EXPLICIT LEARNING IN DOWN SYNDROME:

A CROSS-SECTIONAL DEVELOPMENTAL TRAJECTORY APPROACH

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A THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Arts
in the Department of Psychology
in the Graduate School of
The University of Alabama

TUSCALOOSA, ALABAMA

2012

ABSTRACT

Introduction: The purpose of the current study was to analyze the cross-sectional developmental trajectories of explicit category learning in individuals with Down syndrome compared to individuals with intellectual disability and typically developing individuals. Explicit learning is active, conscious, controlled, and intentional; it is a deliberate attempt to acquire new knowledge or skill from repeated tries with feedback. Explicit learning improves with age throughout childhood and is closely related to intelligence. Because of its relation to intelligence, we expected individuals with Down syndrome to perform below the level expected for their chronological age and nonverbal ability.

Methods: The sample was comprised of 41 individuals with Down syndrome, 25 individuals with intellectual disability, 40 individuals who were typically developing chronological age matches, and 27 individuals who were typically developing nonverbal mental age matches. All participants completed a measure of nonverbal ability, the Leiter International Performance Test-Revised, and two measures of explicit learning, the Category Task and the Concept Formation subtest of the Woodcock-Johnson-III.

Results: Cross-sectional developmental trajectories were created examining explicit learning over chronological age and explicit learning over nonverbal ability. For the Category Task over chronological age trajectory, the Down syndrome and intellectual disability groups had a delay in onset in explicit learning. For the Woodcock-Johnson-III over chronological age trajectory, the Down syndrome and intellectual disability groups had a delay in onset in explicit learning, and the Down syndrome group showed a slower rate in development in explicit learning. For the

Category Task over nonverbal ability trajectory, no group showed a delay in onset or slower rate in development in explicit learning. For the Woodcock-Johnson-III over nonverbal ability trajectory, the Down syndrome group had a slower rate of development in explicit learning.
Conclusion: The results suggested that in comparison to typically developing individuals and individuals with mixed-etiology intellectual disability, individuals with Down syndrome show similar performance in and development of explicit category learning in relation to their nonverbal ability as long as the explicit learning measure does not constrain their performance.

DEDICATION

This thesis is dedicated to everyone who offered me advise, support, and encouragement throughout this entire process. Specifically, I dedicate this thesis to my loving husband Camaron Phillips, who supports me daily and always reminds me of the bigger picture, and to my amazing mother Belinda Shelton, who has never once stopped believing in me and continuously encourages me to trust in God's perfect plan. Finally, this work is dedicated to my Heavenly Father, who continues to lead me on an amazing journey.

LIST OF ABBREVIATIONS AND SYMBOLS

CA Chronological age

DS Down syndrome

F Fisher's *F* ratio: A ration of two variances

GSV Growth score value

ID Intellectual disability

IQ Intelligence quotient

MA Mental age

p Probability associated with the occurrence under the null hypothesis of a value as extreme as or more extreme than the observed value

t Computed value of *t* test

TD Typically Developing

WJ-III Woodcock-Johnson-III

$<$ Less than

$=$ Equal to

η_p^2 Partial eta squared: effect size

ACKNOWLEDGMENTS

I would like to thank my advisor and thesis chair, Dr. Fran Conners, for providing me with wonderful advice, knowledge, and guidance throughout the entirety of this project. Additionally, I would like to thank the members of my committee, Dr. Ed Merrill and Dr. Jason Scofield, for their invaluable advice and for the time and service they invested in my thesis. I would also like to thank my fellow graduate students, Marie Moore and Susan Loveall, the research team at the University of Wisconsin under the direction of Dr. Leonard Abbeduto, and all of the research assistants who devoted great time and effort in collecting the data. Finally, I would like to acknowledge NICHD Grant HD055345. This project was truly a team effort, and I could not have done it without the help of each and every member of this team.

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CHAPTER 1

INTRODUCTION

Learning, or the process in which behavior changes as a result of interactions with the world, is vital for one's survival and well-being. Being able to obtain, assimilate, and apply knowledge correctly is crucial for any aspect of life—from getting ready in the morning to cooking a meal to succeeding at school or a job. In today's society, capacity to learn determines one's overall ability. Learning is important not just for typically developing individuals but also for individuals with an intellectual disability such as Down syndrome. Individuals with Down syndrome can learn, though they learn differently from typically developing individuals. Research has shown that individuals with an intellectual disability want to be independent (Wehmeyer & Metzler, 1995), and such independence requires the ability to learn. Therefore, understanding how individuals with Down syndrome learn is exceptionally important in helping them succeed in life, and knowledge gained about their learning abilities will aid in future intervention approaches.

Learning is not a unitary function; rather, two types of learning exist—explicit learning and implicit learning (Berry & Broadbent, 1988; Hasher & Zacks, 1979; Hayes & Broadbent, 1988; Lewicki, 1986; Reber, 1989; Weinert, 2009). The distinction between explicit and implicit learning has been a primary field of study in cognitive psychology for over forty years with some of the early work using terms such as automatic and effortful processes (Hasher & Zacks, 1979) and unselective and selective learning (Hayes & Broadbent, 1988). Explicit learning is active, conscious, controlled, and intentional. It occurs when deliberate instructions are given and only a few selected factors are being learned. Implicit learning, in contrast, is passive, unconscious, automatic, and non-selective. Further, the explicit learning system is verbalizable and can be explained through rule-based algorithms, while the implicit learning system cannot be verbally expressed or explained (Berry & Broadbent, 1988; Hayes & Broadbent, 1988). Implicit learning, instead, involves consolidating numerous exemplars without one being told to learn anything and without conscious awareness (Berry & Broadbent, 1988; Reber, Walkenfeld, & Hernstadt, 1991).

Explicit learning is a deliberate attempt to learn that is similar to conscious problem solving. Such learning mechanisms involve creating mental representations for a task or forming and testing mental models for task performance (Gentner & Stevens, 1983; Johnson-Laird, 1983). Examples of explicit learning include paired-associate learning, list learning, location learning, repeated exposure learning, and conceptual learning; these can be accomplished by reading materials, listening to a lecture, completing a worksheet, spelling words, and working out mathematical problems. Explicit learning is the type of learning that people commonly think about, encompassing a large array of learning activities.

While several different types of explicit learning exist, the current study specifically examines explicit category learning, which is the process by which one learns to classify stimuli into categories. More specifically, category learning allows one to classify objects, events or ideas based on common relevant features. For example, one might classify an apple as a fruit or a dog as an animal. Category learning requires one to recognize an underlying representation that links together items of the same category. Category learning is based on a hypothesis-testing system that allows one to learn rule-based categories (Markman, Maddox, Worthy, & Baldwin, 2007). Category learning tasks typically follow a specific pattern where participants are presented with a stimulus, make a categorization response, and are given corrective feedback.

In such tasks, the rule-based categories can be learned through some explicit reasoning process and can be easily described verbally. The Wisconsin Card Sorting Test (Heaton, Chelune, Talley, Kay, & Curtis, 1993) is a common task used to measure category learning. In this task, participants must classify cards according to specific sorting rules (e.g., sort based on color). Category learning is crucial to daily functioning as people perform numerous categorizations every day. By the time one reaches adulthood, thousands of categories have been learned and one is able to quickly learn new categories through logical reasoning (Ashby & O'Brien, 2005). As such, having a better understanding of explicit category learning is crucial.

Explicit learning, including explicit category learning, is known to improve with age throughout childhood (Fraas, 1973; Huang-Pollock, Maddox, & Karalunas, 2011; Maybery, Taylor, & O'Brien-Malone, 1995; Minda, Desroches, & Church, 2008). For example, Minda et al. (2008) examined explicit category learning in adults (college students) and children (3-, 5-, and 8-year-olds). They found that on categories determined by a single-dimensional rule (i.e., one dimension determined the rule) or associative learning mechanisms (i.e., each category member resembled the other category members based on all dimensions, but the rule was difficult to verbalize and learn), children performed just as well as adults, but when the categories were determined by a disjunctive rule (i.e., two out of three dimensions determined the rule) or were nonlinearly separable (i.e., one dimension determines the rule, and another dimension determines an exception to the rule), adults performed significantly better than children. With these findings, Minda et al. concluded that children's explicit category learning skills are not as developed as those of adults.

Results of other category learning studies are consistent with this conclusion. For example, Huang-Pollock and colleagues (2011) also compared adults (18- to 25-years-old) and children (9- to 13-years-old) on a rule-based categorization task that could be solved using explicit verbalizable rules. They found that adults were more accurate than children over all five blocks of trials and that adults learned the categories at a steeper trajectory than the children. Also, Maybery et al. (1995) compared performance on an explicit learning task between younger children (5.1- to 7.8-years-old) and older children (10.5- to 12.8-years-old) and found that the older children performed significantly better than the younger children. Finally, Fraas (1973) examined performance differences on a paired-association learning task amongst 10-, 13-, and 16-year-old children and also found that performance significantly improved as children aged.

In addition, explicit learning is known to be closely related to intelligence (McGeorge, Crawford, & Kelly, 1997; Reber et al., 1991). For example, Reber and colleagues (1991) used a series-completion problem-solving task to examine individual differences in explicit learning. In the series-completion task, participants were shown a letter string and were then asked to select the next letter from two options. The letter strings followed a discernable pattern, and participants consciously used code-breaking and problem-solving strategies to determine the correct continuation of the letter sequence. Twenty undergraduate students completed the 21 trials of the explicit series completion task as well as four IQ subtests from the WAIS-R (Picture Arrangement, Vocabulary, Block Design, and Arithmetic). They found that performance on the explicit learning task was strongly correlated with IQ ($r = .69$, $p < .01$).

Similarly, McGeorge et al. (1997) used a series completion task to measure explicit learning and the Wechsler Adult Intelligence Scale—Revised (Wechsler, 1981) to measure intelligence in a sample of 123 participants (mean age = 45.1 years). In the series completion task, participants were given as sequence of letters (e.g., ABACAD) and asked to predict the next letters of the sequence (e.g., AEAF). Each of the 28 sequences followed a specific pattern that varied in complexity, and all of the patterns were verbalizable and learnable. Participants were given a page with all 28 problems and were allotted 20 minutes to complete as many problems as possible. McGeorge and colleagues found that, in contrast to implicit learning, explicit learning showed significant individual differences and was strongly correlated to the Full Scale IQ ($r = .58$, $p < .05$).

Further, intelligence-group differences on explicit learning tasks have been found (Atwell, Conners, & Merrill, 2003; Fletcher, Maybery, & Bennett, 2000; Fraas, 1973). For example, Atwell and colleagues (2003) examined differences in explicit learning for individuals with intellectual disability (ID) compared to typically developing (TD) individuals. Thirty-four participants with ID (mean age = 17.0 years) and 41 college students (mean age = 19.5 years) completed an artificial grammar paradigm. In this task, participants were first exposed to either the grammatical condition or random sequences condition, and then later they were asked to determine whether they had seen the sequences before. In the acquisition phase, participants were exposed to 15 sequences and were asked to reproduce each sequence. Then, during the test phase, participants viewed 30 sequences and were asked if they had seen these sequences before. Explicit learning is shown by the accuracy of recognition of sequences seen in the exposure phase. Atwell et al. found that participants with ID performed significantly worse on the explicit learning measure than participants without ID and, thus, concluded that explicit learning is impaired in individuals with ID. While the work described above has examined the relationship between explicit learning, in general, and intelligence, very little data has looked at the relationship between explicit category learning and intelligence.

The current study sought to more closely examine the intellectual and developmental differences in explicit category learning. To do so, explicit learning was studied in individuals with Down syndrome and individuals with ID compared to TD individuals. Such work provided greater insight into the IQ- and age-dependence of explicit learning.

Explicit Learning and Down Syndrome

Down syndrome (DS) is the most common genetic disorder that results in ID and is caused by an extra copy of chromosome 21 (i.e., Trisomy 21; Pennington, Moon, Edgin, Stedron, & Nadel, 2003). DS affects about one in 1000 live births (McGrowther & Marshall, 1990) and drastically impairs cognitive, emotional, and physical development. Intellectually, individuals with DS are usually moderately to severely delayed with an IQ range of 25 to 55 (Pennington et al., 2003), and they also experience an increased risk for congenital heart disease, respiratory infections, loss of vision and hearing, and early-onset Alzheimer's disease (Van Allen, Fung, & Jurenka, 1999). As a result of such health risks, individuals with DS typically experience a decreased life expectancy compared to TD individuals, though life expectancy is increasing for the DS population (Bittles & Glasson, 2004).

Additionally, DS has a distinct cognitive-linguistic profile. Based on mental age (MA) comparisons, speech, language, and verbal short-term memory are all areas of clear impairment in DS (Chapman & Hesketh, 2000; Pennington et al., 2003). More specifically, individuals with DS show poor articulation, phonology, vocal imitation, mean length of utterance, and expressive syntax (Dunst, 1990; Fowler, Gelman, & Gleitman, 1994; Hulme & Mackenzie, 1992; Rondal, 1993). While verbal abilities are a clear weakness for individuals with DS, visuospatial processing is a strength relative to MA (Silverstein, Legutki, Friedman, & Takayama, 1982; Chapman & Hesketh, 2000). For example, on short-term memory tasks, individuals with DS perform below their MA level when the task involves verbal material (e.g., letters, digits), but similar to or even above their MA level when the task involves visual or spatial material (e.g., pictures, block locations). However, modality differences seem to be limited to short-term memory. Research has shown that on measures of long-term memory, individuals with DS perform below their general cognitive ability level in both verbal and visuospatial domains (Pennington et al., 2003; see Conners, Moore, Loveall, & Merrill, 2011). Such work may indicate a general difficulty integrating or consolidating information for the long term, regardless of the modality of information.

Similar results are shown when looking specifically at the cognitive function of explicit learning; individuals with DS show clear deficits in both the verbal and visuospatial domains of explicit learning (Carlesimo, Marotta, & Vicari, 1997; Lanfranchi, Jerman, Dal Pont, Alberti, & Vianello, 2010; Nichols et al., 2004; Pennington et al., 2003; Vicari, 2001; Vicari, 2004; Vicari, Bellucci, & Carlesimo, 2000; Vicari, Bellucci, & Carlesimo, 2005; Vinter & Detable, 2008). In word-list learning, several studies have shown that participants with DS perform worse than MA comparisons, not only when asked to recall words studied 10 to 15 minutes before, but also when given repeated exposures to learn lists of words (Carlesimo et al., 1997; Vicari, 2001; see also Nichols et al., 2004; Pennington et al., 2003; Vicari et al., 2000). For example, Carlesimo and colleagues (1997) asked participants to learn a list of words. For five repeated trials, participants were asked to immediately recall the word list, and then after a 15-minute delay, participants were again asked to recall the words. The participants with DS remembered significantly fewer words in the immediate recall and delayed recall than both a mixed etiology ID sample and a MA-matched TD sample.

Additionally, when evaluating visuospatial explicit learning, participants with DS perform below MA comparisons. This learning deficit has been shown through a virtual water maze task (Pennington et al., 2003), a block sequence task (Vicari et al., 2000), and an object identification task (Vicari et al., 2005). For example, in the water maze task, participants used a joystick to navigate a virtual water maze in search of a blue square presented on the computer. After four practice trials of locating the blue square, the square became invisible to the participant but remained located in the same place as it was during the practice trials. In the next five trials, participants were asked to navigate the maze and locate the square, and as soon as the participant moved the joystick over the hidden target, the square appeared. In this way, participants were learning the location of the target object. Then, a test trial was given in which the square was not present in the maze, but the computer monitored where the participant searched for the target and how much time they spent searching in the correct location. The participants with DS spent significantly less time searching for the target in the correct location compared to the MA-matched TD group (Pennington et al., 2003). They had more difficulty learning the target location with repeated practice.

Similarly, in the block sequence task (Vicari et al., 2000), participants saw nine blocks randomly spaced on a board. The experimenter indicated a sequence by touching each block in increasing lengths and orders and asked participants to indicate the same sequence. After a memory span was established (i.e., the longest sequence that the participant could get correct), the experimenter indicated a sequence that was two blocks longer than the memory span, and participants were given ten tries to get the test sequence correct. Vicari and colleagues (2000) found that it took more trials for participants with DS to correctly repeat the sequence than MA-matched TD controls. Additionally, in the object identification task (Vicari et al., 2005), participants were shown fifteen pictures of common objects. After a study phase, participants were presented with four different versions of the same object and were asked to select the picture seen before. This entire process (i.e., study phase and test phase) was completed three times. The participants with DS identified significantly fewer correct pictures across the three trials than a MA-matched TD group, and while the TD group showed a significant increase indicating learning from trial one to trial two and trial one to trial three, the DS group did not show a significant increase.

Finally, Lanfranchi and colleagues (2010) administered the Modified Card Sorting Test (MCST; Nelson, 1976), used to measure explicit category learning, to adolescents with DS and MA-matched TD controls. In the MCST, four stimulus cards with shapes, colors, and certain numbers of shapes are laid in front of the participant. Using a set of 48 response cards that have all possible combinations of color, shape, and number, participants must match each card according to color, shape, or number. The examiner tells participants if their match is correct or not. After the participant gets six consecutive correct matches (e.g., s/he matches on color six times in a row), the category is completed, and participants are instructed that the sorting criterion has changed. The task is completed either when the participant completes each category twice or when all 48 response cards have been used. They found that individuals with DS completed significantly fewer categories than the MA-matched control group.

Patterns of Cognitive Growth in Down Syndrome

Although quite a bit is known about the cognitive profile of DS, very little work has been conducted to examine the growth patterns related to cognitive abilities. More specifically, while previous studies have clearly established a deficit in explicit learning in individuals with DS compared to TD children, no studies have examined how explicit learning develops within this population. To fully understand the development of explicit learning in this population both development over chronological age (CA) and development over MA must be examined. Some cognitive functions are impaired in DS only for CA comparisons but are equivalent for MA comparisons, while other functions remain impaired even relative to their MA. Only a few studies have examined development over CA and development over MA in individuals with DS, and these select studies have focused on intelligence, language, verbal recall, and face recognition (Annaz, Karmiloff-Smith, Johnson, & Thomas, 2009; Carr, 2005; Chapman, Hesketh, & Kistler, 2002; Mackenzie & Hulme, 1987).

Research has examined the changes in IQ over chronological age, and results generally show that, as individuals with DS get older, IQ declines (for review, see Vicari, 2006). In other words, individuals with DS experience a gradual decline in mental age relative to their chronological age (Hodapp & Zigler, 1990). This decline in IQ does not mean that one's abilities are declining, or that one is losing abilities; rather, one's abilities are not developing at a rate that would be expected according to their chronological age. This decline begins in the first year of life (Pennington et al., 2003), and by adulthood, IQ scores typically fall within the moderate to severe ID range with a mental age of, at most, seven or eight years (Gibson, 1978). Vicari and colleagues (2004) found IQ scores to be between 45 and 71 for children with DS (chronological age = 6.5-8 years) but between 28 and 47 for adolescents and young adults with DS (chronological age = 12.2-25.9 years). Further, Turner and Alborz (2003) longitudinally examined IQ in 106 individuals with DS at three different time points. At each assessment point, they found significant differences between age groups with the younger individuals with DS having higher mean IQ scores than the older individuals with DS. This occurred when comparing 8 and 10 year olds, 12 and 14 year olds, and 20 and 22 year olds.

Research has also examined the development of individuals with DS over MA. For example, Mackenzie and Hulme (1987) examined the development of memory span in DS using both cross-sectional and longitudinal methods. They found that digit span in DS is lower than anticipated based on MA and that digit span does not improve as MA increases, which was contrary to the TD group. Consequently, as MA increases, the delay in digit span also increases. Annaz et al. (2009) found similar results when examining holistic face recognition in children with DS. Additionally, Chapman and colleagues (2002) explored the change in language production and comprehension in individuals with DS. Using longitudinal data and hierarchical linear modeling, they found that expressive language acquisition continues to improve throughout adolescence for most individuals with DS. However, they did not have a TD comparison group in their study.

While skills such as memory span, intelligence, and language have been examined across the life span of individuals with DS, the present study was the first to examine the cross-sectional developmental trajectory of explicit learning in this population. The developmental trajectories approach, while clearly underutilized in understanding the cognitive growth patterns in DS, has several advantages for research on ID in comparison to the typical approach of individual or group matching on MA (Thomas et al., 2009). The majority of previous research has used a TD MA-matched comparison group to determine where individuals with ID are delayed and impaired. If the ID group performs significantly lower than the MA-matched TD group, then experimenters conclude that the ID group struggles with the particular skill measured. However, this matching approach assumes that the rate of development for MA is equal to the rate of development for the target skill, which may not be accurate. In contrast, the developmental trajectories approach allows for an analysis of change over time instead of the static analysis of development used in matching approaches. Developmental trajectories display the relationship between MA and the target skill as it typically develops and then use this relationship to compare groups. Additionally, a cross-sectional developmental trajectory can be reliably created to approximate development of the target skill when the sample covers a broad developmental level (for example, Karmiloff-Smith et al., 2004; Thomas et al., 2006). This approach is cross-sectional and comparative. It can look at overall group differences as the traditional MA-comparison approach, and it gives an approximation of development, as a longitudinal design would.

Purpose of the Current Study and Hypotheses

The purpose of the current study was to examine the developmental trajectory of explicit category learning in individuals with DS compared to individuals with ID and TD individuals. Focusing on a specific etiology has become an important aspect of intellectual disability research because ID is not a universal variation from typical development; instead, individuals with ID display diverse cognitive abilities that can be differentiated qualitatively (Dykens, Hodapp, & Finucane, 2000; Vicari, Albertini, & Caltagirone, 1992). Therefore, our focus on DS greatly added to the literature on the cognitive functioning of individuals with DS. Additionally, when examining the cognitive profiles of individuals with ID, it is important to conduct the research within a developmental framework, taking into account age, developmental level, and etiology interactions (Krinsky-McHale, Kittler, Brown, Jenking, & Devenny, 2005). In this respect, comparing the developmental trajectories of four different groups (i.e., DS, mixed-etiology ID, TD-MA, and TD-CA) gave us an even greater insight into the explicit learning of individuals with DS.

The current study used two assessments to measure explicit category learning—the Woodcock Johnson III Concept Formation task and a category task (the MCST). The DS group (CA 10-21, MA 4-9) was compared to a mixed-etiology ID group and two separate TD groups in terms of overall level of explicit learning as well as growth in explicit learning. To examine the level and growth of explicit learning in youth with DS relative to *chronological age*, the group with DS was compared to a TD group that spanned the same CA (10-21 years). To examine the level and growth of explicit learning of youth with DS relative to *mental age*, the group with DS was compared to a TD group that spans the same MA (4-9 years). Finally, to examine the degree to which the level and growth in explicit learning in DS is uniquely associated with the syndrome rather than more generally associated with ID, the group with DS was compared to a group with non-DS ID age 10-21 with MA 4-9. Developmental trajectories of explicit learning were compared across groups.

For the CA comparison of the developmental trajectories, we hypothesized that the DS trajectory would display a lower intercept and shallower slope than the TD trajectory. This means that explicit learning would begin at a lower point and would show slower growth in DS than in TD. Such differences in intercepts were expected because of the known deficit in explicit learning for DS (Carlesimo et al., 1997; Lanfranchi et al., 2010; Nichols et al., 2004; Pennington et al., 2003; Vicari, 2001; Vicari, 2004; Vicari et al., 2000; Vicari et al., 2005; Vinter & Detable, 2008). Such differences in slopes were expected because IQ increases with CA at a slower pace in individuals with DS compared to TD individuals (e.g., Turner & Alborz, 2003; Vicari et al., 2004; but see Rihtman et al., 2010). Because explicit learning is closely related to IQ (McGeorge et al., 1997; Reber et al., 1991), we expected this same pattern for explicit learning. Further, if the lower intercept and shallow slope were specific to DS, as we predicted, then we expected that the DS group would also have a lower intercept and shallower slope than the ID group.

Hypotheses for the MA comparison of the developmental trajectories were more difficult to determine because little is known about cognitive development in DS over MA. However, we hypothesized that the DS trajectory would display a lower intercept than the TD trajectory and the ID trajectory. This hypothesis was based on the known research showing that explicit learning is poorer in DS than in MA TD comparisons and ID comparisons (Carlesimo et al., 1997; Lanfranchi et al., 2010; Pennington et al., 2003; Vicari, 2001; Vicari, 2004; Vicari et al., 2000; Vicari et al., 2005; Vinter & Detable, 2008). Finally, we hypothesized that the DS trajectory would display a shallower slope than both the ID and TD trajectories. Thus, similar to verbal short-term memory (Mackenzie & Hulme, 1987), the rate of growth in explicit learning could be slower than that of MA in general.

CHAPTER 2

METHODOLOGY

Design

The current study utilized a cross-sectional developmental trajectories approach. Four groups (DS, ID, TD-MA, and TD-CA) completed a battery of tests measuring nonverbal intelligence and explicit learning. Nonverbal intelligence, as opposed to verbal intelligence, was used in the current study due to the known verbal deficits in DS. By using nonverbal intelligence, we were able to get a more accurate measure of their ability. Developmental trajectories of explicit learning over CA were compared statistically across groups, where Group (DS, ID, and TD-CA) was the independent variable, CA was the covariate, Group by CA was the interaction term, and Category Task and WJ-III Concept Formation were the two dependent variables. Additionally, developmental trajectories of explicit learning over MA (using nonverbal ability as the measure) were compared statistically across groups, where Group (DS, ID, and TD-MA) was the independent variable, Nonverbal Ability was the covariate, Group by Nonverbal Ability was the interaction term, and the Category Task and WJ-III Concept Formation were the two dependent variables.

Participants

Participants included 41 individuals with DS, 25 individuals with ID, 40 individuals who were typically developing CA matches (TD-CA), and 27 individuals who were typically developing nonverbal MA matches (TD-MA). More participants with DS were included in the study because the focus is on this population. Participants were recruited from the University of

Alabama Intellectual Disability Registry, the University of Wisconsin Waisman Center Participant Database, agencies in Alabama, schools in Alabama, preschools in Alabama, and the University of Alabama campus. Parental consents and participant assent was received before beginning testing.

The current study was a part of a larger NIH-funded study examining the cognitive predictors of language impairments in DS. To be eligible for the larger study, participants had to (1) demonstrate adequate vision for the study tasks (2) use speech (English) as the primary mode of communication, and English as a native language and (3) complete the nonverbal ability test (Leiter-R), pass one test block on the receptive syntax measure (Test for Reception of Grammar-2nd edition), and pass one item on the phonological memory measure (Comprehensive Test of Phonological Processing, Nonword Repetition subtest). Also, participants in the DS group had to (1) have a chromosomal analysis indicating Trisomy 21 or translocation involving chromosome 21, (2) pass a hearing test and an autism evaluation, and (3) have a CA between 10 and 21 years. Participants in the ID group had to (1) have an educational classification or clinical diagnosis of ID or the equivalent, (2) pass a hearing test and an autism evaluation, and (3) have a CA between 10 and 21 years. Participants in both TD groups had to (1) be ineligible for special education services in school, including gifted/talented and speech and language, and (2) not have a diagnosis of ADD or ADHD per parent report, and (3) have a CA between 4 and 21 years. For the current study, participants also had to be able to complete the two measures of explicit learning (Category Task and WJ-III Concept Formation). Additionally, participants in the DS group, ID group, and TD-MA group had to have a nonverbal MA between 4 and 9 years on the Leiter-R (see Table 1 for Descriptive Statistics).

Table 1
Descriptive Statistics

		Mean	SD	Range
Down Syndrome				
	Chronological Age	15.32	3.19	10.25 – 21.92
	Leiter-R: IQ	44.95	8.87	36 – 71
	Leiter-R: GSV	468.02	9.87	453 – 492
	Category: Learning Efficiency Score	12.93	8.62	0 – 44
	WJ-III: Raw Score	5.32	4.14	0 – 16
Intellectual Disability				
	Chronological Age	15.85	2.54	10.25 – 20.67
	Leiter-R: IQ	54.20	10.18	36 – 77
	Leiter-R: GSV	476.92	8.93	458 – 487
	Category: Learning Efficiency Score	18.56	14.61	0 – 44
	WJ-III: Raw Score	11.16	6.74	2 – 24
Typically Developing- CA				
	Chronological Age	16.20	3.09	10.00 – 20.83
	Leiter-R: IQ	98.63	12.32	76 – 124
	Leiter-R: GSV	507.28	9.96	486 – 532
	Category: Learning Efficiency Score	43.68	3.48	30 – 48
	WJ-III: Raw Score	32.03	6.75	12 – 40
Typically Developing- MA				
	Chronological Age	8.65	4.32	4.25 – 18.42
	Leiter-R: IQ	96.48	14.11	76 – 129
	Leiter-R: GSV	479.52	13.89	459 – 499
	Category: Learning Efficiency Score	27.78	12.20	12 – 46
	WJ-III: Raw Score	14.78	10.07	1 – 35

Participants with DS. Out of the 46 participants with DS who were originally recruited for the larger study, 41 met all criteria, were able to complete the study, and were used for the present data analysis. Of the participants who were excluded from analyses, one scored below the lower nonverbal MA criterion of 4 years, two did not complete all of the measures for the present analyses, one demonstrated signs of fatigue and frustration and did not appear to be engaged during the Category Task or WJ-III, and one was an extreme outlier on the Category Task.

Participants with ID. Out of the 30 participants with ID who were originally recruited for the larger study, 25 met all criteria, were able to complete the study, and were used for the present data analysis. Of the participants who were excluded from analyses, one scored above the upper nonverbal MA criterion of 9 years, two did not complete all of the measures for the present analyses, one had physical limitations that compromised performance on the tests, and one's true birth date was unknown, making it impossible to compute standard scores for the Leiter-R. The etiological make-up of this group (based on parent report) included eleven participants with an unknown etiology, eight participants with Fragile X syndrome, one participant with Rubinstein-Taybi syndrome, one participant with cerebral palsy, one participant with XXYY syndrome, one participant with fetal alcohol spectrum disorder and a traumatic brain injury, one participant with 10q deletion syndrome, and one participant with Smith-Magenis syndrome.

TD-CA Participants. Out of the 42 TD-CA participants recruited for the larger study, 40 met all criteria, were able to complete the study, and were used for the present data analysis. Of the participants who were excluded from analyses, one did not complete all of the measures for the present analyses, and one was an extreme outlier on the Category Task.

TD-MA Participants. Out of the 29 TD-MA participants recruited for the larger study, 27 met all criteria, were able to complete the study, and were used for the present data analysis. Of the participants who were excluded from analyses, one scored above the upper nonverbal MA criterion of 9 years and one did not complete all of the measures for the present analyses. Also, note that 8 participants had a CA between 10 and 21 years, but had a MA of 9 years or below. These participants were included in both the TD-CA sample and the TD-MA sample in order to maximize power in the analyses.

Measures

Nonverbal Ability. The Leiter International Performance Test- Revised brief form (Leiter-R; Roid & Miller, 1997) was used to provide estimates of nonverbal ability. The Leiter-R is a published standardized norm-referenced test designed for ages 2 years through 21 years. We administered the four subtests that make up the Brief IQ battery: Figure Ground, Form Completion, Sequential Order, and Repeated Patterns. These subtests measure visual spatial and inductive reasoning skills typically classified as fluid intelligence. The measure of mental ability we used for the present analysis was the growth score value (GSV). The GSV is the conversion of the raw score in which scale corrections are made for variability in item difficulty, and it ranges from approximately 380 to 560. Compared to the norm-referenced standardized scores, the growth score is more precise especially at the lower ability range. The GSV provides an index measuring the rate at which the child is growing. In the current study, the MA score (or age equivalency score), which is determined from the GSV, was used to determine sample MA ranges between 4 and 9 years, but the GSV was used for the developmental trajectory analyses. The MA scores were not used to create the developmental trajectories because they do not have equal-interval measurement properties, making them inappropriate indexes to use in statistical analyses. The test manual reports that the Leiter-R brief form correlates .85 with both the full version of the Leiter-R and the WISC-III IQ test. Internal consistency reliability is between .88 and .90, and test-retest reliability is between .88 and .96.

Woodcock-Johnson III Tests of Cognitive Abilities (WJ-III). The Concept Formation subtest of the WJ-III (Woodcock, McGrew, & Mather, 2001) was one of two tests used to measure explicit learning. This published standardized test is normed for individuals between 2 and 90 years of age. It requires participants to look at colored shapes that vary on up to four dimensions (color, shape, size, and number). On each page, there is a set of shapes on the left and a box on the right that contains a particular shape or shapes. Participants decide how the shapes in the box are similar to one another and different from those on the left; in other words, they try to discover the rule that defines the shapes in the box (e.g., large, red). The examiner steps the participant through the early trials and provides feedback so that the participant learns how to discover the rules. The Concept Formation subtest of the WJ-III has a strong reliability coefficient of .94. Raw scores were used in data analyses.

Category Task. The Category Task was also used to measure explicit learning. It is an adaptation of the Wisconsin Card Sorting Test (Berg, 1948) and the Children's Category Test (Boll, 1993), introduced by Nelson (1976) and developed by Cianchetti, Corona, Foscoliano, Contu, and Siannio-Fancello (2007). The adaptation makes the task more appropriate for children as young as 4 years, and also emphasizes category learning more so than set-shifting. Lanfranchi et al. (2010) used this same "Modified Card Sorting Task" and determined that it was suitable for populations with moderate to mild ID because the task did not show floor or ceiling effects. The Category Task uses stimulus cards containing triangles, stars, crosses, or circles. Each card has from one to four shapes on it (all the same shape on a card) and the shapes are in one of four colors (all the same color on a card). The participant is shown the stack of these cards and told,

> "We are going to play a sorting game. See these cards? Each card has some shapes on it. See these different shapes? (show a card with each different shape). Each card has a certain color too. See these different colors? (show a card with each different color). One more thing, each card has a certain number of shapes (show a card with each different number of shapes). See—there are different shapes, different colors, and different numbers of shapes."

Next, the examiner lays out four standard cards—(1) one red triangle, (2) two green stars, (3) three yellow crosses, and (4) four blue circles—and hands the participant one card at a time from a stack of forty-eight cards, which contain different combinations of shape, color, and number. The examiner says,

> "Here's how to play the game. I'm thinking of a rule. Your job is to guess the rule. See your first card? Take a guess on which of these it matches (point to the four standard cards and allow the participant to guess and place the card on the standard card)."

The participant's first choice will always be correct, which means that it determines what the rule will be. For example, if the participant matches three blue circles to the standard card with two blue crosses, the first rule will be "Color." The examiner says, "That's right! You may be figuring out the rule. Take a guess on which one your second card matches," and gives feedback again. The task continues in this manner with feedback given after each card is sorted, until the participant correctly sorts six cards in a row. The cards are then picked up and the examiner states, "Now we're going to play again, but the rules have changed. This time you will find a different rule."

The game is played six times with each of the three categories being a rule two times. The participant determines the order of the categories. Games one through three can be any order of the three categories; then, games four through six must be in the same order as games one through three. The task ends when the participant has run out of cards or completes all six games, whichever is first. We used the learning efficiency score described by Cianchetti et al. (2007) as the main measure of explicit learning from this task. The learning efficiency score is the total number of categories correct (i.e., six cards in a row correct) multiplied by six plus the number of un-played cards (if any).

The reliability of the Category Task was analyzed using the Spearman-Brown split-half reliability method. This method determines internal consistency by comparing the scores from one half of the measure to the sores of the other half of the measure. For the Category Task, each of the 48 trials was scored as 1 if it was completed correctly and 0 if it was completed incorrectly. If a participant completed all six categories and still had unused cards, then those remaining cards were also scored as 1. On some participants, the test was stopped early because the participant had fewer than 6 cards remaining and was not going to complete another category. In this situation, the unused cards were scored as 0. The Spearman-Brown split-half reliability compared the even trials with the odd trials. When all participants were included in the analysis, the Spearman-Brown split-half reliability coefficient was .96. Additionally, when the analysis was run on the separate groups of participants (DS, ID, and TD), the Spearman-Brown split-half reliabilities were all above .90.

Procedure

For the larger study, participants were being tested individually on a battery of implicit learning, explicit learning, phonological memory, and language tests, divided into two to four testing sessions. Total testing time was three to seven hours, depending on the individual characteristics of the participant and the participant's ability to remain attentive and engaged. The Leiter-R and Category Task were always administered during the first session, and the WJ-III was always administered at the end of the final testing session. The Leiter-R took approximately thirty minutes. The Category Task took approximately ten minutes, and the Concept Formation subtest of the WJ-III took approximately fifteen minutes. A behavioral reward system, including sticker charts and small prizes, were used to increase attentiveness and engagement, and we encouraged short breaks between tasks when participants could move, talk, or play.

CHAPTER 3

RESULTS

Preliminary Analyses

Means, standard deviations, and ranges for all variables are listed in Table 1. Distributions of the dependent variables were analyzed to look for normality, skewness, and kurtosis, and there were no serious violations of normality. Next, all variables were checked for outliers, and two participants, one from the DS group and one from the TD-CA group, scored outside +/- 3 standard deviations on the Category Task. These two participants were removed from further analyses. After these participants were removed, Cook's D was run to determine if any points were exerting an abnormal influence on the analyses. Cook's D examines distance and leverage to determine how much the residuals of all cases would change if a specific case were to be removed from the analysis of the regression coefficients. The higher the Cook's D score, the more influential the point is. Any Cook's D score above 1.00 would have been removed from the dataset, but no such scores were found for any group.

To prepare for the developmental trajectory analysis, scatterplots were generated within each group showing the function of explicit learning over CA and explicit learning over nonverbal ability. Each scatterplot was analyzed by visual inspection for linearity, and there were no clear nonlinear trends. The extra sum-of-squares test was also used to confirm linearity of the data. The extra sum-of-squares test assesses the increase in variance accounted for by the quadratic model compared to the linear model (or the cubic model compared to the quadratic model), relative to the added degrees of freedom. This is expressed as an F-ratio, which, if significant, suggests that the added variance accounted for by the higher-level model is substantial, and thus the higher-level model should be used. For the current data, the linear function was found to be the best model for both measures of explicit learning over CA and over nonverbal ability for all groups (DS, ID, TD-CA, and TD-MA).

The relationships among CA, Leiter-R GSV, Category Task and WJ-III Concept Formation were analyzed using Pearson product-moment correlation coefficients. For the DS group, there were significant positive correlations between GSV and Category Task, GSV and WJ-III, and Category Task and WJ-III, but there were not significant correlations between CA and GSV, CA and Category Task, or CA and WJ-III. For the ID group, there were significant positive correlations between GSV and WJ-III and Category Task and WJ-III, but there were not significant correlations between CA and GSV, CA and Category Task, CA and WJ-III, or GSV and Category Task. For the TD-CA group, there were significant positive correlations between CA and GSV, CA and WJ-III, GSV and WJ-III, and Category Task and WJ-III, but there were not significant correlations for CA and Category Task or GSV and Category. For the TD-MA group, there were significant positive correlations between CA and GSV, CA and Category Task, CA and WJ-III, GSV and Category Task, GSV and WJ-III, and Category Task and WJ-III (see Table 2).

Table 2
Correlations

		CA	GSV	Category
Down Syndrome				
	CA	---	---	---
	Leiter-R GSV	.11	---	---
	Category	.15	.63*	---
	WJ-III	-.21	.49*	.46*
Intellectual Disability				
	CA	---	---	---
	Leiter-R GSV	.26	---	---
	Category	.23	.28	---
	WJ-III	.29	.58*	.78*
Typically Developing-CA				
	CA	---	---	---
	Leiter-R GSV	.49*	---	---
	Category	.30	.22	---
	WJ-III	.51*	.59*	.41*
Typically Developing-MA				
	CA	---	---	---
	Leiter-R GSV	.83*	---	---
	Category	.77*	.77*	---
	WJ-III	.69*	.76*	.68*

Note. *p < .01, two-tailed

Main Analyses

To compare linear regressions (i.e., trajectories) across groups, Thomas et al. (2009) describe a method of adapting the Analysis of Covariance function within SPSS's General Linear Model. An important assumption in the *traditional* use of the ANCOVA is that the covariate has the same relation to the dependent variable in each group, and the ANCOVA function in SPSS tests this assumption by examining whether there is a significant group x covariate interaction (there should be none to meet the assumption). For trajectory analysis, we are specifically interested in whether Age (or Ability) has a different relation to the performance variable (e.g., explicit learning) across groups. Thus, the ANCOVA function in SPSS can be adapted for a new purpose—to test group differences in slope. This only requires entering Age (or Ability) where the function asks for a covariate, and then requesting that the Group x Covariate effect be entered in the ANCOVA model. Group differences in intercept are indicated by the effect of Group, and group differences in slope are indicated by the Group x Age (or Ability) interaction.

Chronological age-based developmental trajectory analysis. Two separate analyses were conducted for the CA comparisons—one for the Category Task and one for the WJ-III. For these analyses, Group (DS, ID, and TD-CA) was the independent variable, CA was entered as the covariate, Group x CA was the interaction term, and the measure of explicit learning was the dependent variable. The Category Task trajectory revealed a main effect of Group, $F(2, 100) = 29.34$, $p < .001$, $\eta_p^2 = .370$, but no significant Group x CA interaction, $F(2, 100) = 0.72$, $p = .491$, $\eta_p^2 = .014$. Follow-up ANCOVAs examining the pairwise comparisons found a significant difference in the DS and TD-CA intercepts, $F(1, 77) = 98.53$, $p < .001$, $\eta_p^2 = .561$, and the ID and TD-CA intercepts, $F(1, 61) = 28.09$, $p < .001$, $\eta_p^2 = .315$, but not in the DS and ID intercepts, $F(1, 62) = 0.00$, $p = .994$, $\eta_p^2 = .000$. The TD-CA group had a higher intercept than both the DS group and the ID group, which were not significantly different from one another. This intercept difference signifies a delay in onset in explicit learning for the DS and ID groups (see Figure 1 and Table 3).

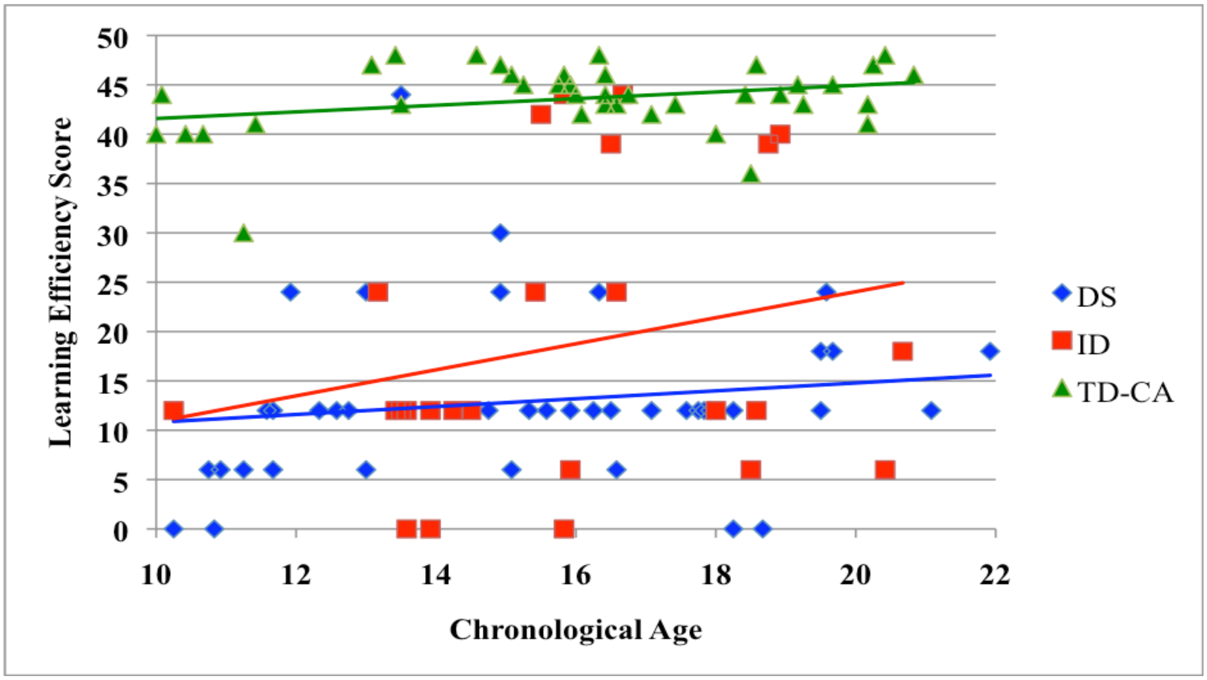

Figure 1. Growth rate of Category Task over CA.

Table 3

Equations of Linear Trajectories

			All Participants	Subsample
Development Over CA				
	Category			
		Down Syndrome	y = 0.40x + 10.80	y = 0.41x + 10.88
		Intellectual Disability	y = 1.32x + 10.85	y = 1.32x + 11.18
		Typically Developing- CA	y = 0.34x + 41.58	y = 0.34x + 41.59
	WJ-III			
		Down Syndrome	y = -0.27x + 6.75	y = -0.32x + 6.87
		Intellectual Disability	y = 0.76x + 6.73	y = 0.76x + 6.92
		Typically Developing-CA	y = 1.12x + 25.09	y = 1.01x + 26.15
Development over Leiter-R GSV				
	Category			
		Down Syndrome	y = 0.55x + 4.70	y = 0.52x + 8.11
		Intellectual Disability	y = 0.46x + 7.54	y = 0.49x + 9.69
		Typically Developing-MA	y = 0.68x + 9.84	y = 0.60x + 14.42
	WJ-III			
		Down Syndrome	y = 0.20x + 2.24	y = 0.22x + 3.31
		Intellectual Disability	y = 0.43x + 0.76	y = 0.45x + 3.07
		Typically Developing-MA	y = 0.55x + 0.13	y = 0.57x + 3.15

The WJ-III trajectory revealed a main effect of Group, $F(2, 100) = 28.77$, $p < .001$, $\eta_p^2 = .365$, and a significant Group x CA interaction, $F(2, 100) = 6.58$, $p = .002$, $\eta_p^2 = .116$. Follow-up ANCOVAs examining the pairwise comparisons found a significant difference in the DS and TD-CA intercepts, $F(1, 77) = 59.34$, $p < .001$, $\eta^2 = .435$, ID and TD-CA intercepts, $F(1, 61) = 22.89$, $p < .001$, $\eta_p^2 = .273$, DS and TD-CA slopes, $F(1, 77) = 14.64$, $p < .001$, $\eta_p^2 = .160$, and DS and ID slopes, $F(1, 62) = 4.42$, $p = .040$, $\eta_p^2 = .067$. Significant differences were not found for the DS and ID intercepts, $F(1, 62) = 0.00$, $p = .996$, $\eta_p^2 = .000$, or the ID and TD-CA slopes, $F(1, 61) = 0.38$, $p = .542$, $\eta_p^2 = .006$. Similar to the Category Task, the TD-CA group had a higher intercept than both the DS group and the ID group, which were not significantly different from one another. This intercept difference signifies a delay in onset in explicit learning for the DS and ID groups. Additionally, the DS group had a flatter slope than both the TD-CA and ID groups, which were not different from one another. This slope difference signifies a slower rate in development in explicit learning for the DS group (see Figure 2 and Table 3).

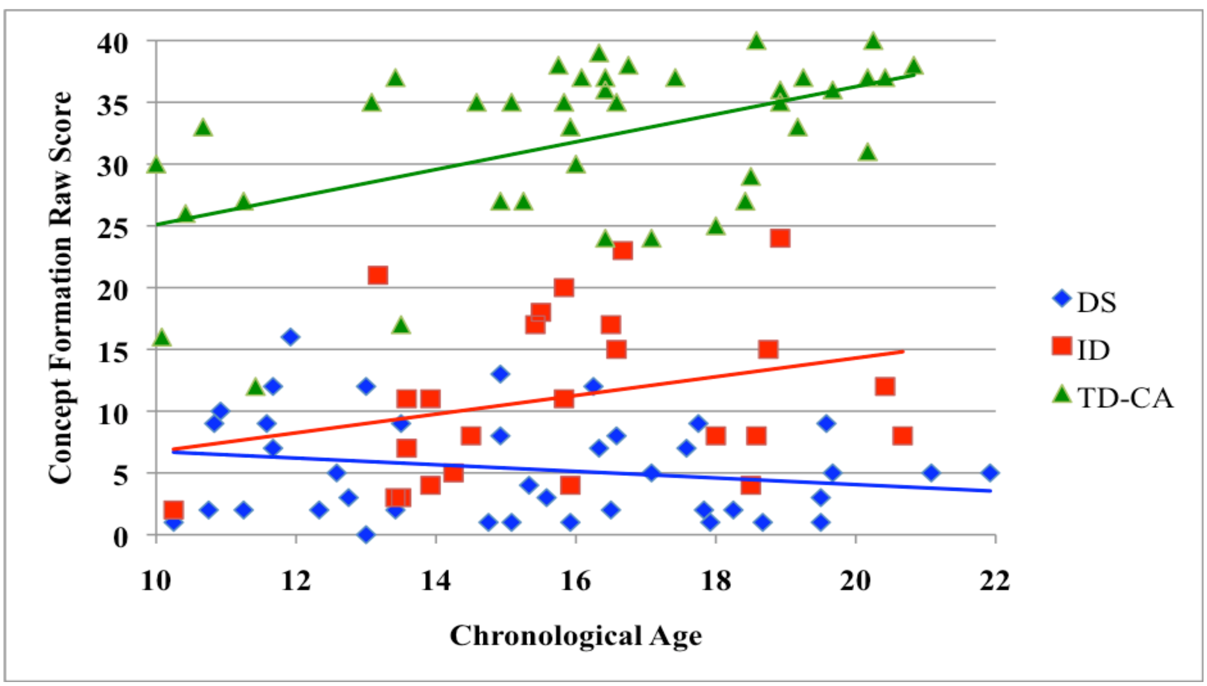

Figure 2. Growth rate of WJ-III Concept Formation over CA.

Nonverbal ability-based trajectory analysis. Additionally, two separate ANCOVAs were conducted for the MA comparisons—one for the Category Task and one for the WJ-III. For these analyses, Group (DS, ID, and TD-MA) was the independent variable, Leiter-R GSV was entered as the covariate, Group x Leiter-R GSV was the interaction term, and the measure of explicit learning was the dependent variable. The Category Task trajectory revealed no overall effect of Group, $F(2, 87) = 0.57$, $p = .570$, $\eta_p^2 = .013$, and no significant Group x Leiter-R GSV interaction, $F(2, 87) = 0.41$, $p = .665$, $\eta_p^2 = .009$. The intercepts and slopes were similar for all three groups, which signifies that no group showed a delay in onset or slower rate of development in explicit learning (see Figure 3 and Table 3).

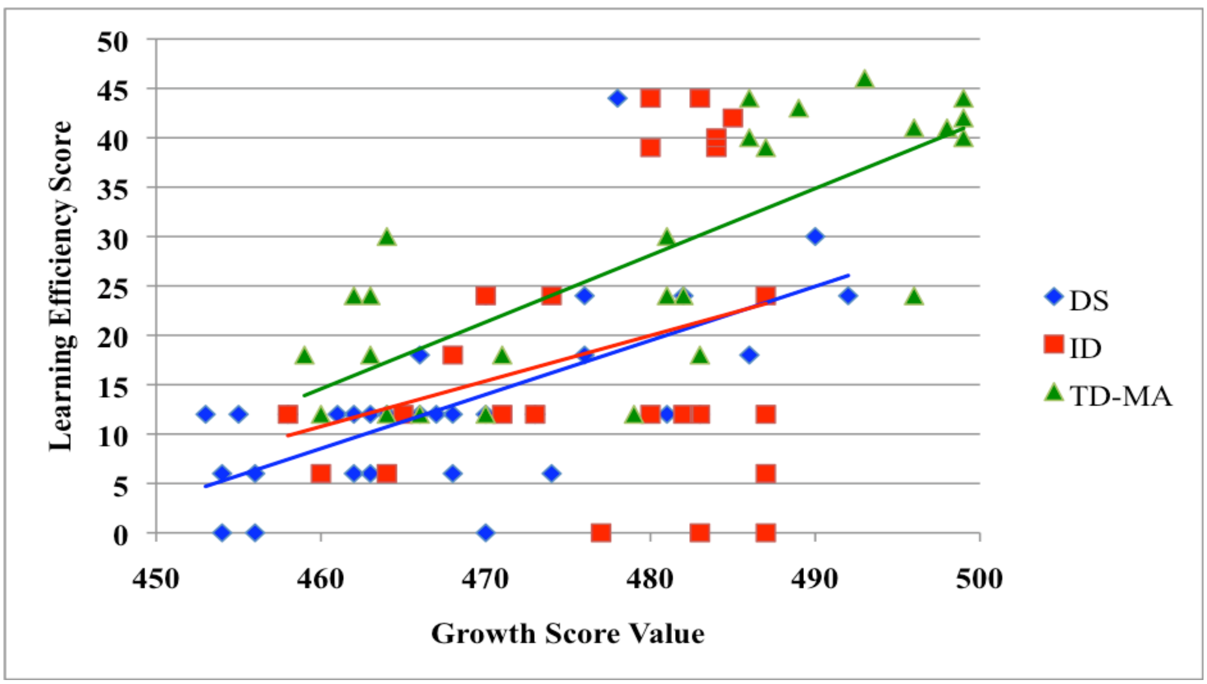

Figure 3. Growth rate of Category Task over Leiter-R GSV.

The WJ-III trajectory revealed no overall effect of Group, $F(2, 87) = 0.35$, $p = .707$, $\eta_p^2 = .008$, but a significant Group x Leiter-R GSV interaction, $F(2, 87) = 4.93$, $p = .009$, $\eta_p^2 = .102$. Follow-up ANCOVAs examining the pairwise comparisons found a significant difference in the DS and TD-MA slopes, $F(1, 64) = 10.43$, $p = .002$, $\eta_p^2 = .140$, but not in the DS and ID slopes,

$F(1, 62) = 3.37$, $p = .071$, $\eta_p^2 = .051$, or the ID and TD-MA slopes, $F(1, 48) = 0.50$, $p = .483$, $\eta_p^2 = .010$. The DS group had a flatter slope than the TD-MA group, which signifies that the DS group showed a slower rate of development in explicit learning (see Figure 4 and Table 3).

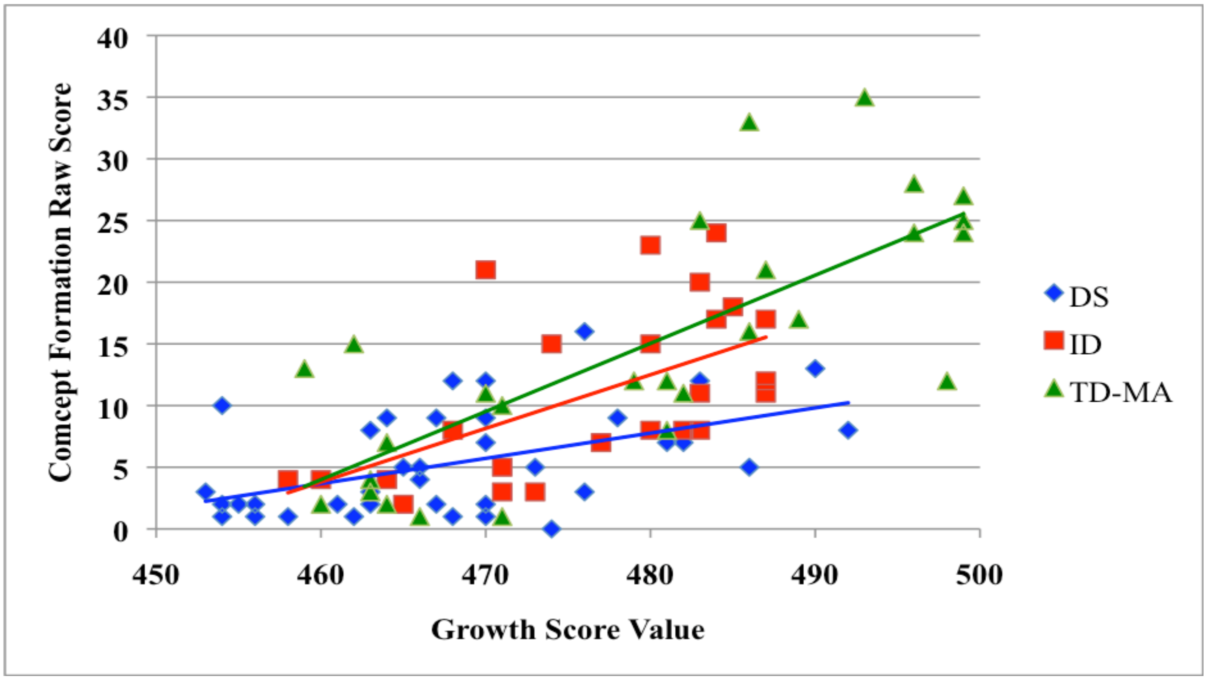

Figure 4. Growth rate of WJ-III Concept Formation over Leiter-R GSV.

Within-group trajectory analysis. The WJ-III trajectories and the Category Task trajectories showed different results. To further analyze the differences between these two tasks, we examined the within-group trajectories. Eight within-group ANCOVAs were conducted to compare the developmental trajectories of the WJ-III and the Category Task within the same group over CA and over GSV (four trajectories over CA and four trajectories over GSV). Z-scores were computed for the WJ-III and the Category Task to make the two tasks comparable. For these analyses, Task was the within-subjects factor, Age (or GSV) was the covariate, and Task x Age (or GSV) was the interaction term. Of these eight trajectories, only two showed significant differences in slope across the two tasks—the TD trajectory over CA, $F(1, 38) = 6.52$, $p = .015$, $\eta_p^2 = .147$, and the DS trajectory over GSV, $F(1, 39) = 9.91$, $p = .003$, $\eta_p^2 = .203$. In the TD-CA trajectory analysis, the WJ-III had a steeper slope than the Category Task. The Category Task slope was fairly flat with performance near the top of the scale. In the DS GSV trajectory analysis, the Category Task had a steeper slope than the WJ-III. The WJ-III slope was fairly flat with little variability in the performance.

Summary. The CA trajectory analyses showed that the DS and ID groups exhibited a delay in onset for the Category Task and the WJ-III, and the DS group also showed a slower rate in development for the WJ-III. The nonverbal ability trajectory analyses showed that neither group showed a delay in onset or slower rate of development for the Category Task, while the DS group showed a slower rate of development for the WJ-III. Finally, the within-group trajectory analyses showed that the WJ-III had a steeper rate of development over CA than the Category Task for the TD-CA group, and the Category Task had a steeper rate of development over GSV than the WJ-III for the DS group.

Exploratory Analyses

Thomas et al. (2009) suggest that the range of the covariate values (e.g., CA or Leiter-R GSV) must overlap between groups but are not required to be identical. However, we felt that the differences in CA (or Leiter-R GSV) ranges may be accounting for the intercept and slope differences. Therefore, we decided to restrict each analysis to participants within the same CA or GSV range. The new CA range was 10.25 years to 20.67 years, and the new GSV range was 459 to 487. For the CA analyses, this reduced the DS sample size from 41 to 39 and the TD-CA sample size from 40 to 37, but it did not reduce the ID sample size. For the nonverbal ability analyses, this reduced the DS sample size from 41 to 31, the ID sample size from 25 to 24, and the TD-MA sample size from 27 to 19.

Chronological age-based developmental trajectory analysis. The Category Task trajectory revealed a main effect of Group, $F(2, 95) = 23.38$, $p < .001$, $\eta_p^2 = .330$, but no significant Group x CA interaction, $F(2, 95) = 0.64$, $p = .531$, $\eta_p^2 = .013$. Follow-up ANCOVAs examining the pairwise comparisons found a significant difference in the DS and TD-CA intercepts, $F(1, 72) = 78.81$, $p < .001$, $\eta_p^2 = .523$, and the ID and TD-CA intercepts, $F(1, 58) = 24.98$, $p < .001$, $\eta_p^2 = .301$, but not the DS and ID intercepts, $F(1, 60) = 0.00$, $p = .964$, $\eta_p^2 = .000$. The TD-CA group had a higher intercept than both the DS group and the ID group, which were not significantly different from one another. This intercept difference signifies a delay in onset in explicit learning for the DS and ID groups (see Figure 5 and Table 3). These findings are identical to those of the original trajectory.

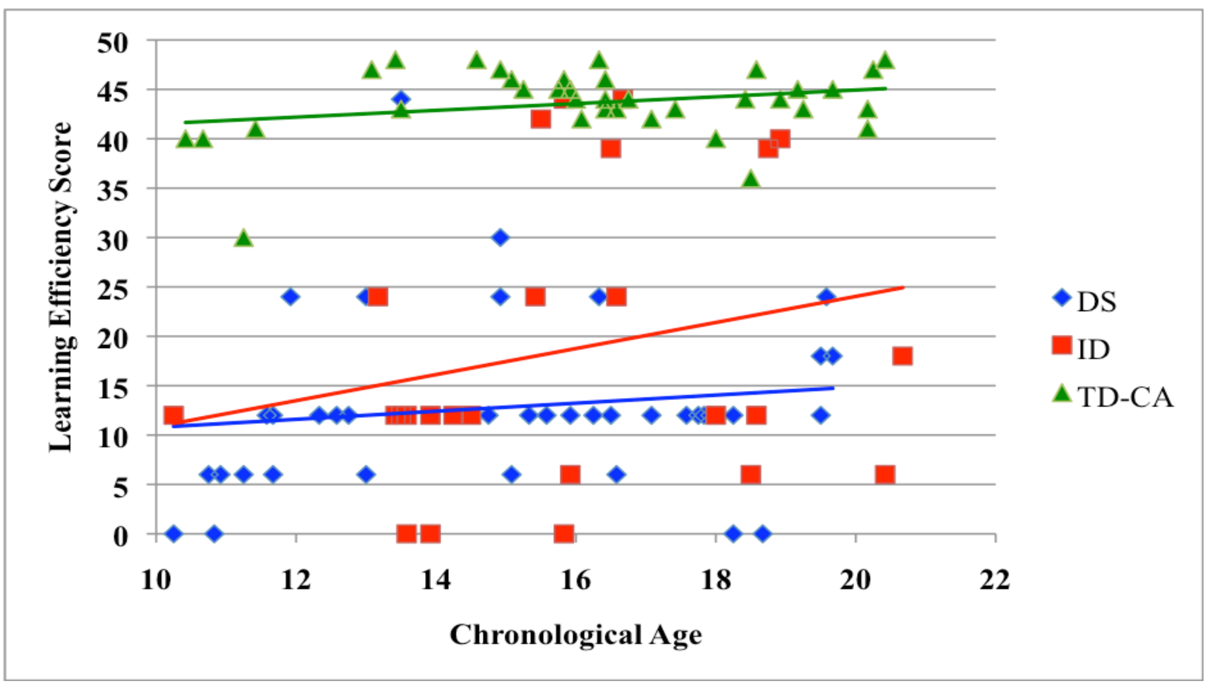

Figure 5. Growth Rate of Category Task over CA with subsample of participants.

The WJ-III trajectory revealed a main effect of Group, $F(2, 95) = 26.47$, $p < .001$, $\eta_p^2 = .358$, and a significant Group x CA interaction, $F(2, 95) = 4.85$, $p = .010$, $\eta_p^2 = .093$. Follow-up ANCOVAs examining the pairwise comparisons found a significant difference in the DS and

TD-CA intercepts, $F(1, 72) = 55.58$, $p < .001$, $\eta_p^2 = .436$, the ID and TD-CA intercepts, $F(1, 58) = 23.92$, $p < .001$, $\eta_p^2 = .292$, the DS and TD-CA slopes, $F(1, 72) = 10.26$, $p = .002$, $\eta_p^2 = .125$, and the DS and ID slopes, $F(1, 60) = 4.45$, $p = .039$, $\eta_p^2 = .069$, . Significant differences were not found for the DS and ID intercepts, $F(1, 60) = 0.00$, $p = .986$, $\eta_p^2 = .000$, or the ID and TD-CA slopes, $F(1, 58) = 0.16$, $p = .687$, $\eta_p^2 = .003$. Similar to the Category Task, the TD-CA group had a higher intercept than both the DS group and the ID group, which were not significantly different from one another. This intercept difference signifies a delay in onset in explicit learning for the DS and ID groups. Additionally, the DS group had a flatter slope than both the TD-CA and ID groups, which were not different from one another. This slope difference signifies a slower rate in development in explicit learning for the DS group (see Figure 6 and Table 3). These findings are identical to those of the original trajectory.

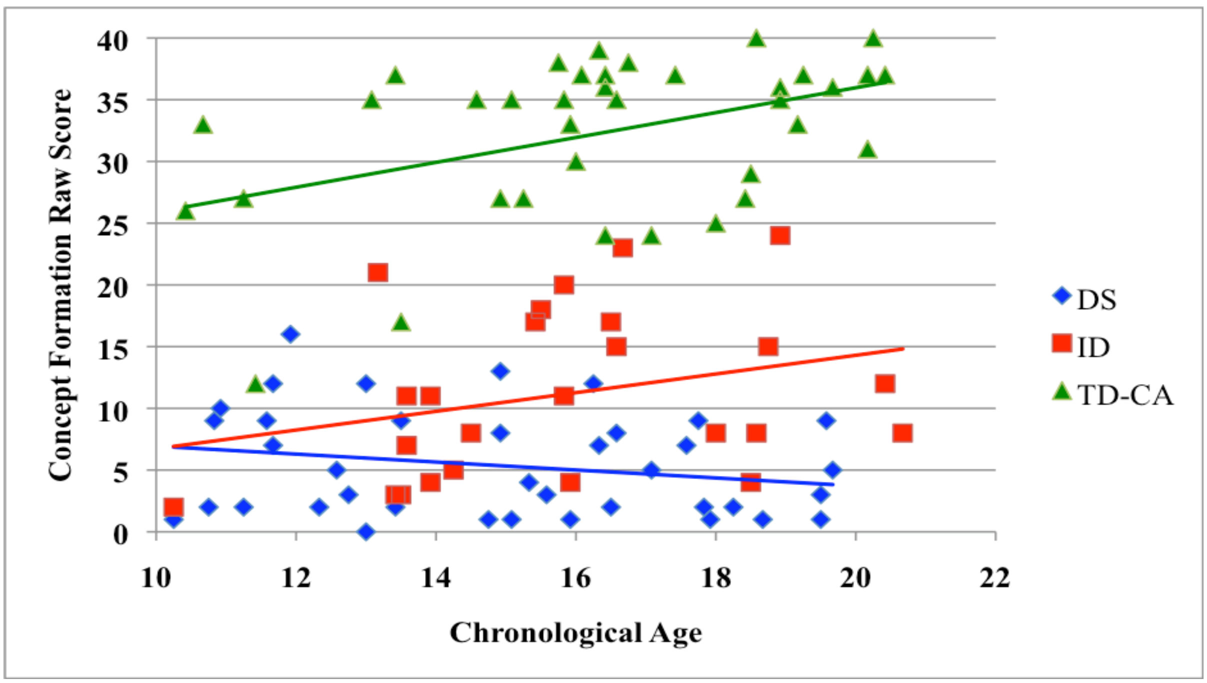

Figure 6. Growth rate of WJ-III Concept Formation over CA with subsample of participants.

Nonverbal ability-based trajectory analysis. The Category Task trajectory revealed no overall effect of Group, $F(2, 68) = 0.68$, $p = .510$, $\eta_p^2 = .020$, and no significant Group x Leiter-

R GSV interaction, $F(2, 68) = 0.05$, $p = .948$, $\eta_p^2 = .002$. The intercepts and slopes were similar for all three groups, which signifies that no group showed a delay in onset or slower rate of development in explicit learning (see Figure 7 and Table 3). These findings are identical to those of the original trajectory. The WJ-III trajectory revealed no overall effect of Group, $F(2, 68) = 0.00$, $p = .997$, $\eta_p^2 = .000$, and no significant Group x Leiter-R GSV interaction, $F(2, 68) = 1.77$, $p = .177$, $\eta_p^2 = .050$. The intercepts and slopes were similar for all three groups, which signifies that no group showed a delay in onset or slower rate of development in explicit learning (see Figure 8 and Table 3). These findings differ from those of the original trajectory, which found a significant Group x Leiter-R GSV interaction. While significance was lost in the current analysis, the pattern remains the same with the DS slope being flatter than the TD slope.

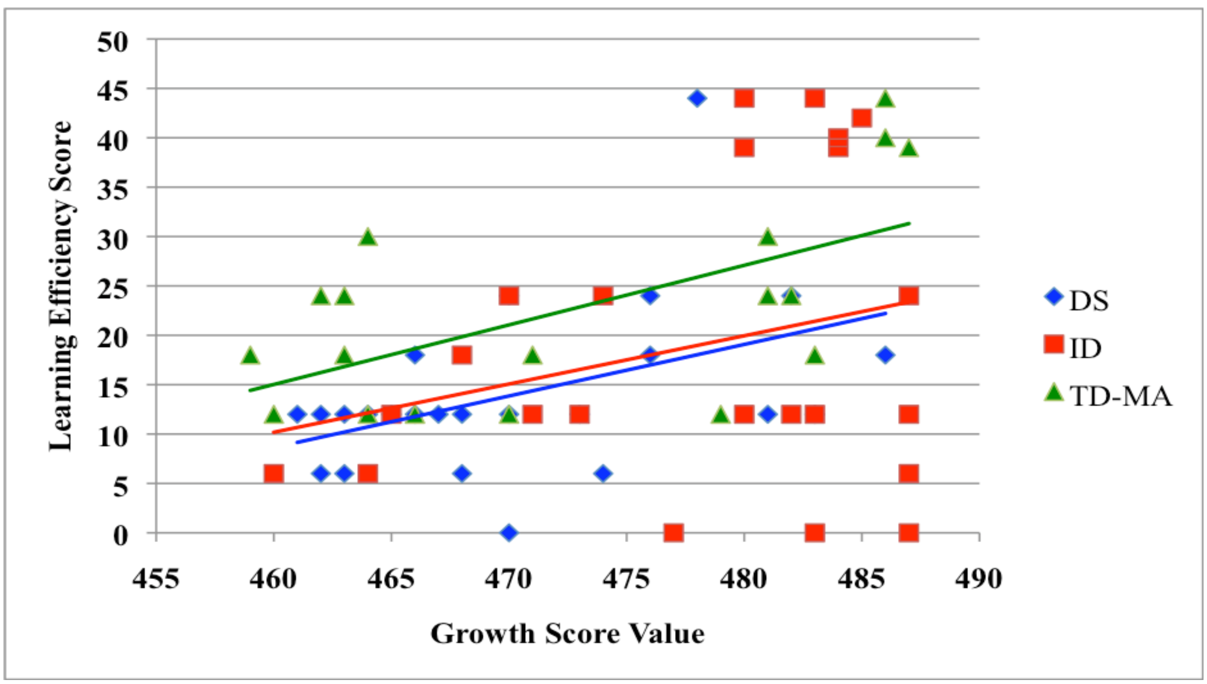

Figure 7. Growth rate of Category Task over Leiter-R GSV with subsample of participants.

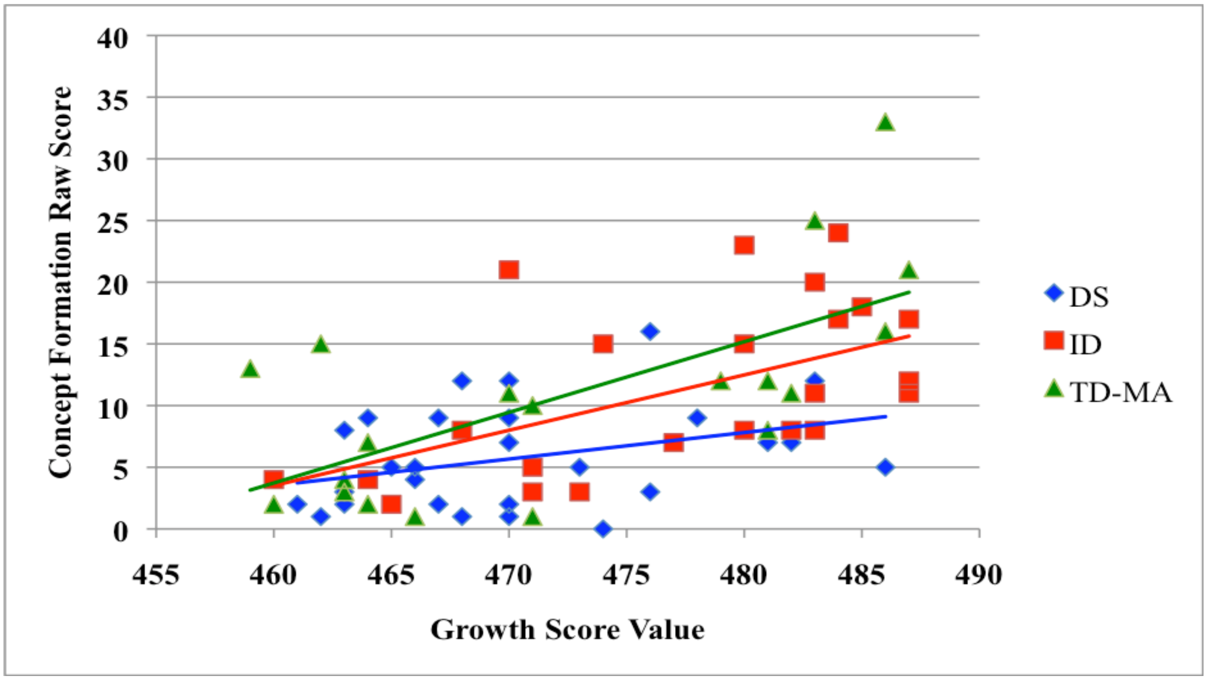

Figure 8. Growth rate of WJ-III Concept Formation over Leiter-R GSV with subsample of participants.

Summary. These exploratory analyses restricted the sample size to include only participants from each group that fell within the same CA range and GSV range. All of the results for both the CA trajectory analyses and the nonverbal ability trajectory analyses were the same except for the trajectory analysis of the WJ-III over GSV. This analysis found that the DS group did not show a slower rate of development, while the original analysis did find a slower rate of development. The exploratory analysis failed to reach significance, but the DS group still displayed the same slope pattern as the original analysis.

CHAPTER 4

DISCUSSION

The purpose of the current study was to analyze the cross-sectional developmental trajectories of explicit category learning in individuals with DS compared to individuals with ID and TD individuals. Developmental trajectories of the WJ-III Concept Formation task and the Category Task were created separately both over CA and nonverbal ability. We hypothesized that the DS group would show a delay in onset and a slower rate of development in explicit learning over CA compared to the ID and TD-CA groups, and we hypothesized that the DS group would also show a delay in onset and a slower rate of development in explicit learning over nonverbal ability compared to the ID and TD-MA groups.

In the CA trajectories, as expected, individuals with DS showed a delay in onset in explicit learning compared to the TD-CA group for both the WJ-III and the Category Task. This suggests that at the youngest age included in this analysis (10 years), those with DS were performing more poorly on both category learning tasks than same-age peers without ID. There was no difference between DS and ID groups in onset, however, suggesting that the poorer performance at the youngest age tested is not specific to DS, but rather, is general to ID.

Also, as expected, individuals with DS showed a flatter slope over CA on the WJ-III compared to the ID and TD-CA groups. This suggests that the rate of growth of category learning is slower for youth with DS than youth with ID or TD from age 10 to 21 years. Though category learning increased with CA on the WJ-III for both ID and TD groups, there was actually no apparent growth over CA in the DS group. Performance in this group was fairly poor regardless of CA.

Contrary to expectations, however, there was no group difference in slope on the Category Task. This can be attributed primarily to the flat slope in the TD-CA group. Even though there were no serious violations of normality, 95% of the TD-CA group's scores on the Category Task fell between 40 and 48, which is the upper range of scores. There was variability within these upper scores, but the variability was not enough to create a steeper slope and show significant growth. Had this task allowed for greater variability in the TD-CA group, significant slope differences might have been found. Also, while little variability was found in the TD-CA group on the Category Task, there was large variability in the ID group. Though the pattern of slopes for the DS and ID groups was very similar on the Category Task to that on the WJ-III, the difference in slopes on the Category Task was not significant. The reason for the high variability in the ID group is unclear, but it could have to do with the wide range of etiologies in this group. Further examination of this group may be helpful in addressing this issue.

The nonverbal ability trajectories for both the Category Task and WJ-III indicated that individuals with DS did not show a delay in onset in explicit learning compared to the ID and TD-MA groups for either task. This is contrary to what we hypothesized based on the background literature. The DS group did not show a delay in onset; instead, the individuals with DS began at the level of explicit learning that would be expected for their nonverbal ability.

The slope results from the WJ-III indicated a slower rate of development in explicit learning over nonverbal ability for the DS group compared to the TD-MA group. Although this is consistent with expectations, the same result was not found for the Category Task. In the Category Task, all three groups increased performance with increasing nonverbal ability, and there was no significant group difference in slopes. Thus, on this task, the group with DS showed a similar rate of growth in category learning over the range of nonverbal age 4-9 years as the TD and ID groups. As in the CA trajectory, the Category Task showed large variability in the ID group.

Finally, within-subject developmental trajectories were conducted to see if the two explicit learning tasks were developing at different rates within the same group. We found that the rate of growth in category learning was different in the TD trajectory over CA and the DS trajectory over GSV. The TD-CA group showed a slower rate of growth in the Category Task than the WJ-III, and the DS group showed a slower rate of growth in the WJ-III. The TD-CA group was restricted in the Category Task because the majority of the participants scored high on this task. This lack of development supports the non-significant interaction found in the original between-subjects trajectory. Had the TD-CA group not been limited in performance by this task, significant differences in the rate of growth between the TD-CA group and the DS group might have been found. The DS group was restricted in the WJ-III because their scores were low and had little variability, which would support the significant interaction found in the original between-subjects trajectory. Further, the steeper rate of growth on the Category Task corresponds with the lack of a significant interaction in that original trajectory. Had the DS group not been limited in performance by the WJ-III, the results from the WJ-III trajectory might have been similar to the results from the Category Task trajectory.

Exploratory Analysis

To explore whether the significant findings could be due to the difference in CA (or Leiter-R GSV) ranges across groups, we restricted the sample size so that the ranges in CA (or Leiter-R GSV) were the same across groups. However, the only difference from the original trajectories that we found was that the individuals with DS no longer showed a slower rate of development in explicit learning over nonverbal ability compared to the TD-MA group for the WJ-III. While not significant, the results of this trajectory did show the same pattern with a slower rate of development in the DS group compared to the TD-MA group. Therefore, this non-significant finding could be due to a lack of power in the analysis. A larger sample size in the nonverbal ability trajectory analysis would determine whether or not a developmental difference truly exists.

Differences Across Tasks

One of the most interesting findings in the present study is that, in the analysis of explicit category learning across nonverbal ability, group differences in slope depended on the task. The DS group showed a flatter slope than the TD group on the WJ-III Concept Formation task but not on the Category Task. Because these tasks both measure explicit category learning, this result was unanticipated. Several similarities exist between the two measures; they both involve shapes, colors, and numbers of shapes, ask participants to determine the "rule," and provide feedback on whether the item was correct or incorrect. However, the tasks also differ in some important ways.

One clear difference is that the Category Task requires the participant to look for similarities, whereas the WJ-III requires the participant to look for differences. In the Category Task, the participant matches each card with one of the standard cards on similarity of color, shape, or number. In the WJ-III, the participant determines what is different about the shape(s) that are in the box from those outside the box. Possibly, understanding the concept of different is more difficult developmentally than understanding the concept of similar. However, this explanation of the differing results would only make sense if it were plausible that the DS group struggles more than the TD group and ID group on understanding the concept of different. No research that we are aware of has examined such cognitive differences within a TD group or otherwise. To confirm this explanation, future studies could examine developmental differences in understanding similarity and difference and then compare the development of these concepts across groups.

Another major difference that we observed in the tasks was that the WJ-III Concept Formation task has a verbal component that the Category Task does not. The first five trials require participants to point to the shape that is different, but after these five trials, participants are required to verbally state what is different about the shape(s) in the box from the shapes outside of the box (e.g., small, big, red, yellow, two, one). The Category Task, in contrast, does not require any type of verbal response; rather, participants must simply match the card to one of the four standard cards. Due to the known expressive language impairments in DS (Boudreau & Chapman, 2000; Chapman, Seung, Schwartz, & Bird, 1998; Dykens, Hodapp, & Evans, 1994; Finestack & Abbeduto, 2010; Price et al., 2008; Rosin, Swift, Bless, & Kluppel Vetter, 1988), the verbal component of the WJ-III may be limiting the DS group's performance on this task, resulting in a slower rate of development and a lack of variability in this group's scores compared to the scores on the Category Task. This verbal limitation may be similar to that found in short-term memory tasks, where individuals with DS perform below their MA level when the task involves verbal material but similar to their MA level when the task involves visual or spatial material (Conners et al., 2011). Future studies should include an expressive language measure in the analysis to see if this explanation is empirically supported. However, it seems a plausible explanation, which if confirmed empirically, would suggest that explicit category learning itself—apart from verbal response requirements—is not particularly poor relative to nonverbal ability in DS. Youth with DS are similar to those with TD and ID at a nonverbal age-equivalent of 4 years, and their growth from age equivalent of 4-9 years, is similar to that of youth with TD and ID.

Differences in DS Findings

This interpretation differs, however, from previous studies that showed a clear deficit in visuospatial explicit learning in a DS group compared to a TD-MA group (Pennington et al., 2003; Vicari et al., 2000; Vicari et al., 2005). These studies used a virtual water maze task, a block sequence task, and an object identification task to measure explicit learning. All of these tasks have a heavy memory component, where participants are exposed to a stimuli, asked to remember the stimuli, and then tested on well they remember the stimuli. For example, on the block sequence task (Vicari et al., 2000), participants are exposed to a sequence that is two blocks longer than their memory span, and then they are given ten tries to get the test sequence correct. These tasks may measure the ability to expand memory skills moreso than they measure explicit learning, and the ability to expand memory skills could be more difficult for those with DS than TD controls. Neither of our explicit learning measures had a heavy memory component, which could account for the differences in results.

However, Lanfranchi and colleagues (2010) conducted a study using the same Category Task used in the current study, and they found significant differences between the DS group and the TD-MA group. In comparing the two studies, the task was identical, the DS and TD-MA sample were very similar in CA and MA, and the nonverbal ability measures used to match the groups were fairly comparable. Consequently, the only major difference in the studies was that we were examining intercept and slope differences, while Lanfranchi et al. were examining mean differences. This also applies to the visuospatial explicit learning studies mentioned above. All of those studies were looking for mean differences, and we were looking for intercept and slope differences. The hypotheses that we made were based on these previous studies, and while the current data did not always conform to the study hypotheses, they may not necessarily be in contradiction to the background literature because of the different analyses used. To replicate the Lanfranchi et al. study, we individually matched 16 participants with DS to 16 TD-MA participants. We matched on the Leiter-R age equivalence score within 3 months, just as was done in the previous study. Additionally, we used number of categories passed on the Category Task instead of the learning efficiency score to make the analyses identical to the Lanfranchi et al. study. We then performed a two-tailed t-test and found that there was a significant difference between the two groups ($t = -2.42$, $p = .029$) with the DS group passing a fewer number of categories than the TD-MA group. Therefore, when running the analyses in the same way as Lanfranchi et al., we were able to replicate their results. This showed that the differences found in the current study were not a contradiction to this previous study; rather, the current analyses simply provide a different way of looking at the data.

Limitations of Current Study

This was the first study to examine the cross-sectional developmental trajectory of explicit category learning in DS, and while this study greatly improves our understanding of explicit learning in this population, several limitations exist. First of all, certain aspects of our sample were not optimal. We had eight older TD participants who had low standard scores and age equivalents on the Leiter-R that put them into the TD-MA group. We included these participants in the nonverbal ability analyses to increase the statistical power, but their older CA could be a confound to these analyses. Additionally, the distributions of the two explicit learning measures were not perfect for every group. We judged that there were not serious violations to normality, but the lack of perfectly normal distributions could be influencing the results.

More generally, the findings from this study were about explicit category learning specifically, and they may not generalize to other types of explicit learning such as paired-associate learning, list learning, or location learning. The trajectory analysis approach would need to be applied to other types of explicit learning to determine the generalization of the current results. Finally, this study utilized cross-sectional data to create a developmental trajectory, but a longitudinal trajectory would obviously provide more reliable results. There are clear limitations to using cross-sectional data to draw conclusions about growth. Different IQs and different CAs may have interacted in the current analyses. More specifically, within the CA analyses, IQ was allowed to vary and this could influence the results, and within the nonverbal ability analyses, CA was allowed to vary and also could influence the results. The cross-sectional developmental trajectory approach allows one to infer group change over time or over increasing ability, which provides more information than the static analysis of differences used in group matching approaches, but it does not allow one to examine actual change over time. This information can only be gained from a longitudinal analysis. While the cross-sectional developmental trajectory approach allowed us to examine how explicit learning varies at different CAs (or Leiter-R GSVs), it only provided an approximation of development. However, this approach has fewer practical limitations than a longitudinal study and provides a richer understand of the target skill than the typically used matching approach, making it the best option for the current study.

Directions for Future Research

Future research should first confirm the conclusions drawn from the current study by empirically examining the explanations given for the different results of the two explicit learning tasks. For example, future work could analyze group differences between the development of the concept of "different" versus the development of the concept of "similar." Future work could also investigate the effect of expressive language abilities on the current results. Additionally, more research is needed to fully understand the development of explicit learning in DS compared to TD and ID. To be able to see the actual development of explicit learning, longitudinal research is required. Finally, future research should use the cross-sectional developmental approach to expand to other types of explicit learning and to other cognitive abilities. This approach provides a more informative way to empirically study developmental questions but remains underutilized in current research on intellectual and developmental disabilities.

Conclusion

Based on the current analyses and discussion, one can conclude that in comparison to TD individuals and individuals with mixed-etiology ID, individuals with DS show similar performance in and development of explicit category learning in relation to their nonverbal ability as long as the explicit learning measure does not constrain their performance. Results of the present study have important implications for education. The use of visuospatial explicit learning techniques may potentially facilitate category learning in individuals with DS, while explicit learning techniques that require verbal abilities seem less promising. However, future research is still needed to apply what we have described to an education setting to determine the actual clinical efficacy of these findings.

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