Research in Developmental Disabilities 35 (2014) 2933–2941

Contents lists available at ScienceDirect

Research in Developmental Disabilities

Patterns of change in nonverbal cognition in adolescents with Down syndrome

Marie Moore Channell [a,*], Angela John Thurman [a], Sara Teresa Kover [b], Leonard Abbeduto [a]

[a] MIND Institute, University of California, Davis, United States
[b] University of Washington, United States

ARTICLE INFO

Article history:
Received 1 May 2014
Received in revised form 2 July 2014
Accepted 7 July 2014
Available online 9 August 2014

Keywords:
Down syndrome
Cognitive development
Nonverbal abilities
IQ
Leiter-R

ABSTRACT

This study was designed to examine longitudinal change in nonverbal cognitive abilities across adolescence for 20 males with Down syndrome (DS). We used hierarchical linear modeling to examine the rate of change in performance on the subtests of the Leiter-R Brief IQ across four annual time points and to determine the relation between maternal IQ and level and rate of change in performance. Results indicated no significant change in IQ (standard scores) with age in the sample, suggesting IQ stability during adolescence for individuals with DS, although several participants performed at floor level on the standard scores for the Leiter-R, limiting interpretation. Growth scores, however, provide a metric of absolute ability level, allow for the examination of change in Leiter-R performance in all participants, and minimize floor effects. Results from the analysis of growth scores indicated significant gain in absolute nonverbal cognitive ability levels (growth score values) over time for the adolescents with DS, although the growth varied by subdomain. Maternal IQ did not explain variability in cognitive performance or change in that performance over time in our sample of adolescents with DS.

With a prevalence of approximately 1 in 691 births, Down syndrome (DS) is the leading known genetic cause of intellectual disability (Parker et al., 2010). DS is caused by a triplication of all or part of chromosome 21, with most cases resulting from full trisomy 21. Although the cause of DS has been identified, its cognitive and behavioral phenotype is less clear, and the developmental emergence of the phenotype is largely unexplored (Fidler, 2005; Rasmussen, Whitehead, Collier, & Frías, 2008; Silverman, 2007). In fact, characterization of the emerging DS phenotype was listed recently by a consortium of leading experts in the field as one of the highest prioritized public health topics for which more research on DS is needed (Rasmussen et al., 2008). Such characterization would provide insight into the nature of the underlying neuropathology in DS and help clinicians and education specialists better tailor interventions to promote cognitive development in this population.

Fundamental to understanding DS is determining the developmental course of its cognitive phenotype (Karmiloff-Smith, 1997, 1998). Standardized tests of intelligence [e.g., Stanford-Binet Intelligence Scales-5 (Roid, 2003), Wechsler Intelligence Scale for Children-IV (Wechsler, 2003), etc.] are commonly used to measure general cognition and can be used to track change in cognitive skills over time. Using age-based norms, such tests provide standard scores that evaluate performance

* Corresponding author at: 2825 50th Street, Sacramento, CA 95817, United States. Tel.: +1 916 703 0425; fax: +1 916 734 8294.
E-mail addresses: marie.channell@ucdmc.ucdavis.edu (M.M. Channell), angela.thurman@ucdmc.ucdavis.edu (A.J. Thurman), skover@uw.edu (S.T. Kover), leonard.abbeduto@ucdmc.ucdavis.edu (L. Abbeduto).

http://dx.doi.org/10.1016/j.ridd.2014.07.014
0891-4222/

relative to chronological age expectations. Thus, if an individual gains cognitive skills at the average rate expected for his or her chronological age, the standard score, or IQ, will remain stable over time. Raw scores or growth scores, however, can be more informative when tracking gain in skills over time, especially in populations where growth may occur slowly, because these scores reflect absolute level of ability. For example, in populations of individuals with intellectual disability, it is not uncommon for standard scores to decrease over time (Kover, Pierpont, Kim, Brown, & Abbeduto, 2013). Unless an additional metric of cognitive ability is examined, it is unclear whether standard scores are decreasing because the rate of learning has slowed relative to age-matched typically developing peers, no acquisition of skills has occurred, or there has been regression. Raw scores can begin to answer this question because an increase in these scores represents gain in raw abilities; however, growth scores are more useful because they take into account item difficulty through scale corrections of raw scores and are comparable across ages (Roid & Miller, 1997).

The primary aim of the present study was to map trajectories of nonverbal cognitive development across adolescence in individuals with DS. To do this, we used a prospective longitudinal design to track change in performance on the Leiter-R Brief IQ assessment (Roid & Miller, 1997) annually over a three-year period. The Leiter-R measures cognition that is assessed nonverbally, thereby providing a means of measuring nonverbal cognition without the burden of linguistic comprehension or production, each of which is particularly impaired in individuals with DS (Chapman & Hesketh, 2000). In order to determine if (1) the level of cognitive delay changed across time and (2) absolute levels of cognitive ability changed over time, we examined performance in terms of both standard scores and growth scores, respectively, on the Leiter-R.

Many researchers have described an IQ decline with age in individuals with DS, and this is a rather widely assumed phenomenon in the field of DS research. Longitudinal studies have documented a decrease in standard scores from various standardized IQ measures in individuals with DS (see reviews by Carr, 2005; Couzens, Cuskelly, & Haynes, 2011). However, the majority of these studies have focused on young children with DS. These studies provide evidence for an early rapid decline in standard scores with age during infancy (Carr, 1970; Dameron, 1963; Dicks-Mireaux, 1972; Piper & Pless, 1980) and early childhood (Carr, 1988; Share, Koch, Webb, & Graliker, 1964), and on a variety of standardized tests [i.e., Bayley Scales of Infant Development (Bayley, 1969), California First Year (Bayley, 1933), Griffiths Mental Scales (Griffiths, 1954, 1970), Gesell Developmental Scales (Gesell & Amatruda, 1941)]. A reasonable explanation for this early rapid decline is that during the first two to three years of life, typically developing infants demonstrate a surge in cognitive development (Lamb, Bornstein, & Teti, 2002). As this surge occurs, the differences between typically developing children and those with DS, who are acquiring new skills more slowly, become more pronounced, resulting in an increasing lag in standard scores for young children with DS. Evaluating that possibility, however, requires moving beyond standard scores to raw scores or, preferably, growth scores. Such data would provide a metric of how much gain in raw cognitive abilities occurs during this timeframe in young children with DS.

Cognitive development during later childhood and adolescence in individuals with DS is even less well understood. Adolescence is characterized by another surge in cognitive development in typical development (Keating, 2004). However, such cognitive change has not been adequately studied in those with DS, with only two longitudinal studies directly addressing the topic (Carr, 1988; Crombie & Gunn, 1998).

Carr (1988) examined cognitive change across childhood and adolescence in a cohort of individuals with DS by comparing their standardized test scores at ages 4, 11, and 21 years. At age 4, participants were administered the Bayley Scales of Mental and Motor Development (Bayley, 1969). They were administered the Merrill-Palmer Scale (1948) at age 11 and the Leiter International Performance Scale (1980) at age 21. The group's standard scores at age 11 were significantly lower than their standard scores from age 4. However, there was no significant difference between standard scores at ages 11 and 21, suggesting that the *rate* of cognitive development was consistent with that expected for this chronological age period. This conclusion, however, is tentative at best due to the use of different standardized measures at each time point. The specific types of cognitive abilities assessed as well as the manner in which such abilities are measured vary dramatically across these tests. For instance, the Merrill-Palmer includes several verbal items and is administered with verbal instructions, whereas the Leiter is completely nonverbal in administration and the concepts measured. Given the known disparity between verbal and nonverbal test performance in individuals with DS (see Næss, Lyster, Hulme, & Melby-Lervåg, 2011), standard scores can be difficult to compare when different types of items (verbal and nonverbal) are used. However, it can be a major challenge in the design of longitudinal studies to find a single test that is appropriate for individuals with DS at different ages. For example, tests designed to assess early developmental skills are often not normed for older chronological ages because in typical development, adolescents or young adults would be expected to perform at ceiling on such a test. As a consequence, no chronological age norms are available on such tests for adolescents and young adults who have cognitive delays (e.g., DS) even though their mental ages fall within the range of the tests. Thus, the challenge in designing a longitudinal study of DS is to find a single standardized test that is normed across a wide enough age range and allows for the appropriate assessment of the cognitive delays observed in this population. A focus on cognitive change within a narrower time frame, such as during adolescence, is one way to circumvent this issue.

In their longitudinal study of cognition in school-age individuals with DS, Crombie and Gunn (1998) used two standardized tests, both administered at multiple time points. Participants were administered the Stanford-Binet Intelligence Scale, Third Edition (Terman & Merrill, 1972) at ages 11, 12, and 14 years, along with the Hiskey Nebraska Test of Learning Aptitude (Hiskey, 1966), a measure of nonverbal cognition, at ages 11 and 12. Participants overall showed a significant increase in mental age (MA) equivalence scores at each time point for both measures, indicating gain in overall cognitive ability and in nonverbal cognitive ability over time. However, the psychometric properties of MA equivalence

scores limit comparisons across different chronological ages because these scores are not on an equal interval scale; in other words, a steady increase in performance does not correspond to a steady increase in MA. Further, no raw scores or standard scores were reported for Crombie and Gunn's (1988) sample, making interpretation challenging.

Studies by Couzens et al. have included broad samples extending beyond adolescence but offer important insights into how studies of adolescence should be designed. Couzens et al. (2011) examined longitudinal change in both verbal and nonverbal cognitive skills in cohorts of individuals with DS across a wide age range (from 4 to 24+ years). Not surprisingly, the authors observed an increase in raw scores on the Stanford Binet Intelligence Scale, Fourth Edition (SB:IV; Thorndike, Hagen, & Sattler, 1986) from childhood to early adulthood. However, because of the wide variability in the ages of participants as well as in the number and timing of the longitudinal assessments, few conclusions could be drawn about change in performance within the narrower window of adolescence. Nonetheless, it is noteworthy that there were differences in the rate of growth across subtests of the SB:IV, demonstrating the importance of examining separately the trajectories of development across the different domains measured by a single standardized measure of intelligence. Identifying differences across cognitive domains may provide clues to the specific difficulties in real-world functioning that limit performance on daily tasks and full participation in community life. Likewise, the present study examined trajectories of change in nonverbal cognition for each of the Leiter-R Brief IQ subtests (Roid & Miller, 1997).

In follow up analyses to Couzens et al.'s (2011) study, Couzens, Haynes, and Cuskelly (2012) examined potential predictors of this cognitive change evidenced in individuals with DS. Specifically, they found several predictors of both level of performance at study entry and change in performance over time that varied across subtests, with aspects of child temperament (i.e., persistence) and maternal education predicting growth in the subtests measuring nonverbal abilities. Theirs was one of the first studies to identify predictors of cognitive development in individuals with DS. Additional research is needed to identify other potential genetic and environmental predictors of cognitive development within this population, especially during more well-defined developmental periods such as adolescence.

One potentially important predictor for cognitive development in DS is maternal IQ. In typical development, maternal IQ and child IQ are strongly linked, even beyond factors such as maternal education or quality of the home environment (Tong, Baghurst, Vimpani, & McMichael, 2007). Although the evidence suggests that maternal IQ could play a role in determining child IQ through its genetic correlation, it is inconclusive because it is difficult to separate the genetic from all potential environmental factors that are closely linked to maternal IQ (e.g., access to early intervention, stress management strategies, differences in interpretation of preventative public health messages, etc.). Further, recent research points to potential epigenetic effects (i.e., environmental effects on genes) as well (Bird, 2007), particularly in genetic syndromes associated with intellectual disability (Grafodatskaya, Chung, Szatmari, & Weksberg, 2010). Regardless of mechanism, maternal IQ is a strong predictor of cognitive ability in typically developing children. This link, however, has not yet been evaluated in DS. Thus, a secondary aim of the present study was to examine maternal IQ as a predictor of performance and growth in performance on each subtest of the Leiter-R in our sample of adolescents with DS. This is useful before determining the separate contributions of the genetic and environmental correlates of maternal IQ.

With the trajectory of cognitive development in DS still largely unknown, focused longitudinal studies of cognitive skills assessed by a consistent measure across time are needed to delineate the pattern of cognitive development within this population. In the present study, we aimed to accomplish this by examining longitudinal change in performance on the Brief IQ subtests of the Leiter-R across four annual time points in adolescents with DS. We also examined the relationship of maternal IQ to performance and growth in performance on the Leiter-R. For an even closer inspection of cognitive change in youth with DS, we mapped trajectories of performance separately for each of the four subtests of the Leiter-R Brief IQ assessment. Understanding these trajectories will provide more specific information about how different cognitive skills emerge during the adolescent period in DS. This should, in turn, aid clinicians in improving outcomes for individuals with DS by developing more targeted interventions to promote cognitive development and change these trajectories.

1. Method

1.1. Participants

Participants for the present study were drawn from a larger longitudinal project of children and adolescents with neurodevelopmental disorders, including DS, and they overlap with participants described in prior studies (Finestack, Sterling, & Abbeduto, 2013; Kover, McDuffie, Abbeduto, & Brown, 2012; Oakes, Kover, & Abbeduto, 2013). The present study focused solely on the sample with DS and their biological mothers. Original study inclusion criteria for the participants with DS included a chronological age of 10–15 years and co-residence with their biological mothers at enrollment as well as parent report that the individual with DS used speech as the primary mode of communication, was a native English speaker, could produce at least 3-word phrases in everyday speech, functioned generally at the kindergarten level or higher, and had no major uncorrected physical or sensory impairments that would interfere with the ability to perform in the project. We relied on parent report or, when available, physician diagnostic report of a diagnosis of DS. All but two participants in our final sample had a diagnosis of Trisomy 21; cause of DS (trisomy, mosaic, or translocation) was unknown for the other two participants. Participants were recruited through a university registry of families who have a child with a neurodevelopmental disorder and postings on websites and listservs of relevant parent support groups and organizations.

A total of 30 individuals with DS (20 males; 10 females; *M* age = 12.75, *SD* = 1.73) met study criteria, and they along with their biological mothers were enrolled; however, because of the specific aims of the larger project, only males were followed longitudinally. Thus, only the 20 males with DS (19 Caucasian, 1 Hispanic) and their biological mothers were included in the present analyses. The participants with DS completed annual assessments across three years for a total of up to four assessments. At the initial visit, mothers were administered an overall IQ assessment along with other measures not included in the present analyses. See Table 1 for descriptive statistics of the participants with DS and their mothers.

1.2. Measures

1.2.1. Dependent measure: nonverbal cognition

The Leiter International Performance Scale-Revised (Leiter-R; Roid & Miller, 1997) is a standardized measure of nonverbal cognition normed for ages 2–21 years. Administration is nonverbal; examiners use pantomime to communicate instructions to examinees, and participants respond nonverbally (e.g., by moving a drawing into its place in a sequence). Each subtest consists of items of increasing difficulty as the administration progresses, and administration continues until the examinee reaches his or her ceiling score.

The four subtests of the Leiter-R Brief IQ screener were given to participants with DS at each of the four time points. The Figure Ground subtest required participants to visually search for stimulus drawings embedded in complex pictures and point to their location within the pictures. Form Completion required participants to mentally synthesize pieces of drawings in order to match them to whole drawings using manipulatives (foam shapes) or stimulus cards. In Sequential Order, participants had to detect visual sequences and select the manipulative (foam shape) or stimulus card containing the next stimulus in the sequence. In Repeated Patterns, participants had to detect patterns within visual stimuli and select the appropriate stimulus shape or card to continue the pattern. For each participant's initial assessment, the examiner chose a start point commensurate with the estimated ability level of the participant based on parent report and initial interaction with the participant. For subsequent time points, start points were determined from the participant's Leiter-R performance at the prior assessment.

We used growth scores and standard scores in analyses. Reported test–retest reliability for the Leiter-R Brief IQ screener is $r = .88$; the Brief IQ screener correlates with the original Leiter IQ test (Leiter, 1980) at $r = .85$ and with the Performance IQ and Full Scale IQ of the Wechsler Intelligence Scale for Children, Third Edition (WISC-III; Wechsler, 1991) at $r = .85$.

1.2.2. Predictor: maternal IQ

The Kaufman Brief Intelligence Test, Second Edition (KBIT-2; Kaufman & Kaufman, 2004) was used to assess IQ, or general cognition, in the mothers of our participants with DS because the chronological age range of our mothers exceeded the upper boundary of the chronological age for the Leiter-R norming sample. The KBIT-2 is a standardized measure consisting of one nonverbal subtest (Matrices) that requires examinees to complete visual puzzles by selecting an option in a multiple-choice format and two verbal subtests that require examinees to point to pictures that represent words spoken aloud by the examiner (Verbal Knowledge) or provide verbal responses to questions read aloud by the examiner (Riddles). Items for each subtest increase in difficulty until the examinee reaches her ceiling score. We used a composite standard score to index IQ. According to the KBIT-2 manual, internal consistency reliability coefficients range from .89 to .96, and the KBIT-2 IQ correlates with the WAIS-III Full Scale IQ (Wechsler, 1997) for adults at $r = .89$. The KBIT-2 is normed for ages 4–90 years. We used the KBIT-2 rather than a measure of nonverbal intelligence because it is reasonable to assume that mothers can promote a child's nonverbal cognitive growth through both what they do and what they say when interacting with their children.

1.3. Data analysis

We used random intercept hierarchical linear models to estimate patterns of change in nonverbal cognition across the four time points in the participants with DS. Using HLM for Windows version 7.01 (Raudenbush, Bryk, Cheong, Congdon, &

Table 1
Participant characteristics at enrollment: means (standard deviations) and ranges.

	Mean (SD)	Range
Participants with DS		
Chronological age	12.88 (1.87)	10.16–15.93
Mental age equivalent[a]	4.70 (0.73)	3.13–6.08
IQ[a]	41.58 (5.83)	36–54
Mothers		
Chronological age	44.77 (6.54)	33.48–55.72
IQ[b]	110.00 (9.58)	93–133
Education level[c]	3.65 (0.59)	3–5

[a] Leiter-R Brief IQ screener.
[b] K-BIT2 composite IQ.
[c] 3: high school degree, 4: college degree, and 5: advanced degree.

du Toit, 2011), we entered Leiter-R scores as the outcome variable and chronological age as a Level-1 predictor. We utilized a variable-occasion design because chronological age varied across participants at onset (Time 1). We centered age at its grand mean (14 years) for ease of interpretation. Then, to determine if maternal IQ predicted ability level or rate of change in nonverbal cognition for the participants with DS, we entered the mothers' KBIT-2 Composite IQ scores as a Level-2 predictor variable. We estimated trajectories of Leiter-R scores across chronological age in five models, one predicting composite scores and four predicting each of the Leiter-R subtests.

2. Results

2.1. Preliminary analyses

For all models, there were 64 occasions across the 20 participants, with a total of 16 missing occasions across 9 of the participants. Each missing occasion was due to lack of administration of the Leiter-R at that time point because of noncompliance or study attrition; there were no partial Leiter-R administrations in this sample. There was not a significant difference in initial Leiter-R performance between the participants who had missing data (total growth score $M = 459.44$, $SD = 3.64$) and those without missing time points ($M = 461.10$, $SD = 9.50$), $t(17) = 0.49$, $p = .630$. There was also no significant difference in initial chronological age between those with ($M = 13.36$, $SD = 1.93$.) and without ($M = 12.44$, $SD = 1.80$) missing time points, $t(17) = 1.08$, $p = .296$.

2.2. Trajectories of Leiter-R performance

2.2.1. Composite scores

There was no significant change with age in Leiter-R Brief IQ scores (standard scores), $t(18) = -0.35$, $p = .729$ (Fig. 1). It should be noted, however, that seven participants (37%) scored at floor at the Time 1 assessment. Thus, it was not possible to determine the true trajectories of change in standard scores for these individuals. However, floor effects were not an issue in the subsequent analyses utilizing growth scores.

There was a significant linear increase with age in composite growth score values from performance on the Leiter-R, $t(18) = 4.62$, $p < .001$, with an average gain of 2.38 ($SE = .52$) points per year (Fig. 2). Maternal IQ (KBIT-2 IQ composite scores) was not a significant predictor of composite growth scores at intercept ($p = .412$), nor was it a significant predictor of change in overall growth scores ($p = .897$). See Table 2 for Leiter-R growth scores at each time point.

2.2.2. Figure Ground

There was a significant linear increase in Leiter-R growth scores with age for the Figure Ground subtest, $t(18) = 2.83$, $p = .011$. The average gain in growth scores was 1.93 ($SE = .68$) points per year. Maternal IQ was not a significant predictor of Leiter-R scores at intercept ($p = .515$) or of growth in Leiter-R scores ($p = .488$).

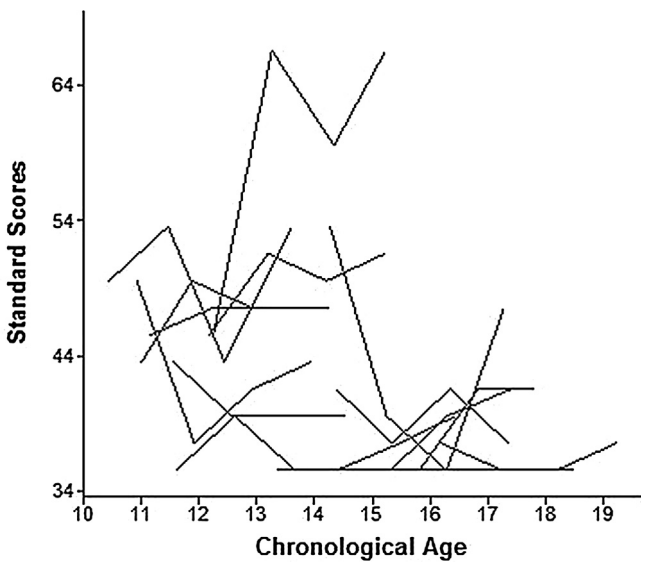

Fig. 1. Trajectories of Leiter-R Brief IQ standard scores among adolescents with Down syndrome. Each line represents an individual's trajectory of nonverbal cognitive standard scores across time.

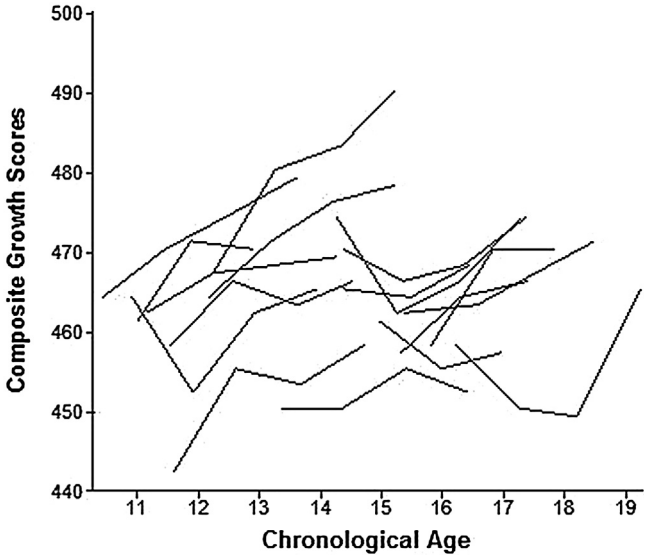

Fig. 2. Trajectories of Leiter-R Brief IQ composite growth scores among adolescents with Down syndrome. Each line represents an individual's trajectory of nonverbal cognitive growth score values across time.

Table 2
Means and standard deviations of Leiter-R growth scores.

	Time 1	Time 2	Time 3	Time 4
	$n = 19$	$n = 17$	$n = 15$	$n = 13$
Composite growth score	460.32 (7.20)	463.29 (8.43)	465.33 (9.15)	469.54 (9.83)
Figure Ground	462.00 (8.76)	465.82 (10.99)	465.33 (13.05)	471.00 (11.34)
Form Completion	466.32 (9.15)	470.29 (13.00)	472.27 (11.54)	475.31 (9.95)
Sequential Order	451.53 (6.37)	450.71 (8.28)	455.40 (10.07)	462.77 (13.00)
Repeated Patterns	462.21 (14.67)	468.12 (12.30)	469.40 (12.25)	470.38 (16.01)

Notes: Leiter-R Brief IQ composite growth scores are scaled from 372 to 548. Subtest growth score ranges = Figure Ground: 375–536; Form Completion: 391–526; Sequential Order: 405–541; Repeated Patterns: 414–529.

2.2.3. Form Completion

There was no significant linear increase in Form Completion growth scores with age, $t(18) = 1.99$, $p = .062$. Maternal IQ was not a significant predictor of Leiter-R scores at intercept ($p = .330$) or of growth in Leiter-R scores ($p = .765$).

2.2.4. Sequential Order

There was a significant linear increase in Sequential Order growth scores with age, $t(18) = 2.97$, $p = .008$. The average gain in growth scores was 2.25 ($SE = .76$) points per year. Maternal IQ was not a significant predictor of Leiter-R scores at intercept ($p = .518$) or of growth in Leiter-R scores ($p = .508$).

2.2.5. Repeated Patterns

There was no significant linear increase in growth scores on Repeated Patterns with age, $t(18) = 1.86$, $p = .079$. Again, maternal IQ was not a significant predictor of either Leiter-R scores at intercept ($p = .859$) or of change in Leiter-R scores ($p = .916$).

3. Discussion

We utilized a prospective longitudinal design to examine change in nonverbal cognition across four annual time points in adolescents with DS. In addition to determining overall change with age, we also focused on patterns of change across four subdomains of nonverbal cognition assessed by the Leiter-R Brief IQ battery. Finally, we examined whether maternal cognition predicted level or rate of change in cognition in their children with DS. This study was the first in-depth longitudinal examination of cognitive development focused solely on adolescence, a particularly important developmental period, in individuals with DS.

We used hierarchical linear modeling to estimate trajectories of Leiter-R scores across chronological age and to determine the influence of maternal cognition on these trajectories for each model. In the first model, to determine whether youth with

DS demonstrated change in overall nonverbal cognitive ability relative to age-based norms over the three-year span (i.e., change in IQ), we estimated trajectories of standard scores. There was no significant change in standard scores, indicating that the rate of learning may not change during adolescence for our participants with DS. This is an intriguing finding given that prior studies have documented declines in IQ during other developmental periods in DS (see Carr, 2005; Couzens et al., 2011). Caution should be used, however, when interpreting the present study's findings because 23–37% of the participants scored at the floor level of standard scores on the Leiter-R Brief IQ at each time point, which could mask the actual trajectories of IQ. In other words, we cannot accurately assess change in IQ standard scores across time for the participants who scored at floor level because a score at floor level reflects an IQ score either at, or indeterminately below, 36. Growth scores, however, provide a useful metric for observing *absolute* gain in nonverbal cognitive ability levels with age without the problematic floor effects often observed for standard scores. Thus, an examination of the change in growth scores is needed to clarify the findings for standard scores of our participants.

Consequently, we tested another model estimating trajectories of Leiter-R growth scores. There was a significant increase in composite growth scores across chronological age, indicating that youth with DS continued to develop general nonverbal cognitive abilities during adolescence. This illustrates that individuals with DS are learning and able to demonstrate new cognitive skills across adolescence, on average. This is not surprising given that we would expect cognitive growth and gain in raw ability levels during adolescence, a time period in which learning continues in typical development (Keating, 2004). This finding paired with the finding of stable IQ across age suggests that, although delayed, many adolescents with DS may be gaining skills at a consistent rate during the adolescent period.

An analysis of the trajectories of Leiter-R Brief IQ subtest growth scores across chronological age provided information about how much the participants with DS gained in each of four nonverbal cognitive domains. These analyses indicated a statistically significant increase in scores for Figure Ground and Sequential Order; there was no significant increase in Form Completion or Repeated Patterns scores, although both of these effects could be considered marginally significant. This pattern of change across subtests suggests significant gain in the ability to perform tasks requiring visual organization and deductive reasoning, but with rather minimal, non-significant gain in the ability to perform on tasks requiring fluid reasoning and inductive reasoning (Roid & Miller, 1997). These results provide a hint that the latter may be areas of relative difficulty in the cognitive domain for individuals with DS.

Clinically, fluid reasoning and inductive skills are important in strategic problem-solving, abstracting and generalizing rules, and other higher-order learning processes, particularly in novel situations. These skills are utilized across a variety of contexts that require reasoning, planning, and decision making (e.g., academic performance, social interaction, etc.). During social interaction, for example, an individual must not only be able to attend to and interpret social input (i.e., another person's behavioral expressions) but also reason through multiple scenarios and hypothetical outcomes, compare them to his or her own goals, and arrive at a decision on how to react behaviorally (Crick & Dodge, 1994). In an academic setting, fluid reasoning and inductive reasoning skills are heavily recruited, particularly during mathematics and reading comprehension (Cattell, Barton, & Dielman, 1972). The interpretation that, compared to lower-order form perception and visual-spatial processing, fluid reasoning skills are an area of relative difficulty for individuals with DS, however, is tentative because trajectories of these skills were not directly compared and because it is unknown whether we should expect equivalent gain across all four Leiter-R subdomains during the adolescent period. Future research is needed to determine whether there is a relative deficit in the acquisition of fluid reasoning and inductive skills for school-age individuals with DS, especially given the clinical and educational implications of these abilities.

There was a wide range of inter-individual variability within our sample, reflecting the heterogeneity of the DS phenotype. Despite such heterogeneity, the trends that emerged in the present study also suggest some continuity to the cognitive developmental phenotype within this disorder, at least across the adolescent period. To account for some of the individual variation, we tested the influence of maternal IQ on level and rate of growth in the cognitive abilities of the participants with DS. One prior study has examined the relation between family demographic variables and cognitive abilities in individuals with DS across a broad age range. In particular, Couzens et al. (2012) found that maternal education level was one of the significant predictors of child general cognitive ability (verbal and nonverbal). However, until now no study has specifically examined the relation between maternal cognition and child nonverbal cognitive ability in DS. In typical development, maternal IQ is a strong predictor of child IQ, even beyond the influence of demographic factors such as socioeconomic status (Tong et al., 2007). This relationship is often attributed to genetics, although potential environmental effects of maternal IQ (e.g., access to early intervention services, stress management strategies, preventative healthcare, etc.) cannot be ignored. In the present study, we found that maternal IQ did not significantly predict level of or change in general nonverbal cognitive ability or in any of the subdomains. It may be that other genetic and environmental factors are more crucial than maternal IQ in determining child cognitive outcomes for youth with DS. For example, the unique educational environments and intervention experiences of individuals with DS may interact with the overexpression of chromosome 21 associated with the genetic disorder to uniquely influence the development of underlying neurological processes that influence cognition (Silverman, 2007). More research is needed, however, to specify such potential factors. It is worth noting that, because we were interested in determining whether the general construct of intelligence (i.e., IQ), rather than individual task performance, of mothers predicted nonverbal cognition in children with DS, we used different instruments to assess maternal and child IQ. It is, therefore, possible that research studies evaluating maternal and child cognitive performance on the same test would result in a stronger relationship.

The findings of this study have several implications. First, they demonstrate that, not surprisingly, many individuals with DS do continue to make gains in nonverbal cognitive abilities throughout the adolescent years and likely well beyond. This statistically significant growth was observed in the examination of change in composite growth scores over time. It is important to remember, however, that our examination of change in standard scores over time did not yield statistically significant results, indicating that the growth trajectories of raw abilities increased at a rate that did not differ from chronological age norms. Future research should confirm this with standardized tests that are normed more than four standard deviations below the mean or include experimental extended norms that can circumvent the issue of floor effects for standard scores (see Hessl et al., 2009). Second, although the participants with DS demonstrated significant growth in composite nonverbal ability scores, a pattern of differential growth emerged when examining trajectories by subdomain. This pattern sheds light on potential strengths and difficulties of youth with DS from a phenotypic perspective, and if confirmed by future research, suggests potential areas to target with clinical interventions. Future studies should examine how much growth is expected in these subdomains during adolescence to confirm this possible profile of strengths and difficulties in DS. If future research confirms that fluid reasoning, for example, is a specific domain of weakness for individuals with DS, then interventions that target component skills, such as working memory, attention shifting, or other executive functions associated with fluid reasoning performance, may prove beneficial. Such interventions, however, should be multi-faceted and target several domains of the DS phenotype that are found to be relative areas of difficulty. Therefore, our study serves as only a starting point for research on the cognitive developmental phenotype of DS. More research is needed to examine trajectories of other domains of cognitive functioning beyond the four nonverbal tests used in the present study. Comparisons of growth scores and standard scores as a function of domain will yield a more complete understanding of how cognitive abilities change with chronological age for these individuals. Additionally, future research should focus on developmental periods beyond adolescence, as it is likely that relative growth in cognition changes across development for individuals with DS. Such information will provide the foundation for designing future interventions and educational programs to enhance cognitive development in this population.

Acknowledgements

We would like to especially thank the families who participated in our study. This research was supported by National Institutes of Health grants R01 HD024356 and U54 HD079125. Leonard Abbeduto has received financial support to develop and implement outcome measures for clinical trials from F. Hoffman-LaRoche Ltd., Roche TCRC Inc., and Neuren Pharmaceuticals Ltd. No other authors have financials disclosures to make.

References

Bayley, N. (1933). *The California First-Year Mental Scale*. Berkley, CA: University of California Press.
Bayley, N. (1969). *Bayley Scales of Infant Development*. New York: Psychological Corporation.
Bird, A. (2007). Perceptions of epigenetics. *Nature, 24*, 396–398.
Carr, J. (1970). Mental and motor development in young mongol children. *Journal of Mental Deficiency Research, 14*, 205–220.
Carr, J. (1988). Six weeks to twenty-one years old: A longitudinal study of children with Down's syndrome and their families. *Journal of Child Psychology and Psychiatry, 29*, 407–431.
Carr, J. (2005). Stability and change in cognitive ability over the life span: A comparison of populations with and without Down's syndrome. *Journal of Intellectual Disability Research, 49*, 915–928.
Cattell, R. B., Barton, K., & Dielman, T. E. (1972). Prediction of school achievement from motivation, personality, and ability measures. *Psychological Reports, 30*, 35–43.
Chapman, R. S., & Hesketh, L. J. (2000). Behavioral phenotype of individuals with Down syndrome. *Mental Retardation and Developmental Disabilities Research Reviews, 6*, 84–95.
Couzens, D., Cuskelly, M., & Haynes, M. (2011). Cognitive development and Down syndrome: Age-related change on the Stanford-Binet Test (Fourth Edition). *American Journal on Intellectual and Developmental Disabilities, 116*, 181–204.
Couzens, D., Haynes, M., & Cuskelly, M. (2012). Individual and environmental characteristics associated with cognitive development in Down syndrome: A longitudinal study. *Journal of Applied Research in Intellectual Disabilities, 25*, 396–413.
Crick, N. R., & Dodge, K. A. (1994). A review and reformulation of social information-processing mechanisms in children's social adjustment. *Psychological Bulletin, 115*, 74–101.
Crombie, M., & Gunn, P. (1998). Early intervention, families, and adolescents with Down syndrome. *International Journal of Disability, Development and Education, 45*, 253–281.
Dameron, L. E. (1963). Development of intelligence of infants with mongolism. *Child Development, 34*, 733–738.
Dicks-Mireaux, M. J. (1972). Mental development of infants with Down's syndrome. *American Journal of Mental Deficiency, 77*, 26–32.
Fidler, D. J. (2005). The emerging Down syndrome behavioral phenotype in early childhood: Implications for practice. *Infants & Young Children, 18*, 86–103.
Finestack, L. H., Sterling, A. M., & Abbeduto, L. (2013). Discriminating Down syndrome and fragile X syndrome based on language ability. *Journal of Child Language, 40*, 244–265.
Gesell, A., & Amatruda, C. (1941). *Developmental diagnosis*. New York: Paul B Hoeber Inc.
Grafodatskaya, D., Chung, B., Szatmari, P., & Weksberg, R. (2010). Autism spectrum disorders and epigenetics. *Journal of the American Academy of Child & Adolescent Psychiatry, 49*, 794–809.
Griffiths, R. (1954). *The abilities of babies. A study in mental measurement*. London: University of London Press.
Griffiths, R. (1970). *The abilities of young children. A comprehensive system of mental measurement for the first eight years of life*. London: Child Development Research Centre.
Hessl, D., Nguyen, D. V., Green, C., Chavez, A., Tassone, F., Hagerman, R. J., et al. (2009). A solution to limitations of cognitive testing in children with intellectual disabilities: The case of fragile X syndrome. *Journal of Neurodevelopmental Disorders, 1*, 33–45.
Hiskey, M. S. (1966). *Manual for the Hiskey–Nebraska Test of Learning Aptitude*. Lincoln, NE: Union College Press.
Karmiloff-Smith, A. (1997). Crucial differences between developmental cognitive neuroscience and adult neuropsychology. *Developmental Neuropsychology, 13*, 513–524.

Karmiloff-Smith, A. (1998). Development itself is the key to understanding developmental disorders. *Trends in Cognitive Science, 2*, 389–398.
Kaufman, A. S., & Kaufman, N. L. (2004). *Kaufman Brief Intelligence Test* (2nd ed.). Circle Pines, MN: American Guidance Service Inc.
Keating, D. P. (2004). Cognitive and brain development. In R. M. Lerner & L. Steinberg (Eds.), *Handbook of adolescent psychology* (2nd ed., pp. 45–84). Hoboken, NJ: John Wiley & Sons, Inc.
Kover, S. T., McDuffie, A., Abbeduto, L., & Brown, W. T. (2012). Effects of sampling context on spontaneous expressive language in males with fragile X syndrome or Down syndrome. *Journal of Speech, Language, and Hearing Research, 55*, 1022–1038.
Kover, S. T., Pierpont, E. I., Kim, J., Brown, W. T., & Abbeduto, L. (2013). A neurodevelopmental perspective on the acquisition of nonverbal cognitive skills in adolescents with fragile X syndrome. *Developmental Neuropsychology, 38*, 445–460.
Lamb, M. E., Bornstein, M. H., & Teti, D. M. (2002). *Development in infancy* (4th ed.). Mahwah, NJ: Lawrence Erlbaum Associates.
Leiter, R. G. (1980). *Leiter International Performance Scale*. Chicago: Stoelting.
Merrill-Palmer Scale of Mental Tests (1948). New York: Harcourt.
Næss, K. B., Lyster, S. H., Hulme, C., & Melby-Lervåg, M. (2011). Language and verbal short-term memory skills in children with Down syndrome: A meta-analytic review. *Research in Developmental Disabilities, 32*, 2225–2234.
Oakes, A., Kover, S. T., & Abbeduto, L. (2013). Language comprehension profiles of young adolescents with fragile X syndrome. *American Journal of Speech-Language Pathology, 22*, 615–626.
Parker, S. E., Mai, C. T., Canfield, M. A., Rickard, R., Wang, Y., Meyer, R. E., et al. (2010). Updated national birth prevalence estimates for selected birth defects in the United States, 2004–2006. *Birth Defects Research Part A: Clinical and Molecular Teratology, 88*, 1008–1016.
Piper, M. C., & Pless, I. B. (1980). Early intervention for infants with Down syndrome: A controlled trial. *Pediatrics, 65*, 463–468.
Rasmussen, S. A., Whitehead, N., Collier, S. A., & Frías, J. L. (2008). Setting a public health research agenda for Down syndrome: Summary of a meeting sponsored by the Centers for Disease Control and Prevention and the National Down Syndrome Society. *American Journal of Medical Genetics Part A, 146A*, 2998–3010.
Raudenbush, S., Bryk, A., Cheong, Y. F., Congdon, R., & du Toit, M. (2011). *HLM 7: Hierarchical linear and nonlinear modeling (version 7.01)*. Lincolnwood, IL: SSI.
Roid, G. H. (2003). *Stanford-Binet Intelligence Scales* (5th ed.). Rolling Meadows, IL: Riverside Publishing.
Roid, G., & Miller, L. (1997). *Leiter International Performance Scale – Revised*. Wood Dale, IL: Stoelting.
Silverman, W. (2007). Down syndrome: Cognitive phenotype. *Mental Retardation and Developmental Disabilities Research Reviews, 13*, 228–236.
Share, J., Koch, R., Webb, A., & Graliker, B. (1964). The longitudinal development of infants and young children with Downs syndrome (Mongolism). *American Journal of Mental Deficiency, 68*, 685–692.
Terman, L. M., & Merrill, M. A. (1972). *Stanford-Binet Intelligence Scale*. Boston: Houghton-Mifflin.
Thorndike, R. L., Hagen, E. P., & Sattler, J. M. (1986). *Stanford-Binet Intelligence Scale* (4th ed.). Chicago: Riverside.
Tong, S., Baghurst, P., Vimpani, G., & McMichael, A. (2007). Socioeconomic position, maternal IQ, home environment, and cognitive development. *The Journal of Pediatrics, 151*, 284–288.
Wechsler, D. (1991). *Wechsler Intelligence Scale for Children* (3rd ed.). San Antonio, TX: The Psychological Corporation.
Wechsler, D. (1997). *Wechsler Adult Intelligence Scale* (3rd ed.). San Antonio, TX: The Psychological Corporation.
Wechsler, D. (2003). *Wechsler Intelligence Scale for Children* (4th ed.). San Antonio, TX: Psychological Corporation.