USE OF THE INTERMEDIATE CATEGORY TEST IN ARITHMETIC DISABILITY SUBTYPES

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For God, the author and creator of life

and

my family and friends for their love and support

USE OF THE INTERMEDIATE CATEGORY TEST IN ARITHMETIC DISABILITY SUBTYPES

by

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Abstract: The Intermediate Category Test (ICT) is a test of nonverbal reasoning and executive functioning, but its single general score may be difficult to interpret in the context of a particular clinical case. In this study, the ICT was applied to groups of subjects with very specific cognitive impairments, so that what is known about those groups, along with patterns of performance on the ICT, might help describe what the ICT measures in greater detail. The convergent and divergent validity of the ICT was examined using archival data from 81 children with arithmetic learning disabilities. Children were divided into groups based on the presence (n=55) or absence (n=26) of a comorbid verbal learning disability. All children were given the ICT, Wechsler Intelligence Scale for Children-Revised, Wide Range Achievement Test-R, Wide Range Assessment of Memory and Learning, Wisconsin Card Sorting Test, Kaufman Assessment Battery for Children Matrix Analogies subtest, and Trail Making Test. A variance test revealed that subtests I and II do not contribute significantly to variance in the ICT. Factor analysis demonstrated different factor structures for children with and without comorbid verbal disabilities. A factor composed of subtests IV, V and VI, and a second factor composed of subtests III and IV was present in children with isolated arithmetic learning disability, with only subtests III and VI strongly related to nonverbal abstract reasoning. In contrast, two ICT factors in children with a combined-type learning disability were composed of subtests V and VI, and III and IV, respectively. None of these factors had strong relationships with measures of nonverbal reasoning, although subtests V and VI were significantly related to arithmetic achievement.

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LIST OF ABBREVIATIONS

AGFI	Adjusted Goodness of Fit Index
ANOVA	Analysis of Variance
ANCOVA	Analysis of Covariance
BCT	Booklet Category Test
CCT	Children's Category Test
CFA	Confirmatory Factor Analysis
EFA	Exploratory Factor Analysis
FSIQ	Full Scale Intelligence Quotient
GFI	Goodnes of Fit Index
HCT	Halstead Category Test
ICT	Intermediate Category Test
K-ABC	Kaufman Assessment Battery for Children
KMO	Kaiser-Meyer-Olkin Sampling Adequacy Test
LD	Learning Disability
NLD	Syndrome of Nonverbal Learning Disability
PIQ	Performance Intelligence Quotient
TMT-A, -B	Trail Making Test, parts A and B, respectively
VIQ	Verbal Intelligence Quotient
WCST	Wicsconsin Card Sorting Test
WISC-R	Wechsler Intelligence Scale for Children, Revised Edition
WRAML	Wide Range Assessment of Memory and Learning
WRAT-R	Wide Range Achievement Test, Revised Edition

CHAPTER I: INTRODUCTION AND LITERATURE REVIEW

The Halstead Category Test (HCT or Category Test) was originally designed by Ward Halstead as a way of examining what he referred to as “biological intelligence” or the impairment thereof. The test was further refined by Reitan and is an important component of the widely regarded Halstead-Reitan Neuropsychological Test Battery – which includes both adult and adolescent versions of the Category Test, with a version for younger children additionally developed for the Reitan-Indiana Neuropsychological Test Battery. The HCT has been in use for over 60 years, but not without criticism. Much of the existing research addresses what essentially amounts to two related problems: the test is very lengthy (Lezak, 1995), and the only official result – the total error score – is of limited utility for interpreting performance (Spreen & Strauss, 1998b). The research that exists has generated a number of shortened Category Test spin-offs (Choca, Laatsch, Wetzel, & Agresti, 1997), and has also indicated that it may be more useful to break the Category Test into several parts rather than one overall total error score. Although there seems to be a consensus that the Category Test can be broken down into several factors (Allen, Goldstein, & Mariano, 1999; Fischer & Dean, 1990; Johnstone, Holland, & Hewett, 1997; Lansdell & Donnelly, 1977), the children’s versions lack a consistent explanation as to how many factors there may be and what parts of the test contribute to which factors (Donders & Strom, 1995; Kelly, Kundert, & Dean, 1992; Livingston, Gray, & Haak, 1996), and there has been no attempt to explain how understanding the Category Test as a multifactorial instrument may be helpful to clinicians. The current study aims to identify a factor structure of the older children’s version of the

Category Test, using a homogeneous sample to facilitate interpretation of the resultant factors.

History of the Category Test

From 1935 to 1969, Ward C. Halstead conducted a long series of inquiries into higher human brain functions at his laboratory at the University of Chicago (Hughes, 1976). He termed this field of study “medical psychology” or “biopsychology.” In 1939 Halstead asked neurosurgical patients (adults) to take 62 objects and place together those which “seem to belong together.” He concluded that brain damage may impair the availability of organizing principles (e.g. shape, size, color) on this task (Halstead & Settlage, 1943). By 1943, he was using geometrical figures instead of actual objects, and using a crude projection apparatus that was set to respond to correct choices only (such that subjects could only proceed by scoring a correct response). Multiple responses were allowed for each item. This version of the test consisted of 9 subtests with 40 items each, for a total of 360 total items! By 1947, when Halstead published his book *Brain and Intelligence*, the administration procedure had been changed to the current procedure, allowing only one trial per item. The number of items was reduced to 208 before the 1958 monograph on cerebral localization published by Shure & Halstead (Choca et al., 1997). By that time, the Category Test had become an important aspect of the Halstead Neuropsychological Test Battery. In 1953, Ralph Reitan at Indiana University modified and simplified Halstead’s tests, so as to create a battery for subjects ages 9-14 – the Halstead Neuropsychological Battery for Children. In 1958, Reitan developed functionally equivalent tests for children of ages 5-8. Although this version of the test was designed to provide measurements of abilities comparable to those required by the

Halstead batteries, the content and difficulty were varied considerably to accommodate children younger than nine years of age. The resultant Reitan-Indiana Neuropsychological Test Battery for Children was also used routinely at the Halstead Laboratory of Medical Psychology at the University of Chicago (Hughes, 1976).

Description of the Category Test

Use with Adults

The adult version of the Category Test consists of 208 items, divided into seven subtests (I-VII). In the original format, all the items are presented by means of a slide projector, which is controlled by the examiner, who is also responsible for recording the responses of the participant. Each item consists of different geometrical figures or designs. The examinee is told that something about the item will remind him/her of a number between one and four, and is instructed to push a key labeled 1, 2, 3, or 4 to indicate their answer. When a correct choice has been made, a bell tone is heard; when an incorrect choice has been made, a buzzer is heard. In this manner, the subject always receives feedback about the correctness of his/her choice. There is no time limit per item, but the examinee is only allowed to respond once to the item before moving on to the next item. Each subtest utilizes a different principle, and each principle must be understood by the examinee before he/she can begin to respond correctly to test items in a consistent manner. For example, the stimuli for the first subtest are Roman numerals from I to IV. If “I” is displayed, the subject pushes the button labeled “1,” if “II” then “2,” and so on. The stimuli for the second subtest consist of one to four separate objects. If three objects are displayed, the correct answer is “3,” if four objects are displayed, the correct answer is “4,” etc. For the third subtest, four figures are presented, three of which are alike. The examinee must indicate the ordinal position of the “odd” object. For example “OXOO” would be answered “2,”and “OOXO” would be answered “3.” Oddness in subtest III can be determined by size, shape, color, or on the basis of filled versus empty figures. In subtest four, the examinee is introduced to a “quadrant framework” (Simmel & Counts, 1957) in which he/she must respond with the number of the quadrant that is different from the others. The fifth and sixth subtests require the examinee to indicate what proportion of the stimulus is composed of solid vs. dotted lines; there is no shift in principle between the fifth and sixth subtests. Finally, subtest VII has no unifying principle but is made up of items reflecting the principles of the prior six subtests. The examinee must recognize and recall the type of problem presented by the stimuli, as well as the appropriate solution. The score on the test is the total number of errors on all seven tests, with more than 50 errors representing Reitan’s impairment criterion (Reitan & Wolfson, 1985). The examiner is free to encourage the participant, in order to elicit the best sample of his/her abilities, but hints/prompts are strongly discouraged.

Other forms of the HCT include a booklet version and computerized versions. The Booklet Category Test was developed by DeFilippis and McCampbell (1979) and suggested as a replacement for the traditional HCT (although this has been contested by Reitan) (Choca et al., 1997; Donders & Kirsch, 1991). The Booklet Category Test consists of exactly the same items and instructions as the original HCT but in paper form, presented to the examinee in a loose-leaf booklet. The examinee is expected to indicate the answer (1-4) by pointing to an answer key. Computerized versions display the figures on the screen, accept the examinee’s responses, and provide feedback as to whether the answer was correct or not

(Choca et al., 1997). Individual subtest error scores have indicated significant differences between the original HCT and the booklet and computerized forms, with the booklet form more likely to elevate errors on subtest III and the computerized version more likely to elevate errors on subtest VI (Mercer, Harrell, Miller, & Childs, 1997).

Use with Older Children

The older children's version of the test is often referred to as the Intermediate Category Test (ICT) or Intermediate Halstead Category Test, and is intended for ages 9years, 0 months – 14 years, 11 months. The test was developed by Reitan in 1953, who believed that by making the test easier (by shortening it), it would be more suitable for use with children (Reed, Reitan, & Klove, 1965). The slide projector mechanism of the ICT is the same as that used in the adult version. There are 168 items presented over the course of six subtests (I-VI). Like the adult version, the ICT subtest I requires identification of roman numerals "I-IV" and subtest II requires simple counting of objects. Subtest III is also very similar to the adult version, except that color is not used as a stimulus (the ICT never makes use of color). Subtest IV and V of the ICT are similar to subtests V and VI of the adult version, in that the correct response is determined by the proportion of the figure that is composed of solid vs. dotted lines. However, unlike in the adult version, the subtests are not identical – both are answered by identifying ratios (¾ of the stimulus is solid and ¼ is dotted, for example), but subtest IV of the ICT is composed mostly of arrangements of lines, and subtest V is composed mostly of abstract figures. Subtest VI of the ICT is a "memory" test, akin to subtest VII of the adult version. The most obvious differences between the tests are the lack of color in the ICT and the fact that the ICT has no equivalent to the adult version's subtest IV, which requires learning and retention of a four quadrant framework. As with the adult version, a booklet version of the ICT has also been developed (Byrd & Ingram, 1988; Byrd & Warner, 1986).

A shortened form of the ICT is commercially available. The Children's Category Test (CCT; Boll, 1993) was developed by extracting a subgroup of items from the ICT that, upon analysis, retained the psychometric properties of the ICT (Reeder & Boll, 1992). Although the CCT is much shorter than the ICT, it shares the multifactorial nature of the ICT, as discussed below (Donders, 1999; Nesbit-Greene & Donders, 2002).

Use with Younger Children

The Category Test for Young Children is intended for children of ages 5 years, 0 months through 8 years, 11 months, and is very different from the HCT and ICT in that it replaces the numbers with colors; instead of instructing examinees that "something about the pattern will remind you of a number between 1 and 4 (Reitan & Wolfson, 1992, p. 450)," young children are instead told "each picture will make you think of a color, either red, blue, yellow or green (Reitan, 1987, p. 101)." A projection apparatus is used here also, but the numbered buttons are instead replaced with colored ones: the number 1 is replaced by the color red, the number 2 by the color blue, the number 3 by the color yellow, and the number 4 by the color green. There are only five subtests, comprising a total of 90 stimuli. On subtest I, a correct answer is achieved by correctly identifying the color of the single stimulus. The principle of subtest II is to respond according to which color is most prominent in the stimulus: a large red square next to a small blue square would be correctly answered red. The third subtest requires children to correctly respond to the color of an "odd" object: a stimulus consisting of a red circle, a blue circle, a yellow circle and a green square should be answered "green." Subtest IV presents the colors in a quadrant format, and like HCT subtest IV, requires the child to identify the color of the quadrant that has been altered. Subtest V is a "memory" test as is found in the HCT and ICT, and is composed of miscellaneous items from the prior subtests.

Test Length

The Category Test is a lengthy test, no matter which version is used. The adult version consists of 7 subtests and 180 items, the intermediate version consists of 6 subtests and 168 items, and the young children's version consists of 5 subtests and 90 items. The adult version may take over an hour to administer. There have been numerous attempts to shorten the adult version of the test. Rigorous examples of this are reported by Laatsch and Choca (1991) and Lopez, Charter and Newman (2000), who administered the Category Test and performed item analysis, removing original test items that were non-discriminatory by virtue of being either "too easy" (i.e., none of the members from any groups made errors on those items) or "too difficult" (i.e., many members from all groups made errors on the items). The resultant, modified test was then compared to the original, to ensure similar psychometric properties between the original and shortened versions of the Category Test. Even Laatsch and Choca (1991) and Lopez et al. (2000) are not in agreement about the items, with differences probably reflecting different sample populations and statistical methods. Laatsch and Choca used a sample of 195 inpatients, with a trend for younger patients to have had closed head injuries and older patients to have had strokes. A full range of educational levels was represented, and ratios of sex and age were chosen to match that of the research site (a rehabilitation hospital). The authors attempted to take into account the fact that test items are related. Overall, they found 40 items that were too easy (including all of subtests I and II), and 5 items that were too difficult; these items were not able to discriminate between patients who made few errors and patients who made many errors. Lopez et al. used archival data from 398 patients, including 103 referred for neuropsychological testing but found to be neurologically normal, 94 college students with no history of neurological damage, 105 diffusely brain-damaged subjects and 96 undiagnosed patients who may or may not have suffered brain damage. These authors did not attempt to control for the effects of item order. They found that 4 items were too difficult, 52 were too easy (including all of subtests I and II), and 70 total items were not useful for discriminating between subjects with many errors on the test compared to subjects with few errors.

Many investigators have not been so rigorous in their attempts to create a short form of the HCT, and versions have been constructed by various means, from using the first half of each subtest, to using every other item. The items forming the Children's Category Test seem to be chosen at random from the Intermediate Category Test (Reeder & Boll, 1992). The results of the shortened version are compared to the results from the lengthier test (usually the adult HCT) from which the shortened version was derived, and each author typically finds acceptable correlations between the short form and the original. Although no one has compared the assundry shortened Category Test forms for adults, Donders (1996) compared three shortened forms of the test for older children, and found that although all three correlated significantly with the full ICT, only one had a correlation with injury severity or could discriminate between groups with varying degrees of injury severity. By implication, it is not safe to assume that a shortened form of the Category Test retains all of the properties of the original.

Factor Analysis: Looking Beyond the Total Error Score

According to Reitan (1985), a person making greater than 50 errors on the adult Category Test is said to be impaired on the test. More comprehensive norms exist, which convert the total error scores into a T-score (Heaton, Grant, & Matthews, 1991; Heaton, Miller, Taylor, & Grant, 2004), and allow for a greater precision of clinical description regarding performance on the test. The error score and its recommended cut-off have excellent sensitivity, but little specificity (Choca et al., 1997). That is, the indication of impairment is extremely reliable at detecting "brain damaged" subjects (Lansdell & Donnelly, 1977), but tends to mis-classify normal controls as having impairment (Vega & Paul, 1967). The limited clinical utility of making a general judgment of brain damage does not often warrant such a lengthy procedure (Reeder & Boll, 1992). The single error score is formed "without the benefit of psychometric evidence (Fischer & Dean, 1990)."

Given the length of the test and its convenient division into subtests, it is no wonder that examiners have tried to look beyond the total error score in order to facilitate interpretation of results. Hughes (1976) attempted to separate children into *a priori* groups of good, average, or minimally, moderately, or severely impaired. She hoped to find patterns of performance on the ICT that would discriminate the groups but was forced to conclude that the problem was related to the heterogeneity of the sample: "due to the wide variety of variables displayed and the range of neuropsychological abilities described, considerable information as to the pattern of abilities or impairment is impossible" (p. 13-14). Eventually, with the evolution of more sophisticated statistics, factor analytic research on the HCT began appearing more frequently as a way to find patterns in a large quantity of data. In factor analysis, data sharing common variance are lumped together under specific factors (Bryant & Yarnold, 1995), allowing a large quantity of related information to be effectively reduced to a few factors. Typically this has been done by taking Category Tests from "a mixed neurological sample" – usually adults – and then analyzing error scores for each subtest. This means that, in the adult version of the Category Test, each subject yields 7 error scores (one per subtest) rather than only one. These scores are then entered into a computerized factor analysis procedure to determine the presence of multiple factors in the data. Three factors have consistently been reported for the adult version of the HCT, although different researchers have included a variety of other measures in their analyses, and measured different populations, making it difficult to compare the results from one experimenter's analysis to those of a different experimenter (Allen et al., 1999).

Fischer & Dean (1990) administered the adult HCT as part of a larger battery to 1153 children with learning disabilities; the learning disability subtype composition was not described. Using principal components factor analysis of the entire Halstead Reitan Neuropsychological Battery, they found that the raw scores of the seven HCT subtests loaded on four of the resultant nine factors. They conducted factor analyses on the HCT subtest scores exclusively in several samples: the total sample, males only (n=871), females only (n=282), 9-year-olds (n=337), 10-year-olds (n=274), 11-year-olds (n-193), 12-year-olds (n=145) and 13- and 14-year-olds combined (n=204). All of the analyses using the HCT exclusively yielded a similar three factor solution. In the three factor solution, one factor was comprised of subtest I and II and, to a lesser extent subtest IV. Subtests III and IV comprised a second factor, and subtests V, VI and VII comprising the third factor. Unfortunately, the use of an adult battery on children makes interpretation of the factor structure clinically irrelevant. A similar study (Johnstone et al., 1997) examined HCT subtest scores as part of a test battery that also included standard scores from the Wechsler Adult Intelligence Scale-Revised (all subtests), raw scores for Visual Memory I and Visual Reproduction I from the Wechsler Memory Scale-Revised, the times from Trail Making Test, and the times from the Tactual Performance Test. Using a sample of 308 adults referred for evaluation of cognitive dysfunction (of varying neurologic diagnoses), these authors also found that subtests I and II were the only tests loading on a factor that they named “recognition/counting” (p.31), subtests III, IV and VII loaded on a “spatial positioning reasoning” factor and subtests V and VI loaded on a “proportional reasoning” factor. It is most interesting to note that none of these factors shared loadings with subtests or indices from the rest of the battery, illustrating the relative uniqueness of the Category Test. Confirmatory factor analysis conducted in a sample consisting of 195 patients with schizophrenia, 177 with heterogeneous brain damage, and 229 patient controls found that subtests I and II do not offer enough variance to be analyzed and that the remainder of the subtests are best explained with a two factor solution (Allen et al., 1999). The authors labeled the two factors “spatial” and “proportional” (p. 239) for subtests III and IV and subtests V and VI, respectively. Subtest VII was found to load moderately on both factors. In sum, the HCT is consistently broken into three components: 1) subtests I-II, which item analysis studies have found to be too easy, and which consequently may not constitute a factor *per se* but can be considered a distinct unit of the test 2) subtests III and IV, which appear to measure a distinct construct, and 3) subtests V and VI, which appear to measure another distinct construct. Subtest VII has demonstrated factor loadings on both of the latter factors, and in fact is likely to have moderate loadings on both of them.

Analyses performed on the children's versions of the test have yielded somewhat different results, and have mostly indicated an increased relationship between the recall subtest (subtest VI with the ICT) and subtest III. Additionally, the support of subtests I and II as independent factors seems to vary depending on the nature of the sample being examined. Using the ICT in a sample of 652 children with learning disabilities, Kelly, Kundert and Dean (1992) found three factors, similar to those found in adults: Factor One with subtests I and II was labeled "number counting/attention" (p.417), Factor Two with subtests III and VI was labeled "visual abstract reasoning/memory", and Factor Three with subtests IV & V was labeled "visual perception/spatial orientation." Also using the ICT, Donders & Strom (1995) found better evidence for a two factor model, with Factor One incorporating subtests III, VI and aspects of V, and Factor Two incorporating subtest IV, and aspects of V and VI. Subtests I-II did not have enough variance to load on any factors. It should be noted that Donders and Strom used a sample of 87 children with traumatic brain injury, purposefully excluding children with a prior history of learning disability. Livingston, Gray and Haak (1996) examined 285 children with behavioral disorders (63% had a learning disability). They favored a three factor model: subtests I and II were considered a factor, subtests III & VI were placed together (uniqueness and memory), and subtests IV & V were also placed together (proportion). At this time, there appear to be no investigations as to the properties of the Category Test for younger children.

Limitations of Empirical Background

It seems then, that studies utilizing factor analysis are all in agreement that the Category Test is composed of more than one factor, which cannot be adequately described by the total error score. This is a useful starting point, but our knowledge of what the Category Test actually measures is still limited. The multifactorial nature of the Category Test might explain why attempts to pigeonhole the test have, historically, been unable to link performance on the test to single cognitive constructs (Allen et al., 1999; Simmel & Counts, 1957). Additionally, factor analyses have never examined the Category Test beyond the subtest level, which a) limits the ability of these analyses to reflect more than gross estimates of its factor structure, and b) assumes the subtests are homogeneous and unified constructs, even though subtests were clinically (not empirically) constructed, and subtest unity has never been tested. Factor analyses have also been focused on determining the factor structure in heterogeneous populations, which does little to help interpret the test in the context of any specific diagnosis.

An alternate approach, and one that might be more fruitful, would be to apply the HCT (or ICT for children) to groups of subjects with very specific and well-defined cognitive impairments, in the hopes that what is known about those groups, in conjunction with patterns of performance on the HCT, might shed some light on what the HCT really measures. The precedent for this has come from studies of brain damaged patients; as the HCT was known to be sensitive to brain damage, examiners reasoned that something could be learned by examining what it is about brain damage that impairs performance on the HCT. Specifically, brain damaged groups have been used to study the sensitivity of the HCT to lateralization effects, with negative findings, though there has been some disagreement (Cullum, Steinman, & Bigler, 1984; Lansdell & Donnelly, 1977; Russell, 1974). Unfortunately, as is now more widely appreciated, generic brain damage is not a good model for such a study, because of the wide variability of cognitive patterns within this group. Such variability could be limited by focusing on the test performance of a better defined group.

In children, the ICT has been used to assess populations known to have impairment in certain domains, but seldom with intent to understand the test. If known developmental cognitive deficits create consistent patterns of performance on the Category Test, then the deficits and the [presumed] underlying neurobiology can inform our knowledge of what it is that the test really measures, hence increasing its usefulness.

Limitations of Theoretical Background

The original intent of the Category Test was to measure abstraction ability (Halstead & Settlage, 1943). This assertion is widely accepted, and has been empirically validated. Factor analyses of whole test batteries place the HCT on an “abstraction” factor (Arnold, Montgomery, Castaneda, & Longoria, 1994; O'Donnell, MacGregor, Dabrowski, Oestreicher, & Romero, 1994; Russell, 1974; Titus, Retzlaff, & Dean, 2002). However, this conceptualization is not very helpful, due to the panoply of meanings that abstraction can assume. Some have described the Category Test as a measure of learning, for example, Fischer and Dean (1990) state that the HCT “is a highly complex neuropsychological measure of concept learning” (p. 180) and it is also used to assess learning by Fisher, Deluca and Rourke (1997). Still others conceptualize the HCT as a test of problem solving ability (Kelly et al., 1992; Laatsch & Choca, 1991), which is likely consistent with "abstraction." The concept of abstraction is difficult to separate out from that of executive functioning. A survey of the literature on executive functions reveals that mental set-shifting or mental flexibility, updating and monitoring of working memory representations, organization, goal development, problem solving, abstract thinking and concept formation (Anderson, 1998; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Welsh, 2002) have all been attributed to executive functioning capabilities.

Rationale for the Current Study

The HCT purports to measure "abstraction," "executive functioning," or facets thereof, but it is unclear how specifically to interpret test results for any given child. A better understanding of what the test measures has been further complicated by the fact that the single measure, Total Error score, insufficiently describes variations in test performance. Beyond simply applying the test to heterogeneous samples, assessing populations that are known to be impaired in specific cognitive domains may help validate (or challenge) theories on what the Category Test measures. In adults, studies have consistently shown that there are three factors that affect test performance. In children, the factor structure of the ICT is a matter of some scholarly disagreement (Donders & Strom, 1995; Livingston et al., 1996). Examination of the subtest error pattern generated by known developmental cognitive deficits may allow for better understanding of the way developmental disabilities impact performance on the ICT (Baron, 2004), and *ipso facto* what is required of normal development so successfully navigate the test. Factor analysis of the ICT in a sample of children with learning disabilities seems to yield consistent results (Kelly et al., 1992; Livingston et al., 1996), but learning disabilities themselves represent a heterogeneous collection of cognitive strengths and weaknesses that might obscure interpretation of the resultant factors. Learning disability subtypes may represent specific cognitive impairment, measurable by the ICT, and are described below. Only by addressing both the multifactorial nature of the test, and currently ambiguous notions of the cognitive demands of the test, can a better understanding of the Category Test – for any age group—be reached.

Learning disabilities and the Category Test

Prior to the 1970s, learning disorders were generally viewed as a homogeneous diagnostic grouping (Collins & Rourke, 2003; Rourke, 2000). However, similar overall levels of disability were related to very different patterns of cognitive strengths and weaknesses, and the idea of a homogeneous learning disabled population gave way to an understanding that learning disabilities may arise from quite different etiologies (Rourke, 2000). Learning disabilities have moved from a conceptualization of the archetypal "learning-disabled child" to subtyping efforts based on children with either pervasive deficits in reading, spelling and arithmetic; relative strengths in arithmetic along with reading and spelling deficits; or reading and spelling strengths along with deficits in arithmetic (Collins & Rourke, 2003; Fletcher, Morris, & Lyon, 2003; Silver, Pennett, Black, Fair, & Balise, 1999). Such subtyping is based on characteristic patterns of academic and neuropsychological test performance by children with different learning disabilities etiologies, and is supported by both clinical observation as well as empirical classification (Hooper & Willis, 1989). Children with learning disabilities were found to make significantly more errors on the

Intermediate Category Test than children without learning disabilities (Coutts et al., 1987), and have been described as lacking the higher-order executive processes needed to integrate information and to learn appropriately in novel situations (Meltzer, 1991). Thus, amongst children with learning disabilities it might be possible to find a subgroup (or subgroups) with specific cognitive impairments that would facilitate a better understanding of what the Category Test is really measuring.

The Intermediate Category Test in Arithmetic Disability Subtypes

Overall, older children with isolated arithmetic disabilities have been found to display unique patterns of strengths and weaknesses in comparison to children with reading and spelling disabilities (Share, Moffitt, & Silva, 1988; Silver et al., 1999; Strang & Rourke, 1983), although reading and spelling difficulties may often be present in children identified with math problems (Share et al., 1988). Isolated arithmetic disabilities are a hallmark symptom of the nonverbal learning disabilities (NLD) syndrome, and are believed to be manifest in the context of well developed rote-verbal capacities, repetitive verbosities, deficient visual-spatial-organizational abilities and deficient nonverbal problem solving (Harnadek & Rourke, 1994; Strang & Rourke, 1983). Consistent with this, children with isolated arithmetic disability have deficient concept formation, procedural learning and visual-motor integration (Fletcher et al., 2003), while maintaining clear strengths in psycholinguistic skills (Rourke, 2000). In regards to the ICT, children with isolated arithmetic disabilities and NLD perform poorly on this measure (Harnadek & Rourke, 1994; Rourke, 2000; Strang & Rourke, 1983). Some authors indicate that children with learning disabilities characterized by poor mathematics achievement are more likely to have qualitatively worse performance on subtests IV, V, and VI (Fisher, Deluca, & Rourke, 1997; Strang & Rourke, 1983) while others find that subtest III seems to be most sensitive to this population (Donders & Strom, 1995; Kelly et al., 1992).

In contrast, reading and spelling disabilities are a hallmark of a basic phonological processing disorder, and consist of relatively poor psycholinguistic skills in conjunction with well developed visual-spatial organizational and nonverbal problem-solving skills (Harnadek & Rourke, 1994; Rourke, 2000). It is interesting to note that some of these children do exhibit impaired mechanical arithmetic (i.e., using pencil and paper to work out problems) abilities, although their mechanical arithmetic skills are superior to those of children with nonverbal learning disability. On the ICT, children with reading and spelling disabilities generally perform much better than children with isolated arithmetic disabilities (Strang & Rourke, 1983).

As a group, children with isolated arithmetic disabilities have average verbal abilities (VIQ) and lower than expected performance abilities (PIQ), in contrast to children with verbal learning disabilities, who show the reverse pattern (Rourke & Finlayson, 1978). This finding, as well as the deficit patterns described above, led Rourke and his colleagues to hypothesize that the syndrome of NLD may be a manifestation of white matter developmental defect, resulting in broad compromise of the right hemisphere systems in comparison to left hemisphere systems (Fisher et al., 1997). Relatively focal left-sided dysfunction was thought to underlie the faulty phonemic processing behind verbal learning disorders. However, research on the contribution of right hemisphere and white matter abnormalities has shown mixed results (Spreen, 2001), and "systematic investigation of this association is still in its infancy" (Collins & Rourke, 2003).

Children who are comparably impaired in both arithmetic and reading are considered to have a distinct subtype of learning disability, although this subtype has not been investigated to any considerable extent (Collins & Rourke, 2003). Rourke and his colleagues have typically demonstrated that children with a math and verbal learning disability perform very similarly to children with uncomplicated verbal learning problems (Collins & Rourke, 2003; Rourke & Finlayson, 1978). As such, one might expect children with a combined math and verbal learning disability to have ICT performances similar to children with only verbal disability: that is to have superior performance on subtests IV, V and VI of the ICT when compared to children with only arithmetic problems (Fisher et al., 1997). However, there are some aspects of psychomotor functioning where children with combined math and verbal learning disabilities perform similarly to children with only math disability (Rourke & Strang, 1978). Rourke's model for verbal learning disorders heavily emphasizes deficient phonemic processing in verbal learning disability and not math learning disability, and this may be a reason for his tendency to classify children with a combined learning disability as being more like children with pure verbal learning disability. Although children with a combined-type learning disability show phonological processing that is very similar to children with a verbal learning disability, they also demonstrate similarities in other areas to children with a math learning disability, and essentially have both disorders at once (Fletcher et al., 2003).

It is conceivable that children with a combined arithmetic and verbal learning disability may show some aspects of ICT performance that are quite similar to children with pure arithmetic problems, and some aspects of ICT performance that are dissimilar. The importance of further characterizing the differences between isolated arithmetic disability and combined arithmetic and verbal disability is clearly indicated by the way such knowledge might strengthen support for differing arithmetic disability etiologies. Such information might also indicate how different patterns of problem solving warrant different treatment strategies for these groups (Fletcher et al., 2003; Meltzer, 1991; Rourke, 2000).

Summary

Although studies have shown that the ICT does not measure a homogeneous cognitive construct, it is unclear which aspects of the test are most sensitive to which cognitive constructs, or how such knowledge may be useful in a clinical setting. In order to address these issues it is necessary to be able to perceive patterns of performance on the ICT. First, this necessitates dividing the instrument into parts. Prior research has demonstrated that the ICT can be empirically parsed by subjecting the subtests to factor analysis.

Second, this necessitates using children who have cognitive deficits measurable by the ICT. This means using groups of children who have either been shown to have difficulty with the ICT or can reasonably be predicted to have difficulty with the ICT. Children with learning disabilities have been found, as a group, to have problems with the ICT (Coutts et al., 1987). Clear identification of specific subgroups will allow for an examination of what cognitive traits the test is sensitive to in homogeneous samples.

Finally, any method of extracting more information from the ICT should be done in a way that has relevance to the clinician and is not cumbersome. It is not enough to demonstrate that children can be clustered into groups if the meaning of such grouping is not clear. Rather, clinical groups (such as specific learning disability subtypes) must be identified *a priori* and then shown to have distinct ICT profiles.

Current Study and Order of Presentation

This study will facilitate a more detailed awareness of what the Category Test for older children really measures in a sample of children with arithmetic learning disabilities. By focusing on arithmetic disabilities both with and without the presence of an additional verbal learning disability, it will be possible to measure the impact of a verbal learning disability on problem solving, and perhaps to speculate whether isolated arithmetic disabilities are etiologically similar to- or quite different from arithmetic disabilities with additional verbal learning disabilities. First, a formal statement of hypotheses is presented in order to help frame the problem in a way that is conducive to analysis. The methodology for the study involves dividing the ICT into factors that can be interpreted in the context of the cognitive strengths and weaknesses that are specific to children with arithmetic learning disability, with and without verbal learning disability. Results from the study, including assessment of the fit of the ICT factor structure to children with arithmetic disabilities is presented. In addition, the statistical procedures utilized to evaluate factor structure and construct validity of resultant factors are explained. A final section will discuss the applicability of these results to children with arithmetic disabilities, the validity of the factor approach in understanding the ICT, including any aspects of the test that may be differentially susceptible to verbal and nonverbal aspects of reasoning.

Hypotheses

Overall Goal: To account for variance on the Intermediate Category Test (ICT) in a way that will yield a better understanding of what that test is measuring.

Specific Aim Number One: To demonstrate that the ICT is not a unified construct, and to identify factors that account for the variance within the test.

Objective 1: To examine the contribution of subtests I and II to the total variance of the ICT.

Hypothesis 1: The proportion of the total variance in the ICT attributable to subtests I and II will be smaller than five percent (5%) of the total test variability.

Objective 2: To confirm the factor structures previously reported by the literature, in a homogeneous sample.

Hypothesis 2: In a group of children with arithmetic learning disabilities, a two- or three-factor structure for Intermediate Category Test performance will be supported, consistent with what has been reported in the literature. Specifically, if subtests I and II have sufficient variance to be retained for further analyses, a three-factor solution is expected; if subtests I and II contribute less than five percent (5%) of the total test variability, then they will be excluded from further analyses and a two-factor structure is expected.

Specific Aim Number Two: To describe the resultant factors in terms of the cognitive skills assessed by other measures.

Objective 3: To examine the convergent and divergent validity of the resultant factors in the ICT.

Hypothesis 3: Among measures consisting of the Wechsler Intelligence Scale for Children- Revised (Index Scores, and Arithmetic, Vocabulary, Digit Span, Picture Arrangement and Block Design subtests), Wide Range Achievement Test-Revised, Trail Making Test, Kaufman Achievement Battery for Children (Matrix Analogies subtest), Wisconsin Card Sorting Test (perseverative responses), and Wide Range Assessment of Memory and Learning (Visual Index and Visual Learning subtest), significant negative correlations are expected primarily between the ICT factors and WISC-R FSIQ and PIQ, Block Design and Picture Arrangement subtests, K-ABC Matrix Analogies and the WRAML Visual Index Score. A significant positive correlation is expected between the ICT factors and WCST perseverative responses.

Specific Aim Number Three: To confirm the relationship of factors to cognitive measures in two different diagnostic groups.

Objective 4: To determine the nature of the relationship between the ICT and other cognitive measures for each diagnostic group, independent of the effects of the alternate group.

Hypothesis 4: For every factor found by factor analysis, differences in correlation between the two diagnostic groups will be explored. A correlation matrix will be generated for ICT factors and other cognitive measures for the group of children with isolated arithmetic disability and for the group of children with combined arithmetic and verbal disabilities. The two correlation matrices (Cohen & Cohen, 1983) will be compared for statistically significant differences.

CHAPTER II: METHODS

Participants

Archival data from patient files used for this study were provided by the Luke Waites Child Development Center (formerly Child Development Division) of the Texas Scottish Rite Hospital, in Dallas. IRB approval to utilize these archival data was obtained (see Appendix A). Criteria for inclusion of participants in this study were as follows:

1) Diagnosis of arithmetic learning disability: FSIQ greater than 90 on the Wechsler Intelligence Scale for Children – Revised (Wechsler, 1974) and standard score less than 90 on either the Arithmetic subtest of the Wide Range Achievement Test—Revised (Jastak & Wilkinson, 1984) or the Calculation or Applied Problems subtests of the Woodcock-Johnson Psycho-Educational Battery-Revised (Woodcock & Johnson, 1990). Children demonstrated a 15 point discrepancy between the highest of Verbal, Performance, or Full-Scale IQ and the lowest arithmetic achievement test.

2) Exclusion of children with acquired brain injury or medical condition affecting the central nervous system;

3) Age between 9 years and 14years, 11 months;

4) Completion of the ICT as part of a neuropsychological evaluation.

An additional learning disability in reading or spelling was defined by the same criteria noted above for arithmetic, but using the WRAT-R Reading and Spelling subtests. Only first evaluations, not repeat evaluations, were used in this study.

Data were collected from 81 children with arithmetic disability. The sample consisted of 26 children with an isolated arithmetic learning disorder, and 55 children with an arithmetic disorder and comorbid reading or spelling disorder.

Procedures and Analyses

The original slides version of the ICT was administered to all subjects as part of a larger neuropsychological test battery. Other tests selected from the battery to be used in the current study included the Wechsler Intelligence Scale for Children – Revised (Wechsler, 1974), Wide Range Achievement Test-3 (WRAT-3), Wide Range Assessment of Memory and Learning (WRAML), Wisconsin Card Sorting Test (WCST), Kaufman Assessment Battery for Children (K-ABC) Matrix Analogies, and Trail Making Test. Many of these measures are well known instruments of neuropsychological and/or cognitive assessment (Lezak, 1995; Sattler, 1992). However, a brief description of each measure is presented in Appendix B and as follows:

Wechsler Intelligence Scale for Children-Revised (WISC-R). The WISC-R is a general measure of cognitive functioning for children aged from 6.0 to 16.11 years that provides reliable IQs for each of three scales: Verbal, Performance and Full Scale. The 12 subtests of the WISC-R have been described as measuring Verbal Comprehension, Perceptual Organization and Freedom from Distractibility. Verbal Comprehension is comprised of the Information, Similarities, Vocabulary and Comprehension subtests. Perceptual Organization is comprised of the Picture Completion, Picture Arrangement, Block Design and Object Assembly subtests. Freedom from Distractibility encompasses the Arithmetic, Digit Span and Coding subtests. Verbal Comprehension subtests are more highly correlated with each other than Perceptual Organization subtests, but most subtests are also thought to maintain an adequate degree of specificity to be interpreted in their own right. Only the Similarities and Object Assembly subtests are especially prone to measurement error and lack specificity to be interpreted independently (Sattler, 1992). Among the WISC-R subtests included for comparison to the Intermediate Category Test are:

Digit Span. In the Digit Span subtest, examinees are asked to repeat increasingly lengthy strings of numbers. Digit Span has been demonstrated to have very low correlation with performance on the Halstead Category Test (Lansdell & Donnelly, 1977), and has not been found to discriminate between groups of children with different learning disability subtypes (Ozols & Rourke, 1988). It does not measure anything mathematical *per se*, and is used as a test of attention and concentration (Lezak, 1995; Sattler, 1992). It is included here for divergent validity.

Block Design. In the Block Design subtest, examinees are asked to reproduce a geometrical design using colored blocks. Performance is subject to a time limit, and designs become increasingly complex. The Block Design subtest is very highly correlated with Category Test performance (Lansdell & Donnelly, 1977), and seems ideal for convergent validity of the ICT as a visuospatial organization test. Block Design scores may be lowered in response to any factor undermining overall brain integrity, but seem especially sensitive to problems in the right parietal lobe (Lezak, 1995). It is included here for convergent validity.

Picture Arrangement. In Picture Arrangement, the examinee is asked to put a series of cards, depicting social scenes, in the order that portrays a coherent story. The Picture Arrangement subtest has been reported to have relatively high correlation with the Category

Test (Lansdell & Donnelly, 1977). It requires being able to consider several visual stimuli simultaneously and to assemble separate events according to a greater thematic principle; it is primarily a nonverbal reasoning test which may be viewed as a measure of planning ability (Sattler, 1992). Picture Arrangement has been shown to involve bilateral cortical activation, and patients with frontal lobe damage complete test items impulsively and with insufficient processing (Lezak, 1995). It was included as a measure of convergent validity.

Arithmetic. The Arithmetic subtest requires that children be able to solve word problems in their head. This mental arithmetic does not allow the use of paper and pencil, as opposed to the mechanical arithmetic of the WRAT-R. A variety of mathematical concepts are assessed, and items become progressively more difficult. Each item requires that the examinee pay careful attention to the examiner, as no paper or pencils are provided. Rather than being a pure measure of arithmetic capability, this subtest requires good attention, concentration and verbal reasoning (Lezak, 1995; Sattler, 1992). Low correlations with the Category Test are reported (Lansdell & Donnelly, 1977), and it was included to examine divergent validity.

Vocabulary. For the Vocabulary subtest, examinees must provide adequate definitions of English words, which increase in difficulty as the test progresses. Vocabulary has high correlations with overall intelligence (Sattler, 1992), but poor correlation with the Category Test (Lansdell & Donnelly, 1977), indicating that the Category Test is likely to measure cognitive skills that are more specific than just general ability. Vocabulary was included as an indicator of divergent validity.

Wide Range Achievement Test -Revised (WRAT-R). The WRAT-R is a brief, individually administered achievement test containing three subtests: Reading, Spelling, and Arithmetic. The reading subtest measures the ability to recognize and name letters, and to correctly pronounce words. The spelling subtest measures the ability to write letters, write one's name and correctly spell words. The Arithmetic subtest measures skills such as counting, reading numbers, and solving oral problems, but is mostly concerned with completing written computations (Sattler, 1992). The presence of discrepancies between WRAT-R achievement and WISC-R tests was used to define the groups utilized in this study, and variations in performance on the WRAT-R were originally used by Rourke (Rourke & Finlayson, 1978) to describe children with learning disability subtypes. Although the WRAT-R and the ICT have never been directly compared, it is included here for convergent validity because children with arithmetic disability subtypes are expected to perform poorly on the ICT.

Wide Range Assessment of Memory and Learning (WRAML). The WRAML is designed to assess memory and learning in children. The test is composed of several subtests, which form the indices of Verbal Memory, Visual Memory, and Learning, in addition to an overall General Memory score. Several aspects of the WRAML are of particular theoretical interest in a sample of children with arithmetic learning disabilities. The Visual Memory Index may be useful to test certain theories that hypothesize arithmetic difficulties as resulting from an inability to retrieve arithmetic facts from semantic memory. The tests in this index assess visual memory broadly, including visuospatial processing and attention to details (Lezak, 1995; Sattler, 1992; Spreen & Strauss, 1998a), and the Index

Score is included here for convergent validity. From the Learning Index, the Visual Learning subtest requires the subject to remember where visual patterns are “hidden” on a grid. Each pattern on the grid is revealed to the examinee once and then covered; the examinee is then asked to remember where each specific pattern was located. When the examinee makes a mistake and does not correctly remember where on the grid the visual stimulus was located, he/she is corrected. In this way, over several trials, the examinee is given the opportunity to learn the placement of each pattern. In this sense, the Visual Learning subtest is a suitable comparison to the ICT, in that it requires nonverbal, visuospatial memory and the ability to correct decisions according to feedback from the examiner. It also is included here primarily as a comparison measure for convergent validity.

Wisconsin Card Sort Test (WCST). The WCST is often referred to as “the gold standard” of tests of executive function, and performance on this measure has been robustly linked to the integrity of the frontal lobes of the brain. The test requires that subjects match a series of cards according to one of three principles. The principle is changed once it has been successfully grasped by the examinee. In this way the examinee is required to switch between several different strategies for correctly matching cards, and is expected to adjust his/her strategy based on verbal feedback from the test administrator. Although the test is conceptually similar to the Category Test in that it requires grasping a larger principle in order to correctly classify visual stimuli (Lezak, 1995; Spreen & Strauss, 1998a), performance on the WCST does not often correlate with performance on the Category Test, and the two tests do not likely measure the same thing (Bond & Buchtel, 1984; Brandon & Chavez, 1985; Donders & Kirsch, 1991; Franzen, Smith, Paul, & MacInnes, 1993). As such, the inclusion of the WCST here is as a measure of divergent validity. Despite the empirical differences, and perhaps because the WCST and the Category Test are so conceptually similar, almost every analysis of the Category Test has compared it to the WCST.

Kaufman Achievement Battery for Children (K-ABC). The K-ABC is a measure of intelligence and achievement designed to be administered to children in school and clinical settings. The test is composed of 16 subtests, but because different subtests are administered depending on the child's age, a maximum of 13 subtests is given during an administration. From this test, the Matrix Analogies subtest was selected for comparison to the ICT. Matrix Analogies requires the selection of a picture or design that best completes a visual scene or pattern, and is very similar to Raven's Progressive Matrices (Spreen & Strauss, 1998a); it is a nonverbal measure in that the examiner conveys instructions through gestures and the child responds with movements (Sattler, 1992). The idea was later successfully incorporated into the Wechsler tests as Matrix Reasoning, but was never a part of the WISC-R. The Matrix Analogies subtest of the K-ABC and the ICT both require visuospatial reasoning and pattern analysis, and Matrix Analogies is included here as a likely indicator of convergent validity.

Trail Making Test (TMT). The TMT is a paper and pencil test with two forms, A and B. On part A, numbered dots are scattered on the paper, and the examinee must connect the numbers in order, as quickly as he/she can. Like Digit Span, Part A measures attention (primarily) that requires an appreciation of the symbolic significance of numbers and letters (Spreen & Strauss, 1998a). It is also influenced by visuo-perceptual abilities. On part B, numbers and letters are scattered on the form, and the examinee must connect numbers and letters, in serial order, in order to complete the test. As such, TMT-B is a measure of visuo-perceptual processing and mental flexibility. The total time needed to complete the test (in seconds) is used as the score. Slowed processing speed is often evident on TMT-B when brain functions are compromised, regardless of the location (Lezak, 1995). Along with the Intermediate Category Test, forms A and B of the TMT are traditionally included as part of the Halstead-Reitan Neuropsychological Test Battery for Older Children. The TMT-B has been shown to have moderate correlation with the Category Test in patients with schizophrenia and brain damage (Allen et al., 1999). However, given its sensitivity to many forms of brain insults and abnormalities, it is included here to help establish divergent validity.

All data analyses were performed with SPSS 12.0 for Windows unless otherwise indicated. Statistical significance was set at the level of $p = .05$.

Data Screening and Analysis

Data Screening

Age, education and IQ – especially PIQ—have been found to have significant influence on Category Test performance, in adults and children (Cullum et al., 1984; Donders & Strom, 1995; Johnstone et al., 1997; Lansdell & Donnelly, 1977). An analysis of covariance (ANCOVA) was performed to determine the effect of diagnostic group on the ICT while holding constant the variables of age, education and PIQ. The ANCOVA model included two between group factors (group and gender), ICT was chosen as the dependent variable, and PIQ and age-in-months were used as covariates. Education was not examined in the same analysis as age, because age and education are highly related (r [79] = .876, p <.001); rather, separate analyses were performed with each of these variables. Independent samples t tests were used to determine if diagnostic groups differ in age, education, and PIQ. Age and PIQ were expected to be similar for both diagnostic groups because of the restrictions on how the sample was selected. Likewise, an impact of gender on ICT scores between the diagnostic groups was not expected, because gender differences from this sample were not previously observed on the tests included in this study (Nyberg, Silver, Ring, & Black, 2003). The results of the screening analysis are presented in the Results section.

Hypothesis 1

To determine whether subtests I and II contribute significantly to the total variance within the ICT, the variance contributed by subtests I and II was compared to III, IV, V and VI using a variance test and by inspection of the proportion of the total variability that subtests I+II contribute to the whole test. The variability in the sum of the raw scores from subtests I and II (I+II) was compared to the variability of the sum of the raw scores from the remaining subtests (III+IV+V+VI) by means of a t test for equality of variances in dependent samples (Kirk, 1990). A proportion of variability was inspected as the sum of the variability in (I+II) divided by the sum of the variability in the entire test, with the expectation that this would be small (< 5%). Finally, a similar variance test compared the variance in (I+II) to each of the other subtests individually.

Hypothesis 2

Confirmatory Factor Analysis (CFA) was performed to confirm the factor structures reported in the literature. If subtests I and II were retained, a three factor model (Figure 1) was proposed to test subtests I and II as a factor, III and VI as a factor and IV and V as a factor. If subtests I and II were not retained, a two factor model (Figure 2) would be tested. The null hypothesis was a one factor model (Figure 3), representing a single homogeneous factor as adequately accounting for performance on the Intermediate Category Test. A CFA that would simultaneously assess the model fit in both diagnostic groups was preferred, providing that there were enough subjects in each diagnostic group to perform the analysis. If simultaneous CFA of both diagnostic groups could not be performed, equivalent factor structures would become a basic assumption for this study. Two models were planned, one with correlated factors (as shown in Figure 2) and the other with uncorrelated factors: if major differences between the factor structures were not observed, the most simple solution (uncorrelated factor structure) would be presented.

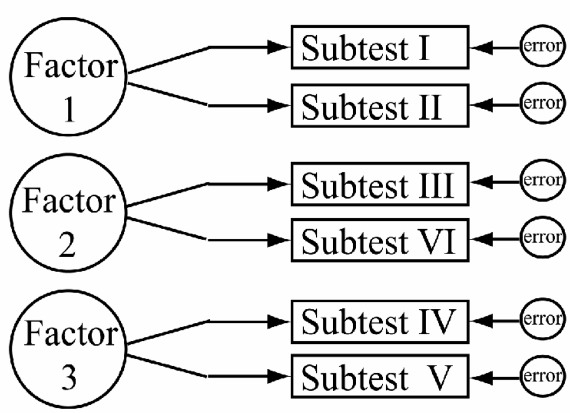


Figure 1. Three factor model of the Intermediate Category Test.

CFA in this small sample may not adequately assess the relationships among the variables as proposed by the model. To anticipate this problem, exploratory factor analyses were planned to examine the factor patterns that emerged from the data, and compare these to the hypothetical model. Exploratory factor analyses would be conducted on the entire sample, as well as for each diagnostic group separately, to examine the factor relationships among the subtests.

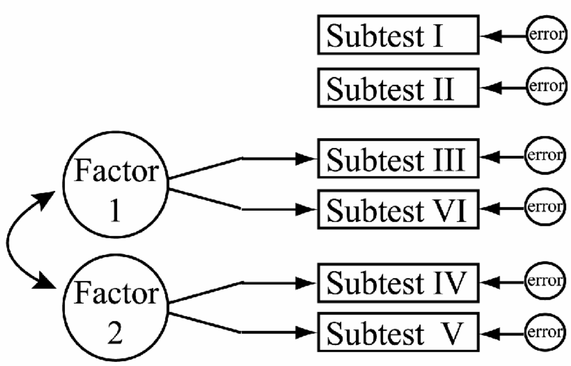


Figure 2. Two factor model of the Intermediate Category Test.

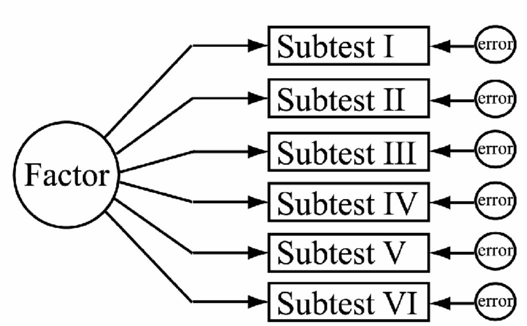


Figure 3. Traditional single factor model of the Intermediate Category Test.

Hypothesis 3

To examine the convergent and discriminant validity of the resultant factors for the entire sample, a correlation matrix was generated, comparing other cognitive measures from the test battery to the factors derived from the ICT. The measures of interest are described in more detail in Appendix B. It was expected that the ICT would predominantly demonstrate significant relationships with the WISC-R PIQ, FSIQ, block design and picture arrangement subtests, WCST perseverative responses, K-ABC Matrix Analogies and WRAML Visual Index score, as these are measures of general nonverbal ability, visuospatial processing, perceptual organization, and nonverbal abstract reasoning and planning. All cognitive measures were also correlated with individual ICT subtests (I, II, III, IV, V, VI), to examine the pattern of these correlations compared to the correlations with the established factor structure. The cognitive measures were expected to have greater correlations with the factor structure than with Total Score, demonstrating that one subtest does not overly influence the characteristics of a given factor.

Hypothesis 4

In order to examine the correlations in each diagnostic group separately, the correlation matrix described above was created for each diagnostic group. Between group differences existing in the correlations of ICT factors with other cognitive measures were examined with a two sample correlation test (Cohen & Cohen, 1983).

CHAPTER III: RESULTS

The purpose of this study was two-fold. First, it was to refine interpretation of the Intermediate Category Test; using a group of children with an arithmetic learning disability, a child's performance might be better understood using subtest scores instead of a single total score. Secondly, the construct validity of the factor structure in a clinical population is examined, with the aim of better understanding what the various components of the test are really measuring. It was further proposed that elaboration of the constructs measured by the ICT would reveal differences in reasoning between children with isolated arithmetic learning disability and children with a learning disability characterized by combined arithmetic and verbal learning disability. The data were analyzed through a sequence of statistical and analytic procedures. The findings from the data analysis will be discussed in detail, and each hypothesis will be examined in light of the findings.

Description of the Sample

Archival data were used for this study; the data were originally collected over a period of 15 months in 1991-1992 at a local hospital for children, in a clinic specializing in learning disabilities. Eighty-one (81) children with arithmetic learning disability participated in the study: 26 with isolated arithmetic learning disability and 55 with a combined-type arithmetic and verbal learning disability. Children were between the ages of 9 and 14; the mean age was 139.77 months (11.65 years). Most subjects were male (72.8%), Caucasian (90.1%), and right-handed (82.7%). Children ranged from grades 3-8, with most (90.2%) in grades 4-7. Demographic characteristics for the entire sample and each group are presented in Table 1, and a summary of the performance of each diagnostic group on the ICT and other tests in the battery are presented in Table 2 (Appendix C).

Results

The results of the statistical analysis from the study are presented in five parts. First, group and gender differences on the raw ICT total score are examined with the covariates age, education, and PIQ. Second, an analysis of the relative raw score contributions of subtests I and II, in comparison to the other ICT subtests, is presented. Third, a factor analysis of the subscales of the Intermediate Category Test is performed. Fourth, the factors for the model are examined for convergent and divergent validity in the context of other neurocognitive measures. Finally, once the construct validity of the ICT is examined, differences in performance between the diagnostic groups are summarized.

Screening

In order to examine the effects of variables known to have a significant influence on raw ICT total score, a preliminary analysis of covariance (ANCOVA) was conducted. Gender (male/female), and diagnostic group (isolated arithmetic / arithmetic+verbal), were the between groups factors and PIQ, age (in months), and education were used as covariates. Two different ANCOVA models were fit to these data because age and education are highly related ($\underline{r}$ [79] = .876, $\underline{p}$ <.001).

In the ANCOVA with the covariate age, the homogeneity of variance assumption was not significant, indicating that the error variance in the ICT Total score did not differ significantly across groups. Group differences in gender were not observed. Contrary to expectations, both covariates PIQ and age were significant (F [1, 74] = 7.10, p = .004 and F [1, 74] = 8.60, p = .004, respectively). In addition, after correcting for PIQ and age, the effect for diagnostic group was significant (F [1, 74] = 4.99, p = .029) (Table 3). The covariate adjusted mean ICT total scores for the isolated arithmetic and combined arithmetic+verbal groups were 33.51 (SD = 15.60) and 42.76 errors (SD = 18.83), respectively.

To further examine the significant main effects for diagnostic group, t tests comparing the two diagnostic groups on age and PIQ were performed (Table 4). Low scores indicate fewer errors on the test. The mean PIQ for both groups is within the average range, and between group differences in PIQ were not significant. Age was significantly different for the two groups, with the lower scoring isolated arithmetic group approximately nine months older than the higher scoring combined-type arithmetic and verbal LD group.

A second ANCOVA was performed using years of education as a covariate instead of age, and similar group differences for ICT total score were found (F [1, 74] = 5.35, p = .024). A t test reflected a significant difference of approximately one academic year: children in the isolated arithmetic group average a 6^{th} grade education level, whereas children in the combined-type group average only a 5^{th} grade education level (Table 4). Again, no group differences in gender were observed. A third ANCOVA was performed using the log10 of ICT total score as a dependent variable. Although this analysis shows the main effect for diagnostic group as non-significant (F [1, 74] = 2.64, p = .11), the significant effects of covariates age and PIQ persisted.

Because between group differences existed for the raw ICT total score, age adjusted transformations were performed. ICT total scores were converted to T scores, based on the normative values provided by Knights and Norwood (1980). The means and standard deviations used for the transformation to T scores are presented in Table 5. When T scores were analyzed using an ANCOVA model, the covariates age and PIQ were non-significant; a second ANCOVA model with covariates education and PIQ showed that education effects were also non-significant. The result of a t test performed on the transformed scores showed that diagnostic groups are not significantly different (Table 6). Mean ICT total score T scores for the isolated arithmetic and combined arithmetic+verbal groups were 47.37 (SD = 10.13) and 45.84 (SD = 10.50), respectively.

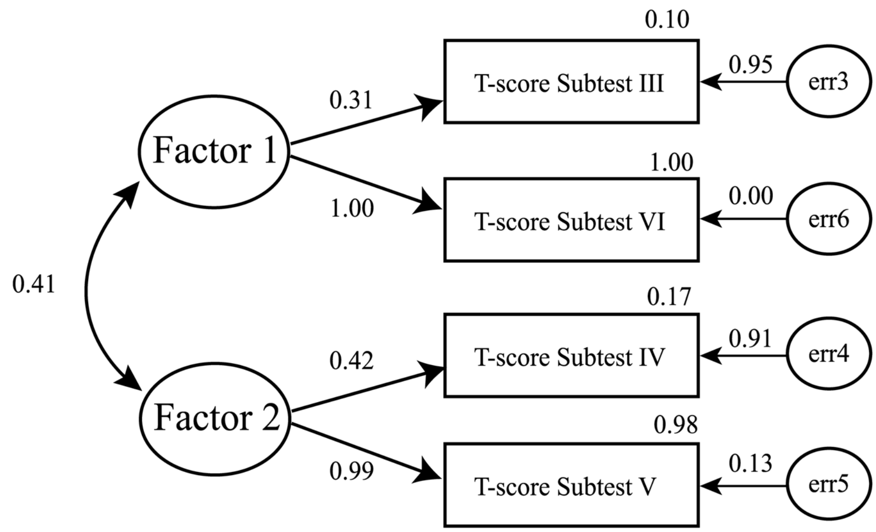
Hypothesis 1

To examine whether scores on subtests I and II contribute significantly to the overall variance in the test, the variability of raw scores from subtests I and II combined (I+II) was compared to the variability of other subtests (III+IV+V+VI) and the total variability of the ICT. Given the prescreening results, comparing the variability of the scores after adjusting for age was considered, however, when transforming raw scores to T scores, a small standard deviation in the conversion formula can magnify slight differences in the raw scores. As shown in Table 5, the standard deviations for subtests I and II are less than one (1.0) in all age ranges for the normative scores. Raw scores were used for the purpose of testing variances. The results, provided in Table 7, are as follows: The variability of (I+II) compared to the entire test was found to be very small (0.56%), and the equality of variance test (Kirk, 1990) was used to compare the variance in (I+II) to the variance in all other subtests. The variance for subtests (I+II) was significantly smaller than all other variances. This same result also was found for each diagnostic group separately. Overall, these results suggest that subtests I and II do not contribute significantly to the variability in performance on the Intermediate Category Test, and these subtests are excluded from further analysis.

<u>Hypothesis 2</u>

With the exclusion of subtests I and II, a two-factor model would be expected to account for performance on the ICT. Using AMOS 4.0, a two-factor confirmatory factor analysis (CFA) was performed using ICT T scores with one factor consisting of subtests III and VI, another factor consisting of subtests IV and V, and allowing these two factors to be correlated. A minimum of 200 subjects is generally recommended when performing maximum likelihood CFA (Bryant & Yarnold, 1995). A 20:1 ratio of subjects to variables is another commonly used benchmark.

The present CFA was within the recommended subject-to-variable ratio (81:4) but not the benchmark of 200 subjects. The results are shown in Figure 4. The fit of the data to this model was assessed using chi-square (χ^2), goodness of fit index (GFI) and adjusted goodness of fit index (AGFI). Chi-square tests the hypothesis that an unconstrained model (variables are related randomly) fits the covariance matrix as well as the proposed model, and should not be significant if there is a good model fit. The use of χ^2 as a measure of how well the theoretical model fits the data is known to be problematic, as it assumes that the model holds for the population (Byrne, 2001). χ^2 tends to be large when the model does not hold exactly or when the sample size is reasonably large. Other indications of model fit were examined, including the goodness of fit index (GFI), and adjusted goodness of fit index (AGFI).



$\chi 2$	df	p	GFI	AGFI
4.657	1	0.031	0.973	0.725

Figure 4. Results of confirmatory factor analysis of the Intermediate Category Test using AMOS 4.0.

GFI is a measure of the relative amount of variance and covariance in the sample that is jointly explained by the population, and is always a value between zero (0) and one (1), where unity indicates a perfect fit. AGFI takes into account the degrees of freedom available for testing the model and addresses the issue of parsimony by incorporating a penalty for the inclusion of additional parameters (Byrne, 2001); like GFI, AGFI is bounded by one as a perfect fit, but does not have a lower bound of zero; however, AGFI less than zero is associated with models with extremely poor fit. Both GFI and AGFI are overly influenced by small sample size and represent information akin to R^2 and adjusted R^2, respectively.

The fit of the data to the analyzed model was poor based upon χ^2 (χ^2 [1] = 4.657; p = .031). In contrast, GFI = .973, which represents a good fit (Byrne, 2001), and AGFI = .725.

In summary, goodness of fit indices for the CFA indicate that the proposed two-factor model fits the data for this sample well, but a significant χ^2 indicates the possibility that the model may not fit well for other samples from this population.

Because confirmatory factor analysis was unable to definitively confirm a two factor structure, even though the model appeared to fit the data relatively well in this sample of children with arithmetic learning disability, exploratory factor analyses were conducted (Table 8 and Figure 5) to further explore the appropriateness of the model. Both orthogonal (Varimax) and oblique (Promax) rotations were performed. Since the results were similar for both rotation methods and the correlation of factors was small (maximum r = 0.15), the Varimax solution will be presented.

The adequacy of the data was evaluated on the basis of the results of a Kaiser-Meyer-Olkin (KMO) sampling adequacy test and Bartlett's test of sphericity (homogeneity of variance). KMO is a ratio of the observed correlation coefficients to the sum of the observed correlation coefficients and the partial correlation coefficients. It is used to evaluate whether the relationship between variables is truly reflective of an underlying process. The value approaches one (1) if partial correlations are small, that is if an overarching factor accounts for most of

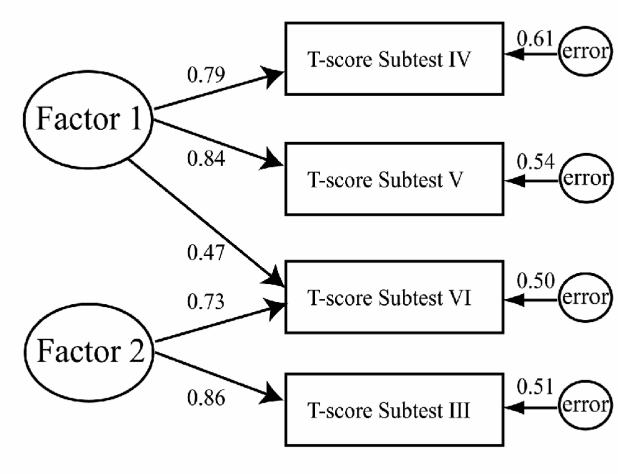


Figure 5. Results of Exploratory Factor Analysis of the Intermediate Category Test.

the observed variance. Bartlett's test of sphericity is used to test that variables in the matrix are uncorrelated, an undesirable result.

The KMO measure of sampling adequacy (.502) and Bartlett's test of sphericity (χ^2 = 40.816, df = 6, p <.01) indicated that, although there were strong relationships between variables in the correlation matrix, there was also a substantial amount of statistical "noise," and factors derived from EFA might not account for all the observed variance. For simple structure of the factor solution, no more than three factors were expected. A principle components factor analysis using Pearson correlations was fit to the data, with the number of factors determined by setting eigenvalues greater than or equal to one (1.0) and performing an orthogonal (Varimax) rotation. Based on the selection criteria, a two factor solution captured a majority of the variance (72.76%). The first factor explained 41.86% of the variance, while the second factor explained 30.90% of the variance. This result provides evidence for the existence of two factors. Subtests IV and V had higher factor loadings on the first factor than on the second. In contrast, subtests III and VI had higher factor loadings on the second factor than on the first factor. Interestingly, although subtest VI most strongly relates to the second factor, there is evidence of moderate loading on the first factor as well.

Based upon the preliminary findings of significant differences in ICT raw error score between diagnostic groups, exploratory factor analysis on the ICT T scores of each diagnostic group was also conducted, even though sample sizes were small. These results are presented in Tables 9 and10, and Figures 6 and 7**.** Results indicate a different factor structure for each diagnostic group. For the group of children with an isolated arithmetic disability, KMO = .463, and Bartlett's test was significant (χ^2 = 60.79, df = 6, p = <.01), indicating an adequate degree of correlation among the variables. Using the criteria of eigenvalue ≥ 1, there were two factors that captured a majority of the variance (92.07%). The first rotated factor (IV and V) explained 52.18% of the variance, while the second factor (III and VI) explained 39.89% of the variance. For the group of children with combined-type arithmetic and verbal LD, KMO = .52 and Bartlett's test was significant (χ^2 = 14.78, df = 6, $\underline{p}$ = .022). Two factors captured a majority of the variance (66.62%). The first rotated factor (V and VI) explained 36.88% of the variance, while the second rotated factor (III and IV) explained 28.62% of the variance.

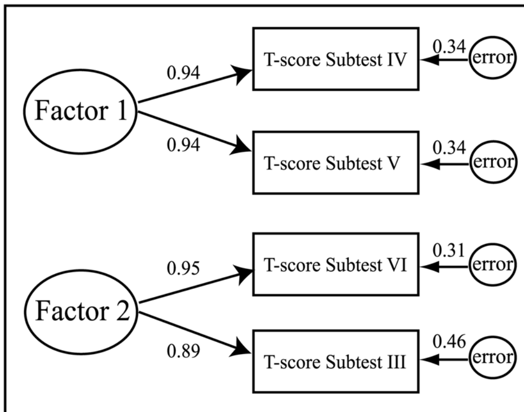


Figure 6. Results of Exploratory Factor Analysis of the Intermediate Category Test T-scores, Isolated Arithmetic group.

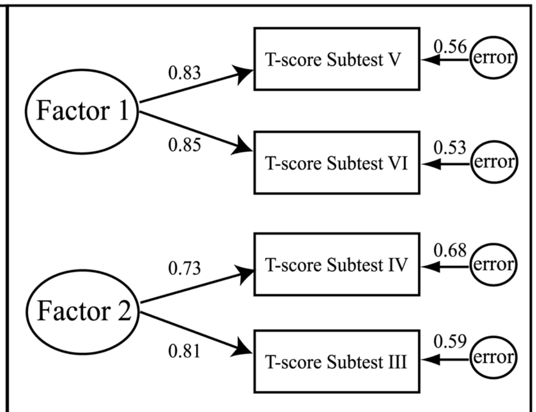


Figure 7. Results of Exploratory Factor Analysis of the Intermediate Category Test T-scores, Arithmetic+Verbal group.

To summarize, the small sample size was a problem for both the confirmatory analyses and the exploratory factor analyses. In EFA, a two-factor model accounted for 72.76% of the variance, but separate factor analyses for each diagnostic group show that the groups do not have comparable factor structures. For children with isolated arithmetic disability, the two factors consisted of subtests IV and V (Factor 1) and subtests III and VI (Factor 2). In contrast, for children with combined arithmetic and verbal disabilities, the two factors consist of subtests V and VI (Factor 1), and subtests III and IV (Factor 2).

Hypotheses 3 & 4

"Factors are interpreted by the variables that correlate with them" (Tabachnick & Fidell, 1996, p. 638). It was expected that the ICT would predominantly demonstrate significant relationships with measures of general nonverbal ability, nonverbal abstract reasoning and planning, and perhaps also with measures of visuospatial processing and perceptual organization. To examine pairwise relationships between variables, Pearson product moment correlations were performed. Confirmatory and exploratory factor analyses indicated a two-factor solution for subtests III through VI, but because arithmetic disability subgroups did not have equivalent factor structures, it was not appropriate to examine the relationship between cognitive measures and factor structure for the entire group. Rather, for each participant, ICT factor scores were determined based on the final two-factor solution for each diagnostic group separately, and correlated with ICT subtest and total score T scores, and the cognitive measures previously described.

The complete correlation matrix for each group is provided in Tables 11 and 12. For children with an isolated arithmetic disability, the primary factor is IV/V and is significantly correlated with none of the other cognitive measures. The secondary factor, III/VI, is correlated with the Wisconsin Card Sorting Test (WCST) perseverations. There is also a trend linking factor III/VI and the K-ABC Matrix Analogies test (the correlation is higher than with the WCST), but the correlation was not significant because of missing data (n = 17).

For the group of children with a combined type arithmetic and verbal disability, the primary factor is V/VI, which correlates significantly with the WRAT-R Arithmetic subtest.

Factor III/IV was secondary, and correlated with no other cognitive measures. There was a trend correlating Factor III/IV with the K-ABC Matrix Analogies subtest ($p = .051$), as well as with the WISC-R Picture Arrangement subtest ($p = .058$), although these relationships were non-significant because of missing data ($n = 48$ and $n = 49$, respectively).

Summary

Data were collected from 81 children with arithmetic disabilities residing in the Dallas/Fort Worth Metroplex. The mean age of the subjects was 139.77 months (11.65 years). Most subjects were male (72.8%), Caucasian (90.1%), and in grades 3-8. The children were divided into two groups based on their learning disorder diagnosis, classifying 26 as having an isolated arithmetic disorder and 55 as having a combined-type arithmetic and verbal learning disorder. The diagnostic groups exhibited significant differences in their overall performance on the Intermediate Category Test, with children in the isolated arithmetic group outperforming children in the combined-type group, even when the covariates of age and PIQ (or education and PIQ) were included in the models. Age and education were significantly different between groups, as the isolated arithmetic group were significantly older by 9 months and also typically one school year more advanced than children in the combined arithmetic and verbal group. When ICT scores were age adjusted, using score norms, all effects in the ANCOVA model were non-significant. The t test result comparing diagnostic groups was also non-significant.

Significant differences were found between the variance of children's performance on subtests I and II of the ICT, and the variance of performance on the remainder of the test. The variance for subtests I and II was relatively small in comparison to combined variances for subtests III-VI. In addition, variance for subtests I and II was relatively small when compared to each of the other subtests individually. Because proportion of variance contributed to the ICT total score by subtests I and II was smaller than 1%, subtests I and II were excluded from further analyses.

A confirmatory factor analysis of the age-adjusted scores from the four remaining subtests of the ICT was unable to confirm the modeled two-factor structure; the sample size was too small to conduct a maximum likelihood analysis. Exploratory factor analysis supported a two-factor solution, although the factor structure was different for each diagnostic group. The two factors derived from the performance of children with an isolated arithmetic disability were composed of subtests III and VI (Factor 1) and subtests IV, V and VI (Factor 2). In contrast, the two factors derived from the performance of children with combined-type arithmetic and verbal disability were composed of subtests V and VI (Factor 1) and subtests III and IV (Factor 2).

Pearson product-moment correlations between the EFA factors and other cognitive measures were performed to establish the construct validity of the factors for each diagnostic group. For children with an isolated arithmetic disability, Factor IV/V did not relate to any of the chosen cognitive measures, and Factor III/VI was significantly related to WCST perseverations and was also highly correlated with K-ABC matrix analogies. For children with combined arithmetic and verbal disability, Factor V/VI was related to WRAT-R Arithmetic, and Factor III/IV approached significant correlation with K-ABC Matrix Analogies.

CHAPTER IV: DISCUSSION

The lack of an adequate understanding of what the Category Test really measures prompted interest in examining the factor structure of the test in a well defined sample. This initiated the primary aim of the study, to confirm a two- or three-factor structure for the Intermediate Category Test in a sample of children with arithmetic learning disability. Furthermore, the current study aimed to use the Category Test as an instrument for the description and clarification of two types of arithmetic learning disorder: *isolated* arithmetic disorder, which is an impairment of academic achievement in mathematics, and *combined-type* arithmetic and verbal learning disorder, which is an impairment of achievement in mathematics simultaneous with impaired academic performance in reading or spelling. The process of validating the Category Test in this sample helps to illustrate the different kinds of mental processing that are demanded by the test, as well as highlight the cognitive differences between groups of children with seemingly related learning disorders. The demonstrated utility of using the Category Test in this sample will hopefully pave the way for similar studies in other samples, resulting in increased use and renewed interest in the Category Test as a distinctive measure of cognitive functioning. Furthermore, an understanding of the clinical properties of the test will evolve as it is tested across clinical populations, resulting in increased awareness of the cognitive strengths and weaknesses of compromised or at-risk patient groups and in more effective interventions, treatment planning and patient care.

Order of Presentation

A discussion of findings follows, beginning with the implications of initial data screening and progressing through Hypothesis 1-4 sequentially. Hypotheses 3 and 4 are included together because of the similarity of their aims and methods. Consideration of study limitations and concluding comments end the section.

Discussion of Findings

Data Screening

Although the study centered upon factor analysis, there was an effort to ensure that results of the factor analysis would reflect on the properties of the Intermediate Category Test and not be complicated by interactions with other variables. In particular, it has been reported in the literature that age, education, as well as overall intellectual abilities (particularly non-verbal ability, PIQ) may exert a strong influence on an individual's performance on the ICT. These variables were tested for differences between the diagnostic groups by means of ANCOVA. Results indicated differences between the diagnostic groups for the variables of PIQ, age and education, as well as significant differences between diagnostic groups for overall ICT performance. The finding that the group of children with isolated arithmetic learning disorder performed better on the ICT than children with combined-type arithmetic and verbal learning disorder was not outside of expectation (Fletcher et al., 2003), and was consistent with the hypothesis that differences between the two diagnostic groups would be revealed. However, the possibility that this difference could be confounded with differences in PIQ, age and education was concerning. Follow up examination of the PIQ results indicated that the observed differences were statistically, but not clinically, significant. On average, the group of children with better ICT performance (the isolated arithmetic group) had a PIQ that was three (3) points lower than the PIQ of children from the other diagnostic group, although both groups were securely within the average range. The finding of an age difference between the diagnostic groups is of greater gravity. The mean age of the isolated arithmetic group was approximately 12 years of age, whereas the mean age for the combined-type arithmetic and verbal group was approximately 11 years of age. This age difference represented a difference of one academic year. It must therefore be noted that although children with isolated arithmetic disability outperformed children with combined arithmetic and verbal disability, the isolated arithmetic children were older and had more education.

Because of the observed age and education effects on the ICT total score, raw scores were converted to T scores according to the normative information provided by Knights & Norwood (1980) for the Halstead-Reitan Neuropsychological Battery for Children. When the age-adjusted performance of the sample was examined, there were no differences in overall ICT performance between the two diagnostic subgroups.

It is tempting to speculate that differences in diagnosis might themselves exist as a function of age. Perhaps combined-type arithmetic and verbal learning disorder represents an earlier, less-differentiated problem in which verbal abilities take extra time to develop but eventually “catch up,” resulting in isolated arithmetic learning disability? Based on the observation that neuropsychological deficits in learning disorders tend to become worse over time, one cross-sectional study verified that older children with nonverbal learning disability showed significantly greater levels of impairment (relative to age-based norms) than did younger children with the same diagnosis (Casey, Rourke, & Picard, 1991). These results serve as evidence that older children with nonverbal learning disability (of which arithmetic learning disabilities without verbal learning disabilities is a hallmark characteristic) are likely to perform relatively worse than their younger counterparts. All the children in the current study were originally chosen as part of a longitudinal study of the stability of arithmetic disorder diagnoses – that of Silver et al (1999). The results from that study indicated that the more complex disabilities, that is those that affected the most systems, were the most temporally stable (as compared to the more simple diagnostic variations). In other words, it was not likely that a child with combined-type arithmetic and verbal learning disability would shed their verbal difficulties over time, whereas the diagnosis of isolated learning disability was less stable over time. The convergence of these research studies indicates that the results of the current study (that older children with isolated arithmetic learning disability performed better than younger children with a combined-type learning disability) are not consistent with what had been previously described in the literature. Fortunately, using available normative data to age-adjust ICT raw scores alleviated this problem.

Hypothesis 1

In order to confirm a factor model for the ICT in a sample of children with learning disabilities, it was first necessary to know which model to confirm. Although use of the Total Score (a one-factor model) has been rejected as not adequately representing a child's performance on the test, both two- and three-factor models have been presented in the literature (Allen et al., 1999; Donders & Strom, 1995; Fischer & Dean, 1990; Johnstone et al., 1997; Kelly et al., 1992; Livingston et al., 1996). Specifically, three factors have been reported in heterogeneous learning disorders, learning disorders mixed with emotional disturbances, schizophrenia and brain damage, whereas two factors have been reported in mild traumatic brain injuries. The two-factor model reported is very similar to the three-factor model, except in the two-factor model subtests I and II are not included because they do not contribute a degree of variance that is useful for statistical comparisons. The variance to be found in subtests I and II were specifically examined as a part of this study. For this portion of the study only, raw scores were used instead of age adjusted scores, because the very small standard deviations in the normative data magnified what, in actuality, were very small differences between scores on subtests I and II. Results indicated that the variance in subtests I and II contributed very little to the variance in the test overall. Rather, the remainder of the subtests (III, IV, V and VI) accounted for the vast majority of variance in the ICT. Furthermore, the variance to be found in subtests I and II was significantly less than the variance found in any of the remaining subtests, i.e., subtests I and II contributed significantly less to overall performance than did subtest III, IV, V, or VI. These results offered substantial evidence that subtests I and II were contributing very little to childrens' overall performance on the ICT, and so it was decided to eliminate these subtests from the remainder of the statistical analyses.

The researchers who have previously reported a three-factor structure for the ICT do not report on the amount of variance contributed by each subtest, so it is impossible to tell whether this was taken into account. Differences in sample populations might explain the discrepancy in findings; previous studies have tended to utilize heterogeneous samples, whereas the present study focuses on homogeneous learning disorder groups that exhibited a restricted range of performance on this portion of the test. Regardless, in this sample of children, it appears that the lack of variance in subtests I and II is due to a ceiling effect; very few errors were made on this portion of the ICT, indicating the ease with which children are able to complete these items.

Hypothesis 2

Once subtests I and II had been rejected as sources of statistical variance, an attempt was made to confirm a two-factor model for the ICT in this sample, using confirmatory factor analysis (CFA) of ICT subtest T scores. Results from the attempted CFA indicate that the sample size was too small for the model to adequately account for the variance in the data. Although the CFA was unable to confirm model fit, the goodness of fit indices did seem to indicate that the model fit the data relatively well for the sample, if not other samples from the same population. In order to follow up on these promising results, exploratory factor analyses (EFAs) were conducted. Principal components EFA indicated a two-factor solution, accounting for 72.76% of the variance in the data. The subtests loading on factors 1 and 2 in the EFA were very similar to the model tested in the CFA; Factor 1 consisted of subtests IV and V, and Factor 2 of subtests III and VI. The only difference was that, although subtest VI loaded most strongly on Factor 1, it also loaded moderately on Factor 2. This result has been reported elsewhere in the literature (Allen et al., 1999) and makes sense, as subtest VI is a "memory" subtest composed of items from *both* factors 1 and 2.

However, it soon became apparent that this factor structure, which was obtained by looking at all children in the sample, was not representative of the true factor structure of the ICT for children belonging to either diagnostic group. When diagnostic groups were considered separately, each yielded a different two-factor solution to ICT subtest performance. Specifically, EFA of the subtest T scores from the isolated arithmetic disability group found a primary factor composed of subtests IV and V, and a secondary factor composed of subtests III and VI, whereas EFA of the subtest T scores from the arithmetic and verbal disability group found a primary factor composed of subtests V and VI and a secondary factor composed of subtests III and IV. That is, factor structures for the two diagnostic groups were different.

This finding helps to clarify the results of the CFA. The two factor model that was specified called for one factor composed of subtests III and VI, and one factor composed of subtests IV and V. The results of EFA make evident the fact that this factor structure is only found in the children with an isolated arithmetic learning disability, a group which only constituted approximately 1/3 of the total sample. Although a two factor structure was maintained by the arithmetic and verbal learning disability combined group, the factor structure was different from the hypothesized model.

Finding different factor structures on the ICT for two diagnostic subgroups underscores the importance careful sample selection for factor analytic studies, especially when an attempt is made to interpret the meaning of the resultant factors. This is not the first study to subject the ICT to factor analysis. Donders and Strom (1995) used a sample composed of children suffering from closed head injuries, caused by a variety of different types of impact. Perhaps it was because of their awareness of the heterogeneity of the sample that the authors did not feel comfortable naming the two factors that they obtained in that study. However, Livingston, Gray and Haak (1996) interpreted their three factor solution to the ICT in a sample of behaviorally disordered children, even though only 63% had been diagnosed with a learning disorder. Similarly, Kelly, Kundert and Dean (1992) interpreted a three factor structure for the ICT in a sample of children with learning disabilities, even though Rourke had been questioning the homogeneity of the broad learning disabled diagnosis since 1978. The heterogeneity of the samples in these studies makes interpretation of the results risky at best. If portions of the sample suffer from one disability, and other portions from another disability, how does the factor structure from the pooled sample relate to the performance of any individual child?

The current study hoped to sidestep this problem by focusing only on a single diagnostic subgroup of learning disabilities, arithmetic learning disability. However, as reflected in the differing factor structures, even this group is not homogeneous with regard to their cognitive abilities. Specifically, when the sample was divided into two groups based on the presence or absence of a verbal disability, the factor structure of the ICT was shown to be different between the two groups.

Even given these misgivings about the composition of previously published samples, it is noteworthy that only the isolated arithmetic disability group maintained the hypothesized factor structure, whereas the group of children with combined arithmetic and verbal disabilities resulted in a factor structure for the ICT that has not been previously described. Although the existence of different factor structures for the two groups points to clear differences in how the groups approach or solve the ICT, the correlations between the resultant factors and other cognitive measures do not provide much to facilitate an understanding of what the important differences may be (see next section). For example, although results clearly support Rourke's separation of isolated arithmetic disability and arithmetic disability in combination with verbal disability (Rourke & Finlayson, 1978), the results do not necessarily support a common underlying explanation (e.g. phonemic processing difficulties) for verbal achievement difficulties and ICT performance in children with a combined-type disability. Unfortunately, many of the studies focusing on learning disability subtypes have neglected to study the convergence of arithmetic and verbal learning disabilities, resulting in a poor understanding of this diagnosis (Collins & Rourke, 2003). Perhaps prior researchers have avoided the apparent "middle ground" of combined verbal and arithmetic disability because of a desire to maximize differences between the "more distinct" learning disorder subtypes of isolated arithmetic learning disability and [isolated] verbal learning disability. The results of the current study call this reasoning into question, at least by demonstrating a clear distinction between the combined-type diagnosis and the isolated arithmetic diagnosis.

Hypotheses 3 & 4

Given that the two different diagnostic subgroups did not yield equivalent factor structures, it did not make sense to perform correlations with intent to interpret the factor structure for the pooled sample, and so this portion of the analysis was bypassed and diagnostic groups were examined independently.

Looking first at the correlations between ICT factors and other cognitive measures in the isolated arithmetic group, the secondary factor (III/VI) has strong correlations with the Wisconsin Card Sorting Test (WCST) and the Matrix Analogies subtest from the K-ABC. This indicates the significant degree that abstract reasoning and non-verbal reasoning play in this factor. It is worth noting that the correlations between Factor III/VI and Block Design, Picture Arrangement, or TMT-B were small, indicating that the type of nonverbal reasoning measured was relatively independent from visuospatial organization and processing.

The pattern of correlations between cognitive measures and ICT factor structure in the combined arithmetic and verbal learning disability group is more difficult to interpret. The only statistically significant finding was the relationship between Factor V/VI and WRAT-R Arithmetic achievement. Because arithmetic learning disability was defined in terms of WRAT-R Arithmetic performance, the finding that ICT performance might have something to do with arithmetic achievement is not surprising. In fact, what is more surprising is the lack of such a relationship in the isolated arithmetic subgroup, indicating that the isolated arithmetic subgroup probably did not have as broad an array of nonverbal reasoning deficits as might be seen in a full Nonverbal Learning Disorder.

Although the secondary factor – Factor III/IV -- in the combined disability group did not demonstrate statistically significant relationships with any cognitive measures, moderate correlations exist between this factor and the Matrix Analogies of the K-ABC and the Picture Arrangement subtest of the WISC-R, and as significance was missed by .001 in one case and .008 in another, the results are probably worth discussion. These findings seem to indicate the importance of nonverbal reasoning in solving this factor but, unlike children with isolated arithmetic disability, the reasoning employed seems to have a greater emphasis on appreciating the structure/organization of the visual material. Note again that correlations with visuospatial organization measures, such as Block Design or Object Assembly, are small; it is possible that the correlation between Factor III/IV and Picture Arrangement has more to do with assembling a logical sequence of events than with moment-by-moment assimilation of visual detail.

Taking this one step further, it is possible that the factor structures generated by the different diagnostic groups could be related to the relative importance of the sequence of the ICT subtests. Considering that subtests IV and V are solved by using the same principle (that is, successful completion of subtest IV does not require a "shift" in strategy in order to progress smoothly through subtest V), it seems to make more sense that these subtests would belong to a common factor, as indeed they do in the ICT as performed by children with isolated arithmetic learning disability. However, children with combined arithmetic and verbal learning disability seem to approach subtest IV differently than they do subtest V. It is possible that the relationship between subtest IV and V changes depending on how a child handles the sequential transition between them. Children in the two diagnostic groups perform similarly on subtest V, but children in the combined-type group perform comparatively worse on subtest IV. Perhaps children in the combined-disability diagnostic group take longer to learn the principle common to subtests IV and V. This might cause subtest IV to be as "challenging" to learn as subtest III, but could also allow subtest V to benefit from the immediate memory of subtest IV; consequently III and IV could represent the challenge of novelty and subtest V and VI more of an acquired skill or memory, at least for children with arithmetic and verbal learning disabilities combined. In opposition to this theory is the fact that visual memory as measured by the WRAML, does not seem to relate to Factor V/VI. Children with isolated arithmetic learning disability perform similarly on subtests IV and V, explaining the existence of Factor IV/V in this group only.

In spite of the possibilities discussed above, one of the most striking findings of the current study was that the resultant ICT factors demonstrated significant correlations with very few of the chosen cognitive measures. In children with an isolated arithmetic disability, the primary factor (Factor IV/V) did not demonstrate significant correlations with any of the other cognitive measures. Similarly, Factor V/VI, the primary ICT factor for children with combined arithmetic and verbal learning disability, correlated only with WRAT-R Arithmetic, which was used to define the group to begin with. It was expected that the factors comprising the ICT would have a much stronger relationship to nonverbal reasoning and visuospatial organization, and relatedly, that it would probably be governed significantly by overall nonverbal ability. However, significant relationships consistently failed to be demonstrated between the ICT factors and Block Design, Object Assembly, Picture Completion or even IQ on the WISC-R, and in several cases failed to have significant relationships with other measures of executive functioning, as the WCST or K-ABC Matrix Analogies. In many ways, therefore, portions of the ICT did not demonstrate convergent validity with many of the cognitive measures which were hypothesized to be related.

In the same way, however, discriminant validity was supported, as the obtained ICT factors showed a similar lack of significant relationships in regards to cognitive measures with which it was expected the ICT would have little in common. For example, even though children with combined arithmetic and verbal learning disability have, by definition, verbal achievement deficiencies and may struggle with verbal aspects of intelligence testing, no relationship was observed between the ICT and these measures for the combined-type diagnostic group.

It seems, then, that aspects of nonverbal reasoning that are common to known tests (such as the Wisconsin Card Sorting Test, Matrix Analogies subtest from the K-ABC or Picture Arrangement subtest from the WISC-R) are part of what the ICT measures, but certainly not the only thing. Rather, most of the test seems to be relatively unique in comparison to other tests that might seem, at least superficially, to be conceptually similar to the ICT. It may of course be argued that the ICT has too little in common with other measures of its class, and should therefore be dismissed. However, this approach is rather short-sighted. Executive functioning has remained particularly difficult to study, and nobody would claim that the neuropsychologist's current armamentarium can provide a complete assessment or understanding of this particular cognitive domain. In that context, the existence of a test that can measure abstract reasoning abilities, bypass verbal restrictions, and that is not redundant with other measures, would seem to be a welcome source of additional information.

It is useful to consider that executive functioning is not the same thing as planning, mental set-shifting, organization, etc., but that these things have been attributed to executive functioning; they are tools used by this cognitive ability, but are not the ability itself. It is not at all unreasonable to suppose that the ICT is measuring some construct of higher order processing that has not yet been charted out and labeled by contemporary neuropsychologists.

Summary

Even in a sample of 81 children with arithmetic learning disability, the factor structure of the ICT varied according to diagnostic subtype, indicating that clear differences exist in how each diagnostic subtype approaches the test. For children with an isolated arithmetic learning disability, a two factor structure for the ICT emerged and indicated that ICT subtests IV and V compose the primary factor and ICT subtests III and VI compose the secondary factor. This secondary factor is related to the Wisconsin Card Sorting Test and the K-ABC Matrix Analogies subtest, indicating the extent to which subtests III and VI converge with other measures of nonverbal reasoning and executive functioning in this subgroup.

A two-factor structure for the ICT was also supported by the performance of children in the combined arithmetic and verbal learning disability diagnostic group, however the primary factor was composed of subtests V and VI, and the secondary factor was composed of subtests III and IV. The secondary factor for this group was related to the K-ABC Matrix Analogies subtest and the WISC-R Picture Arrangement subtest, indicating some similarity to Factor III/VI in the isolated arithmetic group, although the combined-type diagnostic group may be more sensitive to the sequence of ICT subtests than the isolated arithmetic group. In particular, the difference in factor structures between diagnostic groups is consistent with the idea that children in the combined arithmetic and verbal learning disability group may take longer to learn the principle of subtest IV, resulting in larger differences in performance between subtest IV and the subtest V.

For each diagnostic group, the primary factors (IV/V for the isolated arithmetic group and III/IV for the combined arithmetic and verbal group) did not show meaningful significant relationships with any of the other cognitive measures examined, despite the expectation that ICT factors would be interpretable by examining their relationships with measures of general intellectual ability, visuospatial organization and nonverbal abstract reasoning. Although results make interpretation of these factors difficult, it does appear that the ICT is measuring something that other nonverbal tests do not. Specifically, the fact that other aspects of the ICT are related to executive functioning might indicate that the ICT is a relatively unique measure of executive functioning in that it has little overlap with other "similar" tests.

Limitations

A major limitation of this investigation is the correlational nature of the data. Although some correlations existed between ICT factors and measures of higher order reasoning, it cannot be absolutely concluded that children are *using* this ability while solving the Intermediate Category Test. In fact, the lack of many meaningful correlations between factors and cognitive measures serves to illustrate how a cognitive domain, such as executive functioning, may overlie several measures that may not be correlated, or may be correlated but not directly related to each other *per se.*

A second limitation of the present study is the lack of a non-learning-disabled control group. For example, ICT factors in the combined arithmetic and verbal learning disability group are different from those that have been reported in other samples, but it is unclear which (if any) of the patterns of performance described are "normal" versus "pathological." Similarly, although it is tempting to attribute different factor structures of the ICT to the problem-solving effects of having a learning disability, this cannot be proven by the current study. Optimally, control subjects would have been in treatment for a non-neurological, nonpsychiatric condition at Texas Scottish Rite Hospital, and received the same battery of tests as the other children in this study. As only archival data were available for this study, no such data was available.

A further limitation of this investigation is that the sample studied may not accurately reflect the general population of children with arithmetic learning disabilities. The sample size was insufficient for purposes of confirmatory factor analysis, and the factor analyses would have benefited from a larger number of subjects. Particularly, confirmatory factor analysis seemed to indicate that the hypothesized factor structures fit the current sample but might not fit other samples drawn from the same population, and this problem might have been rectified with a greater sample size (although the subsequent exploratory factor analyses suggests that the hypothesized model was incorrect). Even though exploratory factor analyses accounted for a minimum of 66.62 percent of the variance in ICT performance (for the combined arithmetic and verbal learning disorder subgroup), small sample size might have resulted in insufficient power to detect additional factors. Similarly, the sample size limited the number of variables that could be statistically analyzed, necessitating the assumption that ICT subtests are themselves homogeneous constructs – an assumption that has never been thoroughly tested. The children participating were mostly Caucasian and male. Socioeconomic data was not available. In future research, the population of children with arithmetic learning disabilities might be more accurately represented by involving a larger group of subjects, recruited from several clinical treatment sites.

Conclusion

Subtests I and II of the Intermediate Category Test were demonstrated to have negligible contribution to the overall variance of performance on the test, because very few errors are made on these subtests. Although this has been commented on before, the current study is the first to quantify this and show that subtests I and II contribute less than 1% to the overall variance in ICT performance.

Even with a small sample size, this study was able to demonstrate that the properties of the Intermediate Category Test vary between groups of children with different diagnoses. Not only does this confirm that a single error score does not accurately reflect on performance of a child on the ICT, but the patterns of performance that are important for understanding a child's performance on this test are likely to be different depending on the diagnosis of the child.

In regards to arithmetic learning disability, subgroups of children with isolated arithmetic learning disability or arithmetic disability combined with verbal learning disability produce different factor structures when their performance on the ICT is factor analyzed. Although nonverbal reasoning ability in both diagnostic subgroups seems to be assessed by the ICT, the aspects of nonverbal reasoning that are assessed are different. Specifically, the sequence of the subtests of the ICT may be more important to understanding test performance in children with a combined arithmetic and verbal learning disability than it is in children with an isolated arithmetic disability. Factor analysis of the ICT performance of children with arithmetic and verbal learning disability generated a factor structure that has not been previously reported for the ICT.

Finally, the primary factors accounting for ICT performance do not seem to overlap with any of the other nonverbal reasoning measures included for comparison, limiting the convergent validity of the test. Factors also did not demonstrate actual relationships with tests that were hypothetically unrelated, confirming its discriminant validity. Given that the limited number of observed relationships were between the ICT and other measures of executive functioning, it may be that the ICT is measuring aspects of executive functioning that are not detected by other tests.

Appendix A

Institutional Review Board Approval

SOUTHWESTERN

THE UNIVERSITY OF TEXAS
SOUTHWESTERN MEDICAL CENTER
AT DALLAS

Institutional Review Board

TO: Tim Nyberg, PhDc
Psychology - 9119

Jan Harrell for

FROM: David Karp, MD, PhD
Institutional Review Board 1 Chairperson
IRB - 8843

DATE: November 2, 2004

RE: **Expedited Approval of Protocol and HIPAA Waiver**
IRB Number: 102004-045
Title: Use of the Intermediate Category Test in Arithmetic Disability Subtypes

The Institutional Review Board (IRB) at the University of Texas Southwestern Medical Center has determined that this research is eligible for expedited review in accordance with 45 CFR 46.110(a)-(b)(1), 63 FR 60364, and 63 FR 60353. The IRB Chairman approved the protocol on 1 November 2004. IRB approval of this research lasts until 31 October 2005. If the research continues beyond twelve months, you must apply for updated approval of the protocol one month before the date of expiration noted above. **The Board waived the use of consent form in accordance with 45 CFR 46.116(d). Your approved subject sample size is 80 subjects.**

The IRB requires that you report to the Board any unexpected adverse events that occur during the study. In the future, if you require a modification to the protocol, obtain review and approval by the Board prior to implementing any changes except when prompt changes are necessary to eliminate apparent immediate hazards to a subject.

The IRB requires that all personnel who interact with research subjects or who have access to research data identified with the names of subjects receive a copy of the Multiple Project Assurance on file with the Department of Health and Human Services. Document their agreement to comply with the statements therein. Such documentation should be kept with other records of the research, which are subject to review by the IRB. Copies of the Multiple Project Assurance and the Federal regulations governing the participation of human subjects in research (45 CFR 46) are available on the IRB website:
(http://www8.utsouthwestern.edu/utsw/cda/dept31018/files/41623.html)
or from Pat Fisher at irb@utsouthwestern.edu.

If applicable, approval by the appropriate authority at a collaborating facility is required before subjects may be enrolled on this study.

If you have any questions related to this approval or the IRB, you may telephone Jan Harrell at 214.648.9453.

Enc: HIPAA Waiver
Project Summary
NR1-EXP copy

DK/iw

Appendix B

Cognitive Measures Included in the Test Battery

Test	Measures	Indicated Region	Description	Scores	Norms	Reference
WISC-R digit span	Span of Attention; Freedom from Distractability; Span of Apprehension; Working Memory; Rote learning and memory (forward); Concentration (backward)	Left—somewhat	Repeat sequences of numbers, of incremental difficulty.	Scaled Score m=10 sd = 3	WISC-R manual	WISC-R Manual (1974) Sattler (1992; p 154-155) Lezak (1995; p359-360, 366-368)
WISC-R Block Design	Constructional Skills; Spatial Perception; Motor Execution; Perceptual/Visuospatial Organiziation	Whole-brain; Right-parietal	Replicate designs with blocks, against a time limit. Designs become increasingly complex.	Scaled Score m=10 sd = 3	WISC-R manual	WISC-R Manual (1974) Sattler (1992; p 158-160) Lezak (1995; p587-594) Spreen & Strauss (1998; p 91)
WISC-R Picture Arrangement	Nonverbal reasoning and planning; Comprehend and evaluate social situations; Perceptual Organization	Bilateral; frontal	Place series of pictures in logical sequence, against a time limit	Scaled Score m=10 sd = 3	WISC-R manual	WISC-R Manual (1974) Sattler (1992; p 157-158) Lezak (1995; p636-640)
WISC-R Arithmetic	Use numerical operations; mental computation and concentration; Freedom from distractability		18 problems of increasing complexity. No paper and pencil allowed.	Scaled Score m=10 sd = 3	WISC-R manual	WISC-R Manual (1974) Sattler (1992; p 149-151) Lezak (1995; 641-644)

Test	Measures	Indicated Region	Description	Scores	Norms	Reference
WISC-R Vocabulary	Expressive vocabulary; word knowledge; general mental ability;	Resilient to brain damage	Define 32 words	Scaled Score m=10 sd = 3	WISC-R manual	WISC-R Manual (1974) Sattler (1992; p 151-152) Lezak (1995; 539-541)
Wide Range Achievement Test (WRAT-R)	Educational achievement in the domains of reading, spelling, arithmetic		Recognize and name letters and words; write single words from dictation; written computations	T-score m=50 sd = 10	WRAT-R manual	Spreen and Strauss (1998; 164-166) Sattler (1992; p 331) Lezak (1995; p552-554, 647-648)
Wide Range Assessment of Memory and Learning (WRAML) Visual Index score	Visual Memory; Visuospatial processing; Attention to visual details		Recall a series of patterns; recall the elements and locations of designs; recall parts of pictures displaying scenes	Index Score m=100 sd = 15	WRAML manual	WRAML manual Spreen and Strauss (1998; p. 419-422)
WRAML Visual learning subtest	Visual memory		Recall locations of designs; includes delayed recall and recognition	Scaled Score m=10 sd = 3	WRAML manual	WRAML manual Spreen and Strauss (1998; p. 419-422)

Test	Measures	Indicated Region	Description	Scores	Norms	Reference
Wisconsin Card Sorting Test (WCST), perseverations	Assess abstract reasoning; ability to form abstract concepts, shift & maintain sets, utilize feedback; Conceptual flexibility; Requires planning, organized search, use of feedback to seek alternatives.	frontal	Match each of 128 cards to one of 4 key cards differing on several dimensions. Task is to figure out which principle is in operation depending on feedback given.	T-scores m=50 sd=10	WCST manual	WCST manual Spreen & Strauss (1998; p219-231) Lezak (1995; p621-628)
Kaufman Achievment Battery for Children (K-ABC), Matrix Analogies	Nonverbal reasoning ability		Selection of a picture or design that best completes a larger picture	Scaled Score m=10 sd=3	K-ABC manual	Sattler (1992; 300-303) Spreen and Strauss (1998; p141-147)
Trail Making Test (TMT)	Visual attention, scanning, sequencing (Part A); mental set-shifting and flexibility (Part B); appreciation of symbolic significance of numbers and letters	Whole brain (highly sensitive)	Part A – connect numbered dots in sequence Part B – alternate between numbers and letters in order	T-score m=50 sd=10	Knights & Norwood	Satter (1992; p701) Spreen and Strauss (1998; 533-547) Lezak (1995: 381-384)

Appendix C

Results and Tables

Table 1. Demographic Characteristics of the Study Participants.

	Isolated Arithmetic		Arithmetic+Verbal		Total Sample	
	Frequency	%	Frequency	%	Frequency	%
N (% = percent of total)	26	32.1	55	67.9	81	100.0
AGE						
Mean age in months (SD)*	145.8 (9.5)		136.9 (13.8)		139.8 (13.2)	
Mean age in years (SD)*	12.2 (0.8)		11.4 (1.1)		11.6 (1.1)	
GENDER						
Male	15	57.7	44	80.0	59	72.8
Female	11	42.3	11	20.0	22	27.2
GRADE						
3rd	0	0.0	5	9.1	5	6.2
4th	1	3.8	11	20.0	12	14.8
5th	3	11.5	13	23.6	16	19.8
6th	15	57.7	16	29.1	31	38.3
7th	6	23.1	8	14.5	14	17.3
8th	1	3.8	2	3.6	3	3.7
HANDEDNESS						
Right	23	88.5	44	80.0	67	82.7
Left	3	11.5	11	20.0	14	17.3

*SD = Standard deviation.

Table 2. Means and Standard Deviations of cognitive measures and ICT scores by diagnostic group.

		Isolated Arithmetic			Arithmetic + Verbal		
Measure	Type of Score	N	Mean	Std. Dev.	N	Mean	Std. Dev.
WISC-R:							
VIQ	Standard Score	25	104.12	8.20	54	104.83	9.81
PIQ	Standard Score	26	103.96	6.86	54	106.98	10.54
FSIQ	Standard Score	26	103.96	6.10	55	106.36	8.43
Information	Scaled Score	23	10.04	1.87	49	10.57	2.55
Similarities	Scaled Score	23	12.48	2.89	49	12.27	3.03
Arithmetic	Scaled Score	23	8.48	1.81	49	8.82	2.04
Vocabulary	Scaled Score	23	11.96	2.57	49	11.47	2.47
Compehension	Scaled Score	23	10.65	2.35	49	10.67	2.33
Digit Span	Scaled Score	23	8.39	2.76	42	8.33	2.40
Picture Completion	Scaled Score	23	11.09	2.39	49	11.47	2.05
Picture Arrangement	Scaled Score	23	11.91	1.95	49	12.76	2.55
Block Design	Scaled Score	23	10.35	1.80	49	10.69	3.22
Object Assembly	Scaled Score	23	10.04	2.10	49	10.86	2.53
Digit-Symbol Coding	Scaled Score	23	9.26	2.80	48	9.04	2.90
WRAT-R:							
Reading	Standard Score	26	98.12	9.09	54	83.04	14.51
Spelling	Standard Score	26	94.31	6.72	54	78.74	10.52
Arithmetic	Standard Score	26	87.65	15.10	54	85.44	14.68
WRAML:							
Visual Index	Standard Score	26	100.88	12.48	55	98.00	13.93
Visual Learning subtest	Scaled Score	26	10.42	2.97	55	9.67	2.80
Other:							
Trails A t-score	T Score	26	52.25	8.43	55	52.50	8.56
Trails B t-score	T Score	26	51.08	6.59	55	49.02	12.93
K-ABC Matrix Analogies	Scaled Score	17	9.94	2.56	48	10.38	2.33
WCST perseverations	T Score	26	53.54	6.28	54	51.33	10.03
WCST total errors	T Score	26	54.50	8.98	54	51.56	10.30
ICT Scores:							
Subtest I	Raw Score	26	0.15	0.46	55	0.36	0.73
Subtest II	Raw Score	26	0.50	0.65	55	0.69	0.92
Subtest III	Raw Score	26	9.54	9.02	55	11.60	10.40
Subtest IV	Raw Score	26	7.42	4.46	55	11.44	7.80
Subtest V	Raw Score	26	12.73	5.92	55	14.05	6.47
Subtest VI	Raw Score	26	2.04	1.78	55	3.55	2.44
Total Error Score	Raw Score	26	32.38	11.26	55	41.76	17.69
Subtest I	T Score	26	59.04	18.56	55	51.52	12.37
Subtest II	T Score	26	51.32	11.19	55	53.20	17.52
Subtest III	T Score	26	44.31	8.88	55	41.41	5.57
Subtest IV	T Score	26	52.61	11.03	55	46.77	7.86
Subtest V	T Score	26	50.35	9.28	55	47.42	8.48
Subtest VI	T Score	26	47.49	7.09	55	43.21	7.34
Total Error Score	T Score	26	47.37	10.13	55	45.84	10.50

Table 3. Age and PIQ adjusted Means and Standard Deviations of ICT total raw score for the two diagnostic groups.

				Test for main effect	
Diagnostic Group	N	Mean	SD	F (1, 74)	p
Isolated arithmetic	26	33.51	15.60		
Arithmetic and Verbal	54	42.76	18.84	4.99	0.03

Covariates appearing in the model are evaluated at the following values:

age in months = 139.65 (F [1,74] = 8.60, p = .004), WISC-R PIQ = 106.00 (F [1,74] = 7.10, p = .009)

Table 4. Means and Standard Deviations for significant covariates by diagnostic group.

	Isolated Arithmetic		Arithmetic + Verbal				
	M	SD	M	SD	t	df	Sig. (2-tailed)
Age (in months)	145.80	9.56	136.91	13.76	3.37	67.86	<.01
Grade in school	6.12	0.82	5.31	1.30	3.39	72.70	<.01
WISC-R PIQ	103.96	6.86	106.98	10.54	-1.54	70.91	0.13

Table 5. ICT normative score transformations (Knights & Norwood, 1980).

Age	9 years		10 years		11 years		12 years		13 years	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Total	54.94	15.47	51.21	14.85	43.50	14.55	38.90	14.50	37.00	14.47
Subtest I	0.12	0.47	0.12	0.46	0.12	0.45	0.12	0.40	0.12	0.40
Subtest II	0.60	0.71	0.60	0.63	0.58	0.55	0.36	0.52	0.34	0.52
Subtest III	21.00	12.10	20.33	12.10	19.58	12.00	18.00	12.10	17.75	12.10
Subtest IV	11.33	7.60	11.33	7.60	11.17	7.60	11.10	7.60	11.00	7.60
Subtest V	16.17	7.00	15.47	7.00	14.50	7.00	14.50	7.00	13.50	7.00
Subtest VI	5.56	3.00	4.87	3.00	4.60	3.00	4.46	3.00	4.33	3.00

Table 6. Means and Standard Deviations for ICT total score T-scores by diagnostic group.

	Isolated Arithmetic		Arithmetic + Verbal				
	M	SD	M	SD	t	df	Sig. (2-tailed)
Age Adjusted ICT Total Score	47.37	10.13	45.84	10.50	0.62	79	0.537

Table 7. Variance in raw ICT Total Score and specific subtests.

Combined Subjects

	Variance	% of Total
(I+II)	1.52	0.56
(III+IV+V+VI)	255.00	94.34
Total score	270.29	100.00

Equality of Variances Test (subtest I+II versus other subtests)

	Variance	t	df	p
(I+II)	1.52			
III	99.41	30.61	79	<.01
IV	50.85	14.17	79	<.01
V	39.61	18.18	79	<.01
VI	5.51	6.42	79	<.01

Isolated Arithmetic

	Variance	% of Total
(I+II)	0.64	0.50
(III+IV+V+VI)	121.80	96.00
Total Score	126.89	100.00

Equality of Variances Test (subtest I+II versus other subtests)

	Variance	t	df	p
(I+II)	0.64			
III	81.30	23.96	24	<.01
IV	19.93	11.19	24	<.01
V	35.08	16.61	24	<.01
VI	3.16	3.21	24	<.01

Arithmetic+Verbal

	Variance	% of Total
(I+II)	1.90	0.61
(III+IV+V+VI)	295.46	94.42
Total Score	312.92	100.00

Equality of Variances Test (subtest I+II versus other subtests)

	Variance	t	df	p
(I+II)	1.90			
III	108.24	31.99	53	<.01
IV	60.84	9.47	53	<.01
V	41.87	18.66	53	<.01
VI	5.96	6.73	53	<.01

Table 8. Results of Exploratory Factor Analysis with Varimax Rotation of ICT subtest T scores for the two groups combined.

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.502
Bartlett's Test of Sphericity	Approx. Chi-Square	40.816
	df	6
	Sig.	.000

Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.674	41.861	41.861	1.674	41.861	41.861	1.596	39.901	39.901
2	1.236	30.904	72.764	1.236	30.904	72.764	1.315	32.863	72.764
3	.648	16.209	88.973						
4	.441	11.027	100.000						

Extraction Method: Principal Component Analysis.

Rotated Component Matrix[a]

	Component	
	1	2
Tscore subtest III	-.227	.862
Tscore subtest IV	.787	-.124
Tscore subtest V	.842	.145
Tscore subtest VI	.465	.731

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 3 iterations.

Table 9. Results of Exploratory Factor Analysis with Varimax Rotation of ICT subtest T scores for Isolated Arithmetic Learning Disability.

KMO and Bartlett's Test[a]

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.463
Bartlett's Test of Sphericity	Approx. Chi-Square	60.793
	df	6
	Sig.	.000

a. Diagnostic Group = Isolated arithmetic LD

Total Variance Explained[a]

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.087	52.179	52.179	2.087	52.179	52.179	1.944	48.596	48.596
2	1.596	39.892	92.071	1.596	39.892	92.071	1.739	43.475	92.071
3	.223	5.584	97.655						
4	.094	2.345	100.000						

Extraction Method: Principal Component Analysis.

a. Diagnostic Group = Isolated arithmetic LD

Rotated Component Matrix[a,b]

	Component	
	1	2
Tscore subtest III	-.387	.893
Tscore subtest IV	.935	-.189
Tscore subtest V	.935	.102
Tscore subtest VI	.214	.946

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 3 iterations.

b. Diagnostic Group = Isolated arithmetic LD

Table 10. Results of Exploratory Factor Analysis with Varimax Rotation of ICT subtest T scores for Combined Arithmetic and Verbal Learning Disability.

KMO and Bartlett's Test[a]

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.524
Bartlett's Test of Sphericity	Approx. Chi-Square	14.775
	df	6
	Sig.	.022

a. Diagnostic Group = Arithmetic and Verbal LD

Total Variance Explained[a]

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.520	38.000	38.000	1.520	38.000	38.000	1.475	36.883	36.883
2	1.145	28.624	66.624	1.145	28.624	66.624	1.190	29.741	66.624
3	.784	19.593	86.216						
4	.551	13.784	100.000						

Extraction Method: Principal Component Analysis.

a. Diagnostic Group = Arithmetic and Verbal LD

Rotated Component Matrix[a,b]

	Component	
	1	2
Tscore subtest III	-.130	.812
Tscore subtest IV	.220	.726
Tscore subtest V	.834	.058
Tscore subtest VI	.845	.022

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 3 iterations.

b. Diagnostic Group = Arithmetic and Verbal LD

Table 11. Correlation coefficients for ICT Factor Scores, and other cognitive measures, Isolated Arithmetic group.

	Isolated Arithmetic					
	Factor IV/V		**Factor III/VI**		**Total Score T score**	
Measure	**r**	**p**	**r**	**p**	**r**	**p**
Factor IV/V	1.000		0.000	1.000	**0.648**	<0.001**
Factor III/VI	0.000	1.000	1.000		**0.716**	<0.001**
ICT total score	**0.648**	<0.001**	**0.716**	<0.001**	1.000	
ICT subtest III T score	-0.387	0.051	**0.893**	<0.001**	**0.446**	0.023*
ICT subtest IV T score	**0.935**	<0.001**	-0.189	0.356	**0.487**	0.012*
ICT subtest V T score	**0.935**	<0.001**	0.102	0.620	**0.697**	<0.001**
ICT subtest VI T score	0.214	0.293	**0.946**	<0.001**	**0.765**	<0.001**
WISC VIQ	-0.180	0.390	-0.070	0.740	-0.164	0.434
WISC PIQ	0.215	0.292	-0.235	0.248	0.007	0.971
WISC FSIQ	-0.012	0.955	-0.208	0.307	-0.134	0.513
WISC Information Subtest	-0.154	0.483	0.160	0.465	0.014	0.949
WISC Similarities subtest	-0.148	0.501	-0.132	0.547	-0.163	0.458
WISC Arithmetic subtest	0.014	0.950	-0.331	0.123	-0.205	0.348
WISC Vocab subtest	-0.086	0.696	-0.202	0.354	-0.241	0.268
WISC Comprehension subtest	-0.229	0.294	0.308	0.153	0.068	0.757
WISC digit span subtest	0.223	0.307	0.161	0.462	0.283	0.190
WISC Picture Completion subt	-0.270	0.213	-0.162	0.460	-0.288	0.182
WISC Picture Arrangement subt	0.313	0.146	-0.089	0.686	0.158	0.471
WISC Block Design subtest	-0.200	0.360	-0.041	0.854	-0.278	0.199
WISC Object Assembly subtest	-0.283	0.190	-0.252	0.246	-0.285	0.188
WISC Digit-Symbol Coding	0.392	0.064	-0.137	0.533	0.208	0.340
WRAT-R reading	-0.164	0.423	0.071	0.729	-0.059	0.776
WRAT-R spelling	-0.261	0.197	-0.126	0.539	-0.232	0.254
WRAT-R arithmetic	0.157	0.445	-0.096	0.641	0.000	0.999
Trails A T-score	0.215	0.291	0.228	0.262	0.313	0.120
Trails B T-score	0.217	0.287	0.256	0.207	0.247	0.223
K-ABC matrices scaled score	0.210	0.418	0.417	0.096	0.417	0.096
WCST perseverations; T-score	0.008	0.968	**0.414**	0.035*	0.300	0.136
WRAML visual index	0.021	0.917	0.150	0.464	0.146	0.477
WRAML visual learning	0.183	0.371	0.330	0.100	0.369	0.064

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 12. Correlation coefficients for ICT Factor Scores, and other cognitive measures, combined Arithmetic + Verbal group.

	Arithmetic+Verbal					
	Factor V/VI		**Factor III/IV**		**Total Score T score**	
Measure	**r**	**p**	**r**	**p**	**r**	**p**
Factor V/VI	1.000		0.000	1.000	**0.788**	<0.001**
Factpr III/IV	0.000	1.000	1.000		**0.270**	0.046
ICT total score	**0.788**	<0.001**	**0.270**	0.046*	1.000	
ICT subtest III	-0.130	0.346	**0.812**	<0.001**	0.149	0.278
ICT subtest IV	0.220	0.106	**0.726**	<0.001**	**0.338**	0.011*
ICT subtest V	**0.834**	<0.001**	0.058	0.674	**0.590**	<0.001**
ICT subtest VI	**0.845**	<0.001**	0.022	0.874	**0.767**	<0.001**
WISC VIQ	-0.085	0.542	-0.010	0.940	-0.048	0.731
WISC PIQ	-0.076	0.585	0.040	0.774	0.005	0.969
WISC FSIQ	-0.079	0.569	0.003	0.983	-0.040	0.771
WISC Information Subtest	-0.052	0.724	0.027	0.856	-0.035	0.810
WISC Similarities subtest	-0.019	0.898	-0.182	0.210	-0.114	0.437
WISC Arithmetic subtest	0.064	0.662	0.051	0.729	0.112	0.444
WISC Vocab subtest	-0.147	0.314	0.036	0.808	-0.117	0.422
WISC Comprehension subtest	-0.077	0.599	0.112	0.442	0.057	0.696
WISC digit span subtest	-0.041	0.796	-0.182	0.248	-0.117	0.459
WISC Picture Completion subt	-0.089	0.544	0.181	0.214	0.081	0.581
WISC Picture Arrangement subt	-0.182	0.210	-0.272	0.058	-0.165	0.258
WISC Block Design subtest	0.046	0.753	0.088	0.550	0.066	0.653
WISC Object Assembly subtest	0.104	0.478	0.076	0.605	0.074	0.614
WISC Digit-Symbol Coding	-0.131	0.375	0.021	0.886	-0.061	0.679
WRAT-R reading	-0.041	0.767	-0.263	0.055	-0.146	0.294
WRAT-R spelling	-0.064	0.644	-0.142	0.307	-0.100	0.470
WRAT-R arithmetic	**-0.301**	0.027*	0.063	0.650	**-0.313**	0.021
Trails A T-score	-0.025	0.859	-0.003	0.983	0.070	0.611
Trails B T-score	-0.003	0.982	0.058	0.676	0.060	0.665
K-ABC matrices scaled score	0.018	0.905	0.283	0.051	0.099	0.503
WCST perseverations; T-score	0.041	0.767	0.043	0.760	0.033	0.814
WRAML visual index	0.158	0.249	-0.073	0.596	0.081	0.557
WRAML visual learning	-0.034	0.804	-0.033	0.809	-0.048	0.728

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

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