual Processing (G*v*), Processing Speed (G*s*), and Quantitative Knowledge (G*q*) were included as variables in order to evaluate discriminant validity of the TAPS-3. None of the TAPS-3 subtests measure any of these abilities, and none of the subtests from the WISC-IV and WIAT-II that measure these abilities share a common method with any of the TAPS-3 subtests, and. For these reasons, no relationships were expected between the measures of these broad abilities and TAPS-3 subtests.

II. METHOD

Participants

The participants in this study consisted of 40 children, ages 6 to 16, who were referred for psychoeducational evaluations because of academic difficulties. All evaluations were conducted at the Behavioral Institute of Atlanta, LLC., where the participants' parents sought assessment services. At the time of the evaluation, parents signed a consent form allowing their child's evaluation results to be included in a database for research on a variety of psychoeducational issues. Data for this study were drawn from this database.

Measures

Auditory Processing. The TAPS-3 (Martin & Brownell, 2005) was the primary measure of interest for this study. Scores from the nine subtests of the TAPS-3 were included in correlational analyses with subtest scores from the other measures.

Intelligence/Cognitive skills. The WISC-IV (Wechsler, 2003) served as the measure of intelligence/cognitive skills for the current study. The Wechsler tests have historically been the most widely used measures of intelligence and are most often used in evaluations of children with learning problems (Flanagan & Kaufman, 2004). The WISC-IV includes ten core subtests and five optional subtests. Subjects in the current study were administered the core subtests and up to three optional subtests which are associated with specific abilities defined by the CHC model.

Academic Achievement. The WIAT-II (Wechsler, 2001) is a widely used measure of academic achievement that is often employed in the determination of learning disabilities. The battery includes tests of reading, math, written language, and oral language. According to Flanagan and Ortiz (n.d.), some of the WIAT-II subtests are appropriate in cross-battery psychoeducational assessment as measures of specific CHC abilities. These include: (a) Word Reading, Reading Comprehension, and Spelling (measures of Reading/Writing Ability [G*rw*]) Numerical Operations and Math Reasoning (measures of Quantitative Knowledge [G*q*]), and (c) Listening Comprehension, which is a measure of Crystallized Intelligence (G*c*) and more specifically, Listening Ability (LS). These subtests were all included in the present study.

Visual Processing. The TVPS-R (Gardener, 1996) and the TVPS-UL-R (Gardener, 1996) were designed to evaluate the visual processing abilities of children ages 4 to 12 and 13 to 18, respectively. Only one subtest from either of these batteries was used in the present study. The Sequential Memory subtest found on both TVPS versions requires subjects to view and memorize a number of shapes in a series. With each successive item, the series of shapes increases in length. The amount of time individuals may view the sequences of shapes is limited, and they must then identify the correct sequence of shapes from a group of four choices. The task demands are identical on both the TVPS-R and TVPS-UL-R. However, the upper level version requires children to memorize five shapes in a row for the first item, while the lower level version starts with only two shapes in a row. It is possible that children taking the lower level version are able to gain some expertise on the initial easy items. This subtest was specifically chosen for the current study as a visually-based measure of Short-Term Memory (G*sm*) to compare with TAPS-3 Auditory Memory subtests.

Procedure

Psychoeducational evaluations included in this study took place over two days within the same week. Testing sessions lasted approximately two and one-half hours each, and all tests were administered according to standardized procedures as noted in the various test manuals. Children were allowed to take breaks as needed between subtests, and young children were given small prizes for appropriate effort during their evaluations.

Test Scoring

All TAPS-3, WISC-IV, WIAT-II, and TVPS subtests were scored according to instructions provided by the test developers in the manuals. All of these measures have a mean of 100 and standard deviation of 15 for standard scores as well as a mean of 10 and standard deviation of 3 for subtest scaled scores.

III. RESULTS

Preliminary Analyses

Interrater reliability

Because the principal investigator conducted all psychoeducational evaluations for subjects included in this study, it was important to examine inter-rater reliability. Test protocols for 25% of the subjects were rescored by two doctoral level licensed psychologists. These reliability scorers had no affiliation with the Behavioral Institute of Atlanta and were in no other way involved with this study. Intraclass correlations (ICC) were computed for TAPS-3, WISC-IV, WIAT-II, and TVPS subtests (Shrout & Fleiss, 1979). Results indicated high inter-rater agreement, with coefficients ranging from .91 to 1.00. The modal coefficient was 1.00.

Demographic Characteristics

Of the 40 participants in this study, 31 were Caucasian (77.5%), 4 were African-American (10%), 3 were Greek (7.5%), 1 was Hispanic (2.5%) and 1 was French (2.5%). Twenty-five of the participants were boys (62.5%) and 15 were girls (37.5%).

Descriptive Statistics

Means and standard deviations for each of the subtests were calculated for the study sample in order to descriptively compare the distribution characteristics to the primary measures' standardization samples (Table 2). Subtest means ranged from 78.33

to 107.92 for subtest standard scores and 8.23 to 11.66 for scaled scores. All subtest means fell in the Average range of abilities (i.e., 90 to 109) except for the mean for the upper level TVPS Visual Sequential Memory (VSM-U) subtest that was in the Below Average Range (M = 78.33, SD = 17.84). The mean score from the lower level TVPS Visual Sequential Memory (VSM-L) subtest was found to be higher and in the Average range (M = 100.18, SD = 23.86). The means of these two versions of the test was found to be significantly different, t (35) = 3.26, p < .01, indicating a strong effect for version of the TVPS administered. As a result, it was necessary to restandardize results from the TVPS Visual Sequential Memory subtests for the current study. All of these scores were converted to z scores for use in the main correlational analyses.

Subtest Correlations with Age and Full Scale IQ

It was important to determine the relationship of age and Full Scale IQ with the subtest scores. As previously mentioned, age was a variable that related to some of the TAPS-3 subtests during test standardization, with most children mastering the skills involved in the Word Discrimination and Phonological Segmentation subtests by age nine (Martin & Brownell, 2005). Correlational analyses revealed that for the current sample, age showed significant positive relationships to three TAPS-3 subtests: Phonological Segmentation, Number Memory Reversed, and Auditory Reasoning. Age was also positively related to two subtests from the WIAT-II, Word Reading and Reading Comprehension. As previously noted, there was a significant difference between scores of children receiving the lower and upper level versions of the TVPS Visual Sequential Memory subtests. This difference was further confirmed when age showed a moderate negative relationship with the z scores that were converted from TVPS standard scores, *r* (35) = -.48, p < .01. Full Scale IQ was also examined as a potential correlate with TAPS-3 subtest scores. Although the CHC model describes interrelated yet independent cognitive abilities, some versions of the model have contained a general intellectual ability (g) that relates to all other broad and narrow cognitive abilities (Flanagan & Kaufman, 2004). For this study, Full Scale IQ served as an approximation to this general intellectual ability. Correlational analyses showed that Full Scale IQ was significantly related to 28 of the 30 subtests included in the current study.

Main Analyses

Partial Correlations, Controlling for Age and Full Scale IQ

Because of the contributions of both age and Full Scale IQ to many of the individual subtest scores for the current study, the impact of these two variables was eliminated in all correlations examining relationships among primary measures. Partial correlation coefficients were calculated to establish the relationships between all subtests of the TAPS-3, WISC-IV, WIAT-II, and *z* scores converted from the Visual Sequential Memory subtests standard scores. Results of these analyses are shown in Tables 2, 3, and 4 and are separated according to the TAPS-3 factors of Phonologic Skills, Auditory Memory, and Auditory Cohesion, to correspond with the hypotheses previously presented. In addition, intra-test correlations for the TAPS-3 and WISC-IV subtests were examined, also controlling for age and FSIQ. However, no specific hypotheses were made regarding these relationships. The analyses served only to aid in interpretation of the main findings. These results can be found in the Appendix.

For the subtests making up the Phonologic Skills factor of the TAPS-3, five significant relationships were found with subtests from other measures (Table 3). The

TAPS-3 Word Discrimination subtest showed a modest negative relationship with the Similarities subtest of the WISC-IV, *r* (34) = -.37, p < .05. Phonological Segmentation showed significant positive relationships with three subtests from the WIAT-II, in that it was moderately related to Word Reading, *r* (33) =.47, p < .01 and Phonological Decoding, *r* (33) = .52, p < .01, and somewhat more strongly related to Spelling, *r* (33) = .59, p < .001.

For subtests comprising the Auditory Memory subtest of the TAPS-3, seven significant relationships were found with subtests from other measures (see Table 3). The Number Memory Forward subtest showed a modest negative relationship to the Picture Concepts subtest of the WISC-IV, *r* (36) = -.33, p < .05, and a strong positive relationship to the Digit Span subtest of the WISC-IV, *r* (36) = .57, p < .001. The Number Memory Reversed subtest showed a modest positive relationship with the Word Reading subtest of the WIAT-II, *r* (35) = .36, p < .05, and was moderately related to the Phonological Decoding subtest, *r* (35) = .45, p < .01, and Spelling subtest, *r* (35) = .44, p < .01 on the WIAT-II. The Word Memory subtest of the TAPS-3 was strongly related to the Digit Span subtest of the WISC-IV, *r* (36) = .55, p < .001. The Sentence Memory subtest of the TAPS-3 was modestly related to two other subtests; it was positively correlated with the Digit Span subtest of the WISC-IV, *r* (36) = .35, p < .05, and negatively correlated with the Symbol Search subtest of the WISC-IV, *r* (36) = -.36, p < .05.

Within the Auditory Cohesion factor of the TAPS-3, ten significant relationships were found between TAPS-3 subtests and subtests from other measures (Table 4). Auditory Comprehension had a modest negative correlation with the WISC-IV Matrix

Reasoning subtest, r (36)= -.33, $p < .05$, and Symbol Search subtest, r (36) = -.37, $p < .05$. Auditory Comprehension also had a modest positive relationship with the Vocabulary subtest of the WISC-IV, r (36) = .37, $p < .05$, and there was a moderate negative relationship with the Visual Sequential Memory subtest of the TVPS, r (33) = -.48, $p < .01$. The Auditory Reasoning subtest of the TAPS-3 also showed a modest negative relationship with Matrix Reasoning from the WISC-IV, r (36) = -.33, $p < .05$. Auditory Reasoning had a moderate positive relationship with the WISC-IV Vocabulary subtest, r (36) = .53, $p < .01$, and strong positive relationships with the WISC-IV Comprehension subtest, r (36) = .63, $p < .001$, and Information subtest, r (36) = .65, $p < .001$. Auditory Reasoning had a modest positive relationship with Word Reasoning on the WISC-IV, r (31) = .35, $p < .05$. It also had a strong negative relationship with the Symbol Search subtest of the WISC-IV, r (36) = .60, $p < .001$.

IV. DISCUSSION

Prior to discussing the main findings of this study, the implications of some of the findings from the preliminary analyses will be addressed. The significant difference between mean scores on the lower and upper level versions of the TVPS Visual Sequential Memory subtest was unexpected. Both of these versions are standardized with a mean of 100 and standard deviation of 15 according to the test developer. However, children ages 12 and older that received the upper level version scored significantly lower than those under 12 that received the lower level version. Because the children receiving the upper level version had mean scores in the Average range of abilities on all other primary measures, the norms for the upper level TVPS are questionable. This may decrease the meaningfulness or interpretability of the main findings regarding the TVPS, compared to other findings in the main analyses.

There were also age-related findings for other subtests that may reflect unique characteristics of the current study sample. Results indicated that children received higher standard scores on Phonological Segmentation, Number Memory Reversed, Word Reading, and Reading Comprehension as their ages increased. Using the CHC model as a guide, these subtests are likely measuring Phonetic Coding: Analysis (PC:A), Working Memory (WM), and Reading/Writing Ability (G*rw*), three cognitive abilities that are interrelated according to previous research (Evans et al., 2002). Phonetic Coding:

Analysis (PC:A) is a narrow cognitive ability contained within the broader cognitive ability of Auditory Processing (G*a*). According to Flanagan and Kaufman (2004), Phonetic Coding: Analysis (PA) is the ability to segment larger units of speech sounds into smaller units of speech sounds; this description matches closely with the task demands of the Phonological Segmentation subtest. The skills involved in Phonetic Coding: Analysis (PA) are also considered to be important for phonological awareness, and the relationship between phonological awareness and reading ability is well-established (Bhat et al., 2003; Gillon, 2004; Vellutino et al., 2004). A moderate relationship between Working Memory (WM) and measures of both basic reading skills and reading comprehension has also been demonstrated previously (Evans et al., 2002). The Number Memory Reversed subtest of the TAPS-3 may be considered a measure of Working Memory (WM), in that it requires, " the ability to store and perform a set of cognitive operations on information that requires divided attention and the management of the limited capacity of Short-Term Memory" (Flanagan & Kaufman, 2004, p. 300). The Word Reading and Reading Comprehension subtests may be considered measures of Reading/Writing Ability (G*rw*) and the narrow abilities Reading Decoding (RD) and Reading Comprehension (RC). Reading Decoding (RD) involves the ability to recognize and decode words or pseudowords, and Reading Comprehension (RC) is the ability to understand a connected discourse while reading (Flanagan & Ortiz, n.d.). The age-related findings regarding these four subtests suggest that younger children in this study likely had more difficulty with some interrelated cognitive abilities associated with early reading problems.

In contrast, standard scores for Auditory Reasoning on the TAPS-3 decreased with age. This relationship has not been previously documented and may represent another unique characteristic of the study sample. Age was not related to performance on other subtests of the TAPS-3 and WISC-IV measuring Crystallized Intelligence (G*c*) or Meaningful Memory (MM), CHC abilities likely measured by the Auditory Reasoning subtest. This finding, therefore, seems quite task-specific to the Auditory Reasoning subtest performance for the study sample.

The finding that Full Scale IQ related to almost all of the subtests from included measures in this study is important, as it further supports a general intelligence component (g) within the CHC model. Although the authors of the TAPS-3 do not provide information about the relationships between individual TAPS-3 subtests and WISC-III Full Scale IQ scores, they reported moderate correlations between TAPS-3 factor scores and Full Scale IQ (Martin & Brownell, 2005). Results of the current study are consistent with these previous findings.

Academic abilities as measured by the WIAT-II were also related to Full Scale IQ, except for the Numerical Operations subtest. In contrast, the other mathematics achievement subtest, Math Reasoning, showed a strong relationship to Full Scale IQ. Both of these subtests are likely measures of Mathematics Achievement (A3), a narrow ability subsumed under Quantitative Knowledge (G*q*). Previous research has shown that Mathematics Achievement (A3) relates moderately to several other CHC broad abilities beyond the predictive effects of Full Scale IQ. These have included Crystallized Intelligence (G*c*), Fluid Intelligence (G*f*), Short-Term Memory (G*sm*), Long-Term

Storage and Retrieval (G*lr*), Processing Speed (G*s*) and Auditory Processing (G*a*) (Floyd, Evans, & McGrew, 2003; Hale, Fiorello, Kavanagh, Hoeppner, & Gaither, 2001).

The only other subtest that did not relate to Full Scale IQ is the Visual Sequential Memory subtest of the TVPS. Neither the lower level nor upper level TVPS scores were related to Full Scale IQ when they were correlated as separate variables, and the *z* scores also were not related. This suggests that the Visual Sequential Memory subtest is unique in that it is not saturated by g.

Relationships Between TAPS-3 Subtests and Other Measures

The main results of the current study provide some support for the initial hypotheses. However, not all convergent validity hypotheses were supported, and some significant correlations were found between subtests where none was expected.

Phonologic Skills

Specific hypotheses were made regarding subtests that comprise the Phonologic Skills factor of the TAPS-3, and some of these were confirmed. As hypothesized, the Phonological Segmentation subtest of the TAPS-3 was strongly related to the Spelling subtest of the WIAT-II. It was also moderately related to the Phonological Decoding and Word Reading subtests of the WIAT-II. These findings further demonstrate the link between phonological awareness and basic reading skills (Bhat et al., 2003; Gillon, 2004; Vellutino et al., 2004). As previously noted, Phonological Segmentation may be considered a measure of Auditory Processing (G*a*) and more narrowly, Phonetic Coding: Analysis (PC:A) according to the CHC model. Subsumed under the broad Reading/Writing Ability (G*rw*) are the narrow abilities, Reading Decoding (RD) and Spelling (SG) that are likely measured by the Word Reading, Phonological Decoding, and Spelling subtests. The relationship between these subtests is consistent with previous research demonstrating the contribution of Phonetic Coding (PC) to reading achievement (Evans et al., 2002).

The Phonological Blending subtest was also hypothesized to relate to these basic reading and spelling tests, but this hypothesis was not supported. An examination of the differences between Phonological Segmentation and Phonological Blending subtests may be helpful in interpreting their differential correlations with the reading and spelling tests. While Phonological Segmentation is likely a measure of Phonetic Coding: Analysis (PC:A) according to the CHC model, Phonological Blending is likely a measure of Phonetic Coding: Synthesis (PC:S). This latter narrow ability is also contained within Auditory Processing (G*a*) and involves blending smaller units of speech together into larger units of speech (Flanagan & Kaufman, 2004). Research on phonological processing has shown these to be separate abilities. Wagner, Torgesen, Laughton, Simmons, and Rashotte (1993) used confirmatory factor analysis to support five distinct phonological processing abilities, and analysis and synthesis skills were distinct in this model. They suggested that, "the type of linguistic knowledge measured by analysis tasks is more subtle, or complex" (Wagner et al., 1993, p. 17). Synthesis skills, conversely, were noted to develop earlier in childhood and are easier to train. Based on these differences, it is understandable that Phonological Segmentation was related to the complex skills of reading and spelling while Phonological Blending was not.

Despite some significant relationships between the basic reading and spelling tests of the WIAT-II and the Phonological Segmentation subtest of the TAPS-3, no relationship was found between any Phonological Skills subtests of the TAPS-3 and the

Reading Comprehension subtest of the WIAT-II, which is contrary to the second hypothesis for this study as well as previously published findings (Evans et al., 2002). This may be related to the specific Reading Comprehension subtest of the WIAT-II, as previous studies have used other measures of Reading Comprehension (RC) with different formats, such as the WJ-III: Tests of Achievement (Evans et al., 2002). The Reading Comprehension subtest of the WIAT-II is unique, in that it requires children to give sometimes lengthy responses to open-ended questions about passages they read (Wechsler, 2001). In contrast, Passage Comprehension on the WJ-III: Tests of Achievement requires children to identify single words that appropriately complete passages (Woodcock et al., 2001a). The lack of significant relationships between the WIAT-II Reading Comprehension subtest and Phonologic Skills subtests from the TAPS-3 may relate to these different methodologies.

The third hypothesis for the Phonologic Skills subtests was supported. Word Discrimination did not show any significant relationships with the reading or spelling subtests of the WIAT-II. Word Discrimination also did not relate to any other academic subtests included in the WIAT-II battery, and this finding is consistent with previous research failing to demonstrate a relationship between auditory discrimination and any academic skills (Simpson et al., 1984; Webster, 1985). Word Discrimination is likely a measure of Speech-Sound Discrimination (US), a narrow ability contained within Auditory Processing (G*a*). Speech-Sound Discrimination (US) refers to the ability to detect differences in speech sounds under conditions of little distraction or distortion (Flanagan & Kaufman, 2004). No other measures of Speech-Sound Discrimination were included in this study, and this also likely contributed to the lack of significant positive correlations involving Word Discrimination.

Auditory Memory

There were six convergent validity hypotheses generated for the TAPS-3 subtests comprising the Auditory Memory factor. The first of these hypotheses was supported, in terms of both the size and direction of the correlation. Digit Span was strongly related to both the TAPS-3 Number Memory Forward and Word Memory subtests. This lends support to the conceptualization of these three tests all measuring Short-Term Memory (G*sm*) and the more narrow cognitive ability of Memory Span (MS). However, contrary to the next two hypotheses, the Number Memory Reversed subtest of the TAPS-3 did not relate to either Letter-Number Sequencing or Digit Span from the WISC-IV. Letter-Number Sequencing requires the cognitive sequencing of both alphabetical and numerical information. It has been considered a Working Memory (WM) task, requiring simultaneous retention of two sets of information and categorization skills, cognitive shifting between sets, and mental flexibility (Kaufman & Lichtenberger, 1999). Number Memory Reversed has only one set of numerical information to hold in working memory, although mental flexibility is still necessary because this information must be rearranged from the initial presentation order prior to being repeated. These task differences may have contributed to the lack of a relationship between the two subtests despite them both matching well with descriptions of the ability Working Memory (WM) within the CHC model.

The lack of a relationship between Number Memory Reversed and Digit Span is interesting, since Digit Span contains items that require reversed recall of number sequences. Because Digit Span related strongly to Number Memory Forward, it may be that the forward recall task included in Digit Span contributed more significantly to the overall Digit Span scores for this study sample. A review of the mean scores for Digit Span, Number Memory Forward, and Number Memory Reversed reveals that this sample of children performed most poorly on Number Memory Reversed, although the mean was still in the Average range. While Digit Span provides a combined measure of Short-Term Memory (G*sm*), assessing both Memory Span (MS) and Working Memory (WM) in the single subtest, the separation of these two tasks into the Number Memory Forward and Number Memory Reversed subtests of the TAPS-3 may be helpful, especially in cases where these abilities are discrepant. It is possible to determine whether children demonstrate a significant difference between forward and reversed recall tasks for Digit Span by calculating the difference between the number of digits recalled forward and backwards. However, this does not translate into scaled scores or contribute to the calculation of the index scores and Full Scale IQ (Wechsler, 2003). Results of the current study suggest that use of the Number Memory Forward and Number Memory Reversed tasks of the TAPS-3 may offer additional information about Working Memory (WM) beyond that gained from Digit Span.

For the next hypothesis, Number Memory Forward and Word Memory were expected to relate to Letter-Number Sequencing from the WISC-IV. The finding that there was no such relationship is not surprising, given that Letter-Number Sequencing did not relate to the even more conceptually and methodologically similar subtest, Number Memory Reversed. Both Number Memory Forward and Word Memory are likely measures of the narrow ability, Memory Span (MS), that is a component of Short-Term

Memory (G*sm*). They both require, “the ability to attend to and immediately recall temporally ordered elements in the correct order after a single presentation” (Flanagan & Kaufman, 2004, p. 300). As previously noted, Letter-Number Sequencing is likely a measure of Working Memory (WM). While these three subtests are all likely measures of Short-Term Memory (G*sm*), the differences in the narrow abilities they measure as well as differences in task demands likely resulted in the lack of significant relationships between them.

One hypothesis was made regarding the Sentence Memory subtest of the TAPS-3. It was expected to be less related to Digit Span and Letter-Number sequencing than the other TAPS-3 Auditory Memory subtests. This was partially supported, as Sentence Memory was modestly related to Digit Span. However, like other Auditory Memory subtests, Sentence Memory was also unrelated to Letter-Number Sequencing. It is possible that Letter-Number Sequencing is assessing an aspect of Short-Term Memory (G*sm*) and Working Memory (WM) that is unique and not measured by any other the TAPS-3 subtests. According to Flanagan and Kaufman (2004), both Digit Span and Letter-Number Sequencing have moderate to high test-retest reliability and internal consistency. They are both considered moderate in their loading on g. However, in the current study, there were clear differences in the degree to which these two subtests related to other measures of auditory memory. While Digit Span was significantly related to three TAPS-3 Auditory Memory subtests, Letter-Number Sequencing was unrelated to all of them.

Finally, the Visual Sequential Memory subtest from the TVPS was expected to be modestly related to the Auditory Memory subtests, but this was not found. This lack of relationship may be due to the difference in the visual versus auditory task demands of these subtests, and this suggests that the distinction between auditory short-term memory and visual short-term memory may be an important one for further study. The task demands of the Visual Sequential Memory task are most similar to those for Number Memory Forward and Word Memory from the TAPS-3. All three of these subtests present individuals with sequences of unrelated items (i.e., digits, words, or shapes) and require the recall in the correct forward order. Thus, all three subtests may be measuring Memory Span (MS). An examination of the pattern of correlation coefficients shows that although they are not significant, Visual Sequential Memory was most related to Number Memory Forward and Word Memory. The relationship with Number Memory Forward was approaching significance as well.

As previously noted, there were also three findings revealing modest to moderate significant relationships between Number Memory Reversed and subtests measuring reading and writing abilities (G*rw*). No hypotheses had been made regarding these relationships. However, previous research has suggested that Working Memory (WM), a skill assessed by Number Memory Reversed, may be essential for initially developing reading abilities and remains related to basic reading skills throughout childhood and adolescence (Evans et al., 2002). Results from the current study indicate a moderate degree of relationship between Number Memory Reversed and the Phonological Decoding and Spelling subtests of the WIAT-II. There was a modest relationship between Number Memory Forward and Word Reading. These findings are consistent with previous research (Dufva, Niemi, & Voeten, 2001; Evans et al., 2002).

Auditory Cohesion

The first two hypotheses for the Auditory Cohesion subtests of the TAPS-3 suggested relationships with measures of Crystallized Intelligence (G*c*) on the WISC-IV. These hypotheses were partly supported, in that five significant correlations were found. However, only one significant correlation involved the Auditory Comprehension subtest while the other four involved the Auditory Reasoning subtest. In addition, relationships found between the Auditory Reasoning subtest and three WISC-IV subtests measuring Crystallized Intelligence (G*c*) were stronger than anticipated. The relationship between Auditory Reasoning and the WISC-IV Comprehension subtest was hypothesized to be moderate, based on the shared CHC narrow ability, Language Development (LD) subsumed under Crystallized Intelligence (G*c*). This relationship was found to be strong. In addition to their common measurement of Language Development (LD), the Auditory Reasoning and Comprehension subtests share a methodological commonality, in that both require children to use social knowledge and reasoning skills to answer questions about social situations. The Similarities subtest of the WISC-IV is also thought to measure Language Development (LD), but this subtest did not relate significantly to either Auditory Cohesion subtest. This may be explained by methodological differences between the Auditory Cohesion subtests and the Similarities subtest.

Three other significant relationships, between Auditory Reasoning and the Vocabulary, Information, and Word Reasoning subtests, were expected to be modest. While Auditory Reasoning was modestly related to Word Reasoning, there was a moderate relationship between Auditory Reasoning and Vocabulary as well as a strong relationship between Auditory Reasoning and Information. These findings strongly suggest that the Auditory Reasoning subtest is measuring Crystallized Intelligence (G*c*). Vocabulary has been considered a measure of the narrow ability, Lexical Knowledge (VL) while Information is thought to measure General (verbal) Information (K0) within the broad Crystallized Intelligence (G*c*) ability (Flanagan & Kaufman, 2004). The strong relationships between Auditory Reasoning and these two subtests suggests that Lexical Knowledge (VL) and General (verbal) Information (K0) may also be measured by the Auditory Reasoning subtest, although the tasks required for these three subtests are quite different.

Of all the WISC-IV subtests measuring Crystallized Intelligence (G*c*), only Vocabulary related to the Auditory Comprehension subtest, and this relationship was modest, as hypothesized. Based on the relationship with the Vocabulary subtest, there is reason to consider the Auditory Comprehension subtest as a modest measure of Crystallized Intelligence (G*c*), but it likely does not measure Lexical Knowledge (VL), or this correlation would be higher. Despite the differences in correlations involving Auditory Comprehension versus Auditory Reasoning subtests, the partial correlation between them was moderately significant (Table A1), and neither one correlated significantly with any other subtests on the TAPS-3. This lends some support to the Auditory Cohesion factor of the TAPS-3 and also suggests that this factor is not purely a measure of Crystallized Intelligence (G*c*).

The next two hypotheses involved expected moderate relationships between Auditory Cohesion subtests and the Listening Comprehension and Reading Comprehension subtests of the WIAT-II. No significant relationships were found. In the case of the correlation between Listening Comprehension and the Auditory Cohesion subtests, this may have been due to differences in task demands. Listening Comprehension involves three different tasks, two related to receptive and expressive vocabulary skills and one requiring children to match pictures with sentences spoken by the examiner. Perhaps one or more of these tasks individually would have related significantly to the Auditory Cohesion subtests, as was the case with the Vocabulary subtest of the WISC-IV. However, standard scores on the Listening Comprehension subtest are only available for the raw score from the three tasks combined. The lack of a significant relationship between Reading Comprehension and the Auditory Cohesion subtests may have been due to the measurement of different broad and narrow CHC abilities. The hypothesis about this relationship was made solely on the commonalities in task demands in these two tasks. However, the difference in whether the material for the task is read to the child by an examiner (i.e., as in Listening Comprehension) or read by the child (i.e., as in Reading Comprehension) prior to being questioned may be the significant task difference that resulted in the lack of a significant correlation.

Discriminant Validity

In 66 of the 72 discriminant analyses, the discriminant validity hypothesis for the current study was supported. No significant relationships were found between TAPS-3 subtests and measures of Visual Processing (G*v*) or Quantitative Knowledge (G*q*). Of the discriminant analyses conducted to examine the correlations between Fluid Intelligence (G*f*) and TAPS-3 subtests, only three were found to be significant, and all of these were negative correlations. Three significant relationships were also found between Symbol Search as a measure of Processing Speed (G*s*) and TAPS-3 subtests. These were also all negative relationships. Overall, these findings provide support for the discriminant validity of the TAPS-3.

Unanticipated Negative Correlations

In addition to the significant correlations demonstrating the convergent and discriminant validity of the TAPS-3, eight unanticipated and significant negative correlations were also found. While these relationships are not the primary focus of this study, it is necessary to address them. These findings are difficult to explain, as none has any previous empirical support, and according to the CHC model, the abilities measured by these subtests should not necessarily be inversely related. Of the eight negative correlations found, one inverse relationship was found for a TAPS-3 Phonologic Skills subtest, two inverse relationships involved Auditory Memory subtests, and five inverse relationships involved Auditory Cohesion subtests. Specifically, the Word Discrimination subtest of the TAPS-3 was inversely related to the Similarities subtest of the WISC-IV. Number Memory Forward on the TAPS-3 was inversely related to Picture Concepts on the WISC-IV. Three TAPS-3 subtests, Sentence Memory, Auditory Comprehension, and Auditory Reasoning, were inversely related to Symbol Search on the WISC-IV. Auditory Comprehension and Auditory Reasoning subtests of the TAPS-3 were inversely related to Matrix Reasoning on the WISC-IV. Finally, Auditory Comprehension was inversely related to the Visual Sequential Memory subtest.

It is possible that these findings signify unique cognitive characteristics of this study sample that distinguishes these children from the general population. Because the children in this study were all referred for evaluations due to academic difficulties, their performance on psychoeducational measures may differ from children with no academic problems or disabilities. Children with disabilities demonstrate significantly more variability across subtests than is found in the general population, and this decreases the meaningfulness of the Full Scale IQ in their psychoeducational evaluations (Fiorello, Hale, McGrath, Ryan, & Quinn, 2002). Clinical populations of children with neurobiological disorders such as autism, ADHD, learning disabilities, and traumatic brain injury have also demonstrated distinctive profiles of strengths and weaknesses on the WISC-III (Mayes & Calhoun, 2004). The negative correlations between some subtests in this study may be related to a higher than typical degree of variability in performance on cognitive subtests. It may also reflect a particular profile of cognitive strengths and weaknesses for this population.

For this study sample, inverse relationships between variables were also not limited to correlations involving the TAPS-3 subtests. A review of the intra-test partial correlations among subtests of the WISC-IV for the current study revealed many negative correlations between these subtests as well (Table A2). Specifically, many of the subtests measuring Crystallized Intelligence (G*c*) (i.e., Similarities, Vocabulary, Comprehension, Information, and Word Reasoning) were significantly inversely related to subtests measuring Fluid Intelligence (G*f*), Visual Processing (G*v*), and Processing Speed (G*s*) (i.e., Matrix Reasoning, Picture Completion, Coding, and Symbol Search). These relationships may help explain why the majority of negative correlations involving TAPS-3 subtests were found for those subtests that measure Crystallized Intelligence (G*c*), Auditory Comprehension and Auditory Reasoning.

Reconceptualization of the TAPS-3 According to the CHC Model

The TAPS-3 was developed to measure aspects of auditory processing as described in the literature by various experts in the field. It was not based on any single, cohesive theory of auditory processing or cognitive processing. However, using the CHC model of cognitive abilities, the current study suggests that the TAPS-3 is likely a measure of multiple cognitive abilities that are also measured somewhat by intelligence and achievement tests. The findings of the current study suggest that primary CHC broad and narrow abilities that may be measured with the TAPS-3 include: (1) Auditory Processing (G*a*) and the component narrow ability Phonetic Coding (PC) which relates to phonological awareness, (2) Short-Term Memory (G*sm*) and the narrow ability Memory Span (MS), and (3) Crystallized Intelligence (G*c*) and the narrow abilities Language Development (LD), Lexical Knowledge (VL), and General (verbal) Information (K0). Overall, results of this study support the conceptualization of the TAPS-3 as a measure of multiple cognitive abilities and not only auditory processing. Therefore, clinicians are cautioned against the use of this test as primary support for the diagnosis of APD or Learning Disabilities with specified underlying auditory processing deficits. Still, it may be an appropriate test for use in cross-battery assessment, particularly when additional measures of auditory Short-Term Memory (G*sm*) would be helpful as follow-up measures to the Digit Span subtest of the WISC-IV.

Limitations and Future Directions

Several limitations need to be addressed regarding the current study. Because the sample for this study was drawn from a private practice population, the findings may not necessarily generalize to a larger population of children with academic difficulties that may be evaluated through public school systems or other settings. The families of these children have the financial capacity to seek private psychoeducational evaluations for their children, so children from lower income or impoverished backgrounds were not represented in this study. Also, the majority of subjects were Caucasian, and the results might not apply to children from other racial and ethnic backgrounds. The effects of different demographic variables could not be addressed in this study due to the restricted sample size and unequal racial distribution of children.

Another limitation of this study involves the choice of primary measures. The WISC-IV and WIAT-II are appropriate measures of intelligence and academic achievement, and several authors have linked their subtests with specific CHC abilities (Flanagan & Kaufman, 2004; Flanagan & Ortiz, n.d.). However, neither of these measures was specifically based on the CHC model. In contrast, the K-ABC-II, SB5, WJ III: Cognitive Abilities, and WJ-III: Tests of Achievement were developed with subtests that correspond directly with specific CHC abilities (Kaufman & Kaufman, 2004; Roid, 2003; Woodcock et al., 2001a, 2001b). Because data for this study was retrospective and children receiving psychoeducational evaluations at the Behavioral Institute of Atlanta were not typically administered these measures, validity analyses examining relationships between TAPS-3 subtests and subtests from these measures were not possible.

The present study sought to investigate the convergent and discriminant validity of the TAPS-3 and reconceptualize this test according to the CHC model. While the test does not seem to be a pure measure of auditory processing, the TAPS-3 subtests may offer valuable information about other cognitive abilities that could affect children's academic performance. Future research should continue to examine the cognitive ability of Auditory Processing (G*a*) and its components as well as the psychometric soundness of other tests of auditory processing. There is a need for an empirically-validated theory of auditory processing that could be used to guide test development as well as diagnoses of APD and Learning Disabilities. Future studies should also examine the TAPS-3 in larger and varied samples in order to more fully examine the validity of the test and the abilities measured. Criterion-based validity studies, using measures of auditory processing in attempts to predict success in academic, social, or other settings are also needed, to demonstrate the diagnostic utility of such measures.

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Table 1

TAPS-3 subtests and corresponding CHC abilities

TAPS-3 Subtest	**TAPS-3 Factor**	**Task Description**	**Broad CHC Abilities Measured**	**Narrow CHC Abilities Measured**
Word Discrimination	Phonologic Skills	Individuals listen to pairs of words spoken aloud by the examiner, make a determination about whether the same word was said twice or two different words were said, and respond by saying, “same” or “different”	Auditory Processing (G*a*)	Speech Sound Discrimination (UA) Ability to detect differences in speech sounds under conditions of little distraction or distortion
Phonological Segmentation	Phonologic Skills	Individuals listen and repeat single words said by the examiner, then individuals repeat the words again, deleting specific syllables or sounds from the words	Auditory Processing (G*a*)	Phonetic Coding: Analysis (PC: A) Ability to segment larger units of speech sounds into smaller units of speech sounds
Phonological Blending	Phonologic Skills	Individuals listen to single words said by the examiner one phoneme (sound) at a time, then decipher the word and say it to the examiner	Auditory Processing (G*a*)	Phonetic Coding: Synthesis (PC:S) Ability to blend smaller units of speech together into larger units of speech
Number Memory Forward	Auditory Memory	Individuals listen to increasingly longer sequences of digits spoken by the examiner and repeat them	Short-Term Memory (G*sm*)	Memory Span (MS) Ability to attend to and immediately recall temporally ordered elements in the correct order after a single presentation
Number Memory Reversed	Auditory Memory	Individuals listen to increasingly longer sequences of digits spoken by the examiner and repeat them in reversed order	Short-Term Memory (G*sm*)	Working Memory (WM) Ability to temporarily store and perform a set of cognitive operations on information that requires divided attention and the management of the limited capacity of short-term memory
Word Memory	Auditory Memory	Individuals listen to increasingly longer lists of meaningfully unrelated words and repeat the list to the examiner	Short-Term Memory (G*sm*)	Memory Span (MS) Ability to attend to and immediately recall temporally ordered elements in the correct order after a single presentation
Sentence Memory	Auditory Memory	Individuals listen to increasingly longer sentences and repeat them to the examiner	Long-Term Storage and Retrieval (G*lr*)	Meaningful Memory (MM) Ability to recall a set of items where there is a meaningful relation between items or the items create a meaningful story or connected discourse

TAPS-3 Subtest	TAPS-3 Factor	Task Description	Broad CHC Abilities Measured	Narrow CHC Abilities Measured
Auditory Comprehension	Auditory Cohesion	Individuals listen to short passages and answer oral questions about information directly presented in the passages	Crystallized Intelligence (G*c*) Long-Term Storage and Retrieval (G*lr*)	Language Development (LD) General development, or the understanding of words, sentences, and paragraphs (not requiring reading) in spoken native language skills Listening Ability (LS) Ability to listen and comprehend oral communications. Meaningful Memory (MM) Ability to recall a set of items where there is a meaningful relation between items or the items create a measningul story or connected discourse
Auditory Reasoning	Auditory Cohesion	Individuals listen to short passages and answer questions that require them to integrate information presented in the passage with basic, common-sense, and social knowledge	Crystallized Intelligence (G*c*) Long-Term Storage and Retrieval (G*lr*)	Language Development (LD) General development, or the understanding of words, sentences, and paragraphs (not requiring reading) in spoken native language skills Listening Ability (LS) Ability to listen and comprehend oral communications. Meaningful Memory (MM) Ability to recall a set of items where there is a meaningful relation between items or the items create a measningul story or connected discourse

Table 2

Descriptive Statistics and Subtest Correlations with Age and FSIQ

Variable Name and Abbreviation	N	*M*	*SD*	Correlation with Age	Correlation with FSIQ
Age	40	10.98	3.08	-	.01
Full Scale IQ (FSIQ)	40	103.3	10.82	.01	-
TAPS-3 Subtests					
Word Discrimination (WD)	38	9.50	2.53	.13	.36*
Phonological Segmentation (PS)	38	9.63	2.51	.38*	.60***
Phonological Blending (PB)	38	8.23	2.55	-.13	.36*
Number Memory Forward (NMF)	40	9.12	2.63	.17	.48**
Number Memory Reversed (NMR)	40	8.77	2.26	.42**	.46**
Word Memory (WM)	40	9.50	2.95	.08	.42**
Sentence Memory (SM)	40	9.70	2.53	.18	.55***
Auditory Comprehension (AC)	40	10.45	1.78	-.13	.44**
Auditory Reasoning (AR)	40	10.43	2.49	-.35*	.45**
WISC-IV Subtests					
Picture Concepts (PC1)	40	11.53	2.18	-.18	.46**
Matrix Reasoning (MR)	40	10.48	2.63	.02	.44**
Similarities (S1)	40	11.58	2.37	.07	.61***
Vocabulary (V)	40	11.35	2.24	.14	.70***
Comprehension (C)	40	10.90	2.82	-.06	.71***
Information (I)	40	11.25	2.65	.11	.66***
Word Reasoning (WR1)	35	11.66	2.41	-.04	.59***
Block Design (BD)	40	9.68	3.12	.12	.72***
Picture Completion (PC2)	40	9.70	2.65	-.04	.51***
Digit Span (DS)	40	9.70	2.37	.12	.57***
Letter Number Sequencing (LNS)	40	10.05	2.30	-.01	.66***
Coding (CD)	40	9.03	2.33	.05	.34*
Symbol Search (SS)	40	10.05	2.29	-.28	.55***
WIAT-II Subtests					
Word Reading (WR2)	39	105.08	11.57	.35*	.62***
Reading Comprehension (RC)	38	104.26	12.38	.35*	.56***
Phonological Decoding (PD)	39	101.95	10.80	.16	.58***
Spelling (S2)	39	103.67	13.87	.19	.48**
Numerical Operations (NO)	39	103.10	13.05	.28	.25
Math Reasoning (MR2)	39	106.82	10.94	-.20	.59***
Listening Comprehension (LC)	36	107.92	10.68	.08	.71***
TVPS Subtests					
Visual Sequential Memory – lower (VSM-L)	22	100.18	21.36	-.14	.16
Visual Sequential Memory – upper (VSM-U)	15	78.33	17.84	-.18	.19
Visual Sequential Memory *z* scores (*z*-VSM)	37	0	1.00	-.48***	.14

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

Table 3

Partial Correlations between Phonologic Skills Subtests and Other Subtests

Measure	CHC Ability	Subtest	TAPS-3 Phonologic Skills Subtests WD	PS	PB
WISC-IV	G*f*	PC1	-.18	-.30	-.22
		MR	.03	.13	.08
	G*c*	S1	-.37*	-.30	-.12
		V	.03	.06	-.04
		C	-.17	-.04	-.06
		I	.11	.06	-.7
		WR1	-.15	-.0	-.07
	G*v*	BD	.04	-.29	-.16
		PC2	.13	.17	.00
	G*sm*	DS	.25	.31	.21
		LNS	.19	.15	.22
	Gs	CD	.14	.11	.03
		SS	.14	.33	.26
WIAT-II	G*rw*	WR2	.17	.47**	.06
		RC	.06	.20	-.27
		PD	.22	.52**	.15
		S2	.08	.59***	.12
	G*q*	NO	.11	-.08	.12
		MR	.10	.30	.03
	G*c*	LC	-.25	.07	-.27
TVPS	G*sm*	*z*-VSM	.03	.35	.13

Covariates in all analyses were age and Full Scale IQ

Refer to Table 2 for subtest names corresponding with abbreviations

G*f* = Fluid Intelligence, G*c* = Crystallized Intelligence, G*v* = Visual Processing, G*sm* = Short-Term Memory, G*s* = Processing Speed, G*rw* = Reading and Writing, G*q* = Quantitative Knowledge

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

Table 4

Partial Correlations between Auditory Memory Subtests and Other Subtests

Measure	CHC Ability	Subtest	TAPS-3 Auditory Memory Subtests NMF	NMR	WM	SM
WISC-IV	G*f*	PC1	-.33*	.03	-.23	-.25
		MR	.01	-.14	.00	-.18
	G*c*	S1	.01	.00	-.06	.29
		V	-.19	.06	.04	.19
		C	-.26	.31	-.09	.22
		I	.08	.7	.14	.19
		WR1	-.15	.00	.03	.04
	G*v*	BD	-.11	-.22	.06	.03
		PC2	-.10	-.18	.09	-.30
	G*sm*	DS	.57***	.21	.55***	.35*
		LNS	.21	.21	.09	.07
	Gs	CD	.07	-.07	-.05	-.20
		SS	-.05	-.23	-.30	-.36*
WIAT-II	G*rw*	WR2	.10	.36*	.08	.11
		RC	.22	.12	.03	.09
		PD	.25	.45**	.30	-.06
		S2	-.03	.44**	.06	.04
	G*q*	NO	-13	.02	.01	.25
		MR	.03	.07	-.06	.08
	G*c*	LC	-.12	.17	-.08	.11
TVPS	G*sm*	*z*-VSM	.32	.12	.27	.07

Covariates in all analyses were age and Full Scale IQ

Refer to Table 2 for subtest names corresponding with abbreviations

G*f* = Fluid Intelligence, G*c* = Crystallized Intelligence, G*v* = Visual Processing, G*sm* = Short-Term Memory, G*s* = Processing Speed, G*rw* = Reading and Writing, G*q* = Quantitative Knowledge

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

Table 5

Partial Correlations between Auditory Cohesion Subtests and Other Subtests

Measure	CHC Ability	Subtest	TAPS-3 Auditory Cohesion Subtests AC	AR
WISC-IV	G*f*	PC1	-.07	.0
		MR	-.32*	-.33*
	G*c*	S1	.24	.30
		V	.37*	.53**
		C	.27	.63***
		I	.27	.65***
		WR1	.30	.35*
	G*v*	BD	-.09	-.25
		PC2	-.10	-.29
	G*sm*	DS	.01	.16
		LNS	.13	.10
	G*s*	CD	.03	-.28
		SS	-.37*	-.60***
WIAT-II	G*rw*	WR2	.15	.37
		RC	.0	.30
		PD	-.02	.22
		S2	-.04	.19
	G*q*	NO	.13	.11
		MR	.05	-.00
	G*c*	LC	.03	.20
TVPS	G*sm*	*z*-VSM	-.48**	-.11

Covariates in all analyses were age and Full Scale IQ

Refer to Table 2 for subtest names corresponding with abbreviations

G*f* = Fluid Intelligence, G*c* = Crystallized Intelligence, G*v* = Visual Processing, G*sm* = Short-Term Memory, G*s* = Processing Speed, G*rw* = Reading and Writing, G*q* = Quantitative Knowledge

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

Appendix

Table A1

Partial Correlations Between TAPS-3 Subtests

	WD	PS	PB	NMF	NMR	WM	SM	AC	AR
WD	-	.27	.37*	.39*	.08	.42*	-.04	.14	.09
PS	.27	-	.35*	.12	.33*	.20	-.11	-.24	.02
PB	.37*	.35*	-	.21	.12	.23	.20	.06	-.08
NMF	.39*	.12	.21	-	-.07	.68***	.24	-.04	-.08
NMR	.08	.33*	.12	-.07	-	.08	.17	.19	.22
WM	.42*	.20	.23	.68***	.08	-	.34*	.04	.02
SM	-.04	-.11	.20	.24	.17	.34*	-	.25	.19
AC	.14	-.24	.06	-.04	.19	-.04	.25	-	.50**
AR	.09	.02	-.08	-.08	.22	.02	.19	.50**	-

Covariates in all analyses were age and Full Scale IQ

Refer to Table 2 for subtest names corresponding with abbreviations

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

Table A2

Partial Correlations Between WISC-IV Subtests

	PC1	MR1	S1	V	C	I	WR1	BD	PC2	DS	LNS	CD	SS
PC1	-	.11	-.16	-.24	-.10	-.03	-.17	.13	.14	-.21	-.14	-.23	-.07
MR1	.11	-	-.34*	-.41*	-.47**	-.35*	-.45**	.29	.35*	-.22	-.41*	-.16	.29
S1	-.16	-.34*	-	.20	.29	.30	.32	-.16	-.48**	.07	.07	-.30	-.47**
V	-.24	-.41*	.20	-	.43**	.53**	.38*	-.23	-.16	-.04	.08	-.18	-.27
C	-.10	-.47**	.29	.43**	-	.45**	.49**	-.23	-.26	-.08	-.05	-.03	-.50**
I	-.03	-.35*	.30	.53**	.45**	-	.28	-.30	-.38*	.31	.16	-.36*	-.39*
WR1	-.17	-.45**	.32	.38*	.49**	.28	-	-.16	-.10	.00	-.13	-.05	-.20
BD	.13	.29	-.16	-.23	-.23	-.30	-.16	-	.56***	-.34*	-.50**	-.21	.05
PC2	.14	.35*	-.48**	-.16	-.26	-.38*	-.10	.56***	-	-.30	-.41*	.05	.24
DS	-.21	-.22	.07	-.04	-.08	.31	.00	-.34*	-.30	-	.33*	-.10	-.35*
LNS	-.14	-.41*	.07	.08	-.05	.16	-.13	-.50**	-.41*	.33*	-	-.12	-.02
CD	-.23	-.16	-.30	-.18	-.03	-.36*	-.05	-.21	.05	-.10	-.12	-	.16
SS	-.07	.29	-.47**	-.27	-.50**	-.39*	-.20	.05	.24	-.35*	-.02	.16	-

Covariates in all analyses were age and Full Scale IQ

Refer to Table 2 for subtest names corresponding with abbreviations

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