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# Identifying Learning Patterns of Children at Risk for Specific Reading Disability

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## Abstract

Differences in learning patterns of vocabulary acquisition in children at risk (+SRD) and not at risk (SRD) for Specific Reading Disability (SRD) were examined using a microdevelopmental paradigm applied to the multi-trial Foreign Language Learning Task (FLLT; Baddeley et al., 1995). The FLLT was administered to 905 children from rural Chitonga-speaking Zambia. A multi-group Latent Growth Curve Model (LGCM) was implemented to study interindividual differences in intraindividual change across trials. Results showed that the +SRD group recalled fewer words correctly in the first trial, learned at a slower rate during the subsequent trials, and demonstrated a more linear learning pattern compared to the SRD group. This study illustrates the promise of LGCM applied to multi-trial learning tasks, by isolating three components of the learning process (initial recall, rate of learning, and functional pattern of learning). Implications of this microdevelopmental approach to SRD research in low-to-middle income countries are discussed.

Learning disabilities (LD) have been a focus of developmental research since the 1970s (Black, 1974; Svoboda, 1974). Approximately 80% of children with LD encounter difficulties related to reading[1] (Lyon, 1996), and children at risk for Specific Reading Disability (SRD) represent up to 25% of school children worldwide (Catts, Adlof & Weismer, 2006; Fletcher, Shaywitz, Shankweiler, Katz, Liberman et al., 1994). This percentage differs dramatically from country to country with, for example, double prevalence odds in the United States as compared to Italy (Lindgren, De Renzi & Richman, 1985; Paulesu, Demonet, Fazio, McCrory, Chanoine et al., 2001). Although there is no universal definition of SRD, it is typically defined with regard to a number of premises (Fletcher, Lyon, Fuchs & Barnes, 2007). First, it is assumed that these difficulties arise in the context of adequate schooling. The quality of schooling varies tremendously between and within societies. Thus, SRD is a concept that is relevant when a large group of school children is considered, regardless of the quality of schooling, as long as its quality is comparable for this group of children. When the quality of schooling is equal, those who

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1Although these difficulties have been signified by a variety of terms (e.g. sterphosymbolia, word blindness, dyslexia), here we follow the argument that SRD is the most appropriate term to use, as there is no evidence that any of these labels captures a condition that is different from SRD either in its manifestation or etiology (Elliott & Grigorenko, 2014).

have severe difficulties compared to the rest of the group are considered to have a SRD or to be at risk for SRD. Second, given that SRD is established through performance on a number of psycho-educational assessments that reflect the distribution of reading and reading-related skills within a particular population characterized by the qualities of its linguistic and educational systems, it dons a certain degree of population (or sample) specificity. Thus, SRD assumes a between-group specificity of reading difficulties, that is, SRD in Finland, given characteristics of the Finnish language and the Finnish educational system, is defined differently from SRD in the USA, given the characteristics of the English language and the U.S. educational system, although the prevalence of SRD in Finland and USA is comparable. Third, SRD is a type of specific LD, which is manifested as a relative difficulty in the acquisition of reading skills despite a typical development of other cognitive-academic skills (e.g. World Health Organization, 1993). Thus, SRD assumes a within-individual specificity of reading difficulties compared to other (e.g. mathematics or quantitative reasoning, science or relational reasoning, and general cognitive ability) cognitive domains that are preserved. SRD is a brain-based condition that has a universal (i.e. language- and culture-free) distinct signature in the brain (Paulesu et al., 2001), that is thought to stem from both genetic and environmental predispositions (Grigorenko, 2007). Most SRD research is conducted in high-income countries and primarily in English; therefore studies conducted in less frequently studied languages and societies are particularly valuable for examining the current assumptions about its psycho-educational texture and etiology (Share, 2008).

Studies of SRD in low- and middle-income countries (LMIC)[2] are particularly important, since previous research also demonstrates that poverty and SRD co-occur and exacerbate one another (Lipina & Posner, 2012; Maulik & Darmstadt, 2007; Wagner & Blackorby, 1996), therefore rendering children in LMIC more vulnerable to SRD. However, little SRD research has been conducted in LMIC. A major hindrance for conducting such research is the lack of culturally sensitive and culturally appropriate measures of academic-cognitive skills and learning potential. In today's ever-globalizing world, developing measures that require minimal resources and that can be easily adapted to different cultural contexts and experiences is essential for conducting successful cross-cultural and comparative research (Baddeley, Gardner & Grantham-McGregor, 1995; Novins, Boyd, Brotherton, Fickenscher, Moore et al., 2012, Shmelyov & Naumenko, 2009).

This study illustrates the advantages of using one such measure in LMIC, the Foreign Language Learning Task (FLLT; Baddeley et al., 1995). The FLLT is a paired associate learning task, which is expected to be sensitive to SRD because individuals with SRD have been demonstrated to experience difficulties in paired associate tasks (e.g. Manis, Savage, Morrison, Horn, Howell et al., 1987). Moreover, individuals with SRD have demonstrated difficulties in tasks involving rapid naming of familiar visual symbols (Savage & Frederickson, 2006). In addition, we introduce a novel analytical approach to scoring the

2We use the terms ‘low- and middle-income countries’ (LMIC) and ‘high-income countries’ (HIC) instead of the more commonly employed terms ‘developing world’ and ‘developed world’ in order to adequately capture the difficulties that emerge in education and disability research as a result of varying economies and to avoid an ideological bias that puts higher-income countries into a more privileged category.

FLLT by outlining learning patterns of rural Chitonga-speaking Zambian children at risk for SRD. Zambia is a particularly relevant context for this purpose because universal education is still in its nascent form and the majority of the population lives in poverty (International Fund for Agricultural Development, 2012). More than 250,000 (6%) of school-aged children are currently not enrolled in school, and 47% of children who are enrolled do not complete their primary education (UNICEF, 2012). Many children read below the expected grade level and, in some cases, fail to progress in literacy during the first two years of school (Mubanga, 2009). Such poor schooling puts children already at risk for SRD at a further disadvantage (Torgesen, 2002).

## Learning with SRD

Previous research in high-income countries (HIC) demonstrated that children at risk (+SRD) versus not at risk (SRD) for SRD differ in the speed and process of learning (Gathercole, Alloway, Willis & Adams, 2006; Pugh, Frost, Sandak, Landi, Rueckl et al., 2008; Perfetti, Wlotko & Hart, 2005; Sperling, Lu & Manis, 2004; Swanson, 2003; Ziegler, Pech-Georgel, George, Alario & Lorenzi, 2005). For example, Sperling and colleagues (2004) found that poor readers learned more slowly than good readers on an implicit categorical learning task. They concluded that poor readers experienced difficulties integrating multiple components of learning, but had less difficulty with tasks requiring focus on a single feature. Similarly, a study of typically developing (TD) children and children with SRD showed that the former learned faster and progressed farther than the latter in auditory, visual, and auditory-visual multi-trial verbal recall and retrieval tasks (Constantinidou & Evripidou, 2011).

Many studies have also mapped the relationship between SRD and memory deficits that may explain the co-occurrence of SRD with other LD. Perfetti and colleagues (2005) found that individuals with superior reading comprehension skills learned more new words, suggesting a link between reading and memory. Swanson (2003) confirmed that skilled readers had superior working memory compared to readers with LD, as the latter group experienced difficulties when more elements were introduced into the learning process. Further, Brosnan and colleagues (2002) showed that readers with SRD consistently demonstrate deficits in executive functioning. Finally, an e-learning fMRI study by Pugh and colleagues (2008) suggested that more effort (i.e. more neural activation) was needed for readers with SRD to recall the presented stimuli. They also noted that although initial recall was much lower in participants with SRD, their performance increased with repetition. This study highlighted the need for more research on various types of learning in children with SRD.

## New vocabulary acquisition with the Foreign Language Learning Task (FLLT)

Studies of foreign vocabulary acquisition have provided important insights for understanding the learning processes of children with SRD (Baddeley et al., 1995) because they engage specific abilities at various stages of the processes that often lag behind in these children. Specifically, longitudinal studies of natural vocabulary development showed that phonological and serial-order short-term memory (STM; chiefly, the ability to repeat non-words) are related to the level of vocabulary learning in the first steps of acquisition as well as to the acquisition of phonological forms of new words (Gathercole & Baddeley, 1989; Gathercole, 2006; Leclercq & Majerus, 2010; Majerus, Poncelet, Greve & van der Linden, 2006; Nicolay & Poncelet, 2013).

In studies of novel word learning using paired associate learning tasks, phonological STM, as measured through non-word repetition and digit span, has been found to be related to the rate at which TD children and children with specific language impairments learn to associate objects or familiar words with non-words as well as their capacity to learn the phonological form of novel, explicitly taught words (Gathercole & Baddeley, 1990; Gathercole, Hitch, Service & Martin, 1997; Gray, 2004; Jarrold, Thorn & Stephens, 2009; Michas & Henry, 1994). Phonological STM has also been associated with the number of trials needed for word learning in second-language vocabulary (Cheung, 1996). Phonological awareness is involved in vocabulary learning over and above phonological memory, in particular at a later stage of novel word learning, arguably through facilitating the representation of unfamiliar phonological forms (de Jong, Seveke & van Veen, 2000; Gathercole, 2006; Metsala, 1999).

Although not initially designed to elicit the learning patterns of children with SRD, the FLLT is one of only a few measures that allows a ‘trial-by-trial’ analysis of new vocabulary acquisition that is adapted to work in LMIC. Originally conceptualized by Baddeley and colleagues (1995) as a French word learning task for children in Jamaica, the FLLT was adapted for work in Tanzania (Jukes, Nokes, Alcock, Lambo, Kihamia et al., 2002) and Zambia (Tan, Reich, Hart, Thuma & Grigorenko, 2014), both times using Spanish instead of French, since Spanish is more likely to be unfamiliar to children in these countries. Participants were presented with pictures of familiar objects named by the examiner in a new language, after which they were asked to point to the appropriate picture when the examiner repeated each of the foreign words. Participants were allowed several trials[3] in order to point to all of the objects correctly before additional words were introduced. One advantage of the FLLT is its ability to capture the learning potential of children at risk for SRD. If a consistent degree of alignment between these learning trajectories and other reading measures can be determined, it will then be possible to use the FLLT to screen for SRD in resource-limited settings.

This study uses a microdevelopmental approach to capture different patterns of learning within the constraints of the task. We introduce a measurement model estimating the initial level of performance, the average rate of learning, and the functional pattern of learning, to elicit the learning processes of children at risk for SRD in a classic vocabulary acquisition paradigm.

## Microdevelopmental analysis of learning

Microdevelopmental studies focus on real-time evolution of learning-related skills (Granott & Parziale, 2002) in order to illustrate change over a short time span. Although time scales vary, trial-by-trial analyses of change in multi-trial cumulative learning procedures have

3For example, Baddeley and colleagues (1995) reported that children in Jamaica were often unwilling to provide novel verbal responses during assessments, which has also been observed in studies with Zambian children (Tan et al., 2012).

been the prevalent approach for describing learning processes, particularly in ageing and developmental neuroscience research (Gross, Rebok, Brandt, Tommet, Marsiske et al., 2012; Jones, Rosenberg, Morris, Allaire, McCoy et al., 2005; Nettelbeck, Rabbitt, Wilson & Batt, 1996; Rast & Zimprich, 2010; Zhang, Davis, Salthouse & Tucker-Drob, 2007). The number of correctly recalled words at each trial (learning slope) is usually used as an indicator of performance in word-learning tasks (Gross et al., 2012). The focus on learning slope has emerged recently in an attempt to partition performance into an initial first recall component and a subsequent learning component (Nettelbeck et al., 1996). Failing to recognize initial recall and subsequent learning as distinct constructs could cloud the interpretation of results (Jones et al., 2005).

Latent growth curve models (LGCM; e.g. Preacher, Wichman, MacCallum & Briggs, 2008) allow for a fine-grained description of the initial or 'baseline' performance level (intercept) as well as the average rate of performance change across trials (slope). Regardless of model specification, intercept and slope are unrelated in so far as intercept and slope represent the unique contribution of 'baseline' performance and change across trials, respectively (Ferrer & McArdle, 2010; Grimm, Ram & Hamagami, 2011; McArdle, 2009). In non-linear LGCM (when the change does not follow a linear function), it is also possible to accurately describe a functional learning pattern across the observation period (in linear LGCM, information on the slope implies knowledge of the total amount of growth which is equally distributed over time; Grimm et al., 2011).

While the initial performance level can easily be isolated, the identification of the functional learning patterns across trials poses conceptual challenges because of the variety of potential growth curves. Whether modeling is theory-driven (e.g. testing a linear vs. a logarithmic curve of learning) or not (i.e. data-driven and model-estimated curve of learning), there is no 'one-size-fits-all' approach (Preacher et al., 2008). In this respect, multi-group modeling (i.e. a specific case of mixture modeling), which can estimate different trajectories or patterns of learning for different participant groups, introduces a significant advance in microdevelopmental research (Cheshire, Muldoon, Francis, Lewis & Ball, 2007). This approach helps to examine not only group differences in parameters of interest, including means and covariances of intercept and slope (Gross et al., 2012; Zhang et al., 2007), but also differences in learning patterns. This parameter is needed to elicit regularity in the rate of learning and to investigate whether certain children show growth spurts or asymptotic levels during the learning process. Moreover, it is central to a current definition of LD within the framework of Response-to-Intervention, (RTI; Compton, 2008). Hence, this approach applied to the classic FLLT may prove useful for identifying specific learning process characteristics for children with SRD in the context of vocabulary acquisition.

## The present study

This research is part of the Bala Bbala Project, [4] a largescale epidemiological study of SRD in Zambia (Hein, Reich, Thuma & Grigorenko, 2014; Hein, Reich, Marks, Thuma & Grigorenko, in press; Hein, Tan, Reich, Thuma & Grigorenko, under review; Tan et al.,

4'Bala Bbala' (Chitonga, pronounced vala bala) means 'read the word'.

2014). By conducting this research in an LMIC and applying an innovative microdevelopmental approach to examine the learning processes of children at risk for SRD, the present study (a) extends SRD research to an understudied LMIC population, (b) further elucidates associations between SRD and learning, especially in the context of vocabulary acquisition, and (c) introduces a rarely implemented LGCM approach to elicit 'real-time' learning processes. This approach was implemented to explore three components of learning and their correlates in the FLLT: (a) initial competence to recall words, (b) average learning rate across trials, and (c) functional form of change across trials characterizing the patterns of learning within the task's constraints. Overall, this microdevelopmental approach was meant to elicit unexplored characteristics of the learning processes of children at risk for SRD.

Several specific hypotheses drove this approach. First, because the initial number of items recalled correctly in this type of task has been found to be influenced by memory (Gross et al., 2012) and because children with reading disabilities have difficulties in tasks that involve memory (Carretti, Borella Cornoldi & De Beni, 2009), we expected that the average number of initially recalled items (mean intercept) would be lower for children at risk for SRD as compared to other children. Second, because reading difficulties are associated with low phonological awareness and are manifested in deficiencies in reading recognition and comprehension (Defior, Gutierrez-Palma & Cano-Marın, 2012; Lyon, 1996), we expected that the average growth rate of learning (mean slope) would be lower for children at risk for SRD as compared to other children. Thus, children at risk for SRD and other children were expected to reach their maximal performance at different points in time (i.e. trials), translating into different functional forms of growth between groups.

Finally, both intercept and slope were hypothesized to be associated with reading-related constructs typically challenged in children at risk for SRD (i.e. phonological awareness, reading recognition, reading comprehension, phonological memory, memory spans, and non-verbal intelligence; Gathercole & Baddeley, 1989; Leclercq & Majerus, 2010; Majerus et al., 2006; Nicolay & Poncelet, 2013). The FLLT requires the association of unfamiliar phonological forms with familiar pictures. This process is closely related to phonological memory skills, particularly the availability of adequate representations of the sound pattern in the phonological loop (Baddeley, Gathercole & Papagno, 1998). Hence, memory capacities were expected to be a strong predictor of FLLT performance, especially on the initial recall (intercept; see, e.g. Gross et al., 2012). At subsequent trials, new words are added to previously learned items, thus presenting both new and familiar items. Solving familiar items establishes stable long-term phonological representations, involving phonological skills and existing language knowledge (Baddeley et al., 1998; de Jong et al., 2000; Gathercole, 2006; Metsala, 1999).Hence, we hypothesized that performance on subsequent trials of the FLLT (as captured by slope) would be related to memory performance and that phonological skills would make additional contributions in explaining learning growth rates (Meschyan & Hernandez, 2002; Speciale, Ellis & Bywater, 2004).

# Method

## Participants

Participants were a subsample of the Bala Bbala cohort of 2309 randomly selected school children (grades 3–7) from rural Chitonga-speaking Zambia (Tan et al., 2014). Children in Zambia are expected to begin school at seven and continue for at least seven years (SACMEQ, 2010). However, students' profiles in rural Zambia are heterogeneous: many discontinue their schooling early, take breaks from their studies, and/or repeat grades. Classes in the study area are large in size, and educational resources are limited. Absenteeism rates are high and the school day is relatively short, which does not always leave adequate time for literacy instruction. To minimize effects of poor educational opportunities, the participants all had at least two years of schooling or equivalent academic skills (i.e. they were academically ready for grade 3).

Per screening and selection processes (see Figure 1), children were excluded if they met exclusion criteria for malnutrition, visual impairments, hearing impairments, or cognitive deficits. The resulting initial sample of the Bala Bbala Project comprised 2153 children (1081 male, 1072 female, $M = 12.77$ years, $SD=2$).[5] Participants were classified as belonging to either the +SRD or the -SRD group using two reading skills screening measures: Zambia Achievement Test-Reading Recognition (ZAT-RR; Stemler, Chamvu, Chart, Jarvin, Jere et al., 2009) and Phonological Awareness test (PA; Reich, Tan, Hart, Thuma & Grigorenko, 2013). Children who scored at or below the 25th percentile on both ZAT-RR and PA were selected as the +SRD group, and children who scored at or above the 75th percentile on both measures were selected as the -SRD group (Catts et al., 2006; Lyon, 1996). Our operational definition matched our theoretical definition of SRD: it focused on in-school children all of whom received schooling of comparable quality; it was country specific (using local data, although these thresholds used are utilized internationally); it included only children with specific reading difficulties whose other cognitive domains were preserved.

A subset of the sample was administered additional measures used as predictors of FLLT performance. In total, 905 children were administered the FLLT (189 children (20.9%) = -SRD, 137 children (15.1%) = +SRD). Males were overrepresented in the +SRD group (-SRD group included 81 boys, i.e. 42.8% of the group; +SRD group included 83 boys, i.e. 60.6% of the group; $\chi^2[1] = 9.98$, $p < .01$, Cramer's $V = 18$). This is consistent with literature from HIC, suggesting that more boys may be at risk for SRD (Berninger, Nielsen, Abbott, Wijsman & Raskind, 2008). The age of children in both groups was comparable ($M_{\text{-SRD}} = 12.67$ years, $SD_{\text{-SRD}} = 1.8$; $M_{\text{+SRD}} = 12.63$ years, $SD_{\text{+SRD}} = 2$). Table 1 shows the sample breakdown by gender, age, and grade.

5The Bala Bbala Project is still ongoing and some of the assessments used in several analyses presented here had not been collected or entered, so analyses involving these instruments are thus considered preliminary. However, we expect that when the remaining data are collected (N ≈ 500), the results pertaining to this study will not change.

## Measures

**Foreign Language Learning Task (FLLT)—**This version of the FLLT (Tan et al., 2014) presents unfamiliar vocabulary (i.e. in Spanish) for pictures depicting culturally familiar objects (e.g. cow, bed, sun, book; see Appendix A). As in previous studies (Baddeley et al., 1995), the foreign language was selected for equal unfamiliarity with verbal stimuli.

**Training:** Students were shown the 16 pictures and asked to name what they saw. Answers were accepted in Chitonga and English (the official national language and the language of education in Zambia). The examiner corrected any unsuitable responses by naming the correct responses in Chitonga.

**Levels 1–4:** The 16 items were incorporated into four levels, each of which was presented to the students upon successfully completing the preceding level. The items were distributed across the levels evenly with regard to grammatical gender and length. Level 1 included four items. Level 2 included the four items from Level 1 as well as four additional items. Level 3 included the eight items from Levels 1 and 2 as well as four additional items. Level 4 included the 12 items from Levels 1, 2, and 3 as well as four additional items.

**Trial 1:** The examiner pointed to each picture from Level 1 and named it in Spanish. Students were then instructed to point to the appropriate picture when the examiner said each Level 1 word in Spanish, in random order. If the students pointed to all the correct pictures, the examiner proceeded to Level 2. If the students made one or more errors, the examiner repeated Level 1 until the students could point correctly to all of the pictures.

**Trials 2–8:** The students could use eight trials to correctly point to a maximum number of pictures. The number of correctly identified pictures for each trial was recorded. The examiner stopped eliciting responses when the students used all eight trials or pointed to all the correct pictures before or during the eighth trial. Thus, the FLLT was designed to track performance across eight trials – a number sufficient to model learning pattern while avoiding ceiling effects due to maximal performance – and therefore did not require participants to recall all 16 items correctly. In the sample, only 68 students (7.5%) were able to remember all 16 items correctly across the eight trials.

**Phonological Awareness (PA)—**The PA assessment (Reich et al., 2013) had 61 items divided into six subtests. First Sound Matching: students were given a target word (e.g. *dolopo*) and three choices (e.g. *balumi*, *inkala*, *delesi*) from which they had to select the one that began with the same phoneme as the target word. Final Sound Matching: students were given a target word (e.g. *tobilo*) and three choices (e.g. *imbeba*, *kasolo*, *munsisi*) from which they had to select the one that ended with the same phoneme as the target word. Rhyming: students were given three words (e.g. *masumo*, *lushomo*, *mugwagwa*) and had to select the two that rhymed (e.g. *masumo*, *lushomo*). Blending Syllables: students were given a word in segmented form (e.g. *ca* + *ku* + *lya*) and instructed to say it as a single continuous word (e.g. *cakulya*). Segmenting into Syllables: students were given a single continuous word (e.g. *zicomba*) and instructed to separate it into individual syllables (e.g. *zi* + *co* + *mba*). Elision: students were given a word (e.g. *cula*) and instructed to produce the same word with one sound missing (e.g. *without c* = *ula*). All stimuli were verbal. The total score is the sum of all correct responses (Cronbach's α = .93).

**Zambian Achievement Test—**The Zambian Achievement Test (ZAT) was based on Zambian school curricula and originally developed in Chinyanga (Stemler et al., 2009), then adapted to Chitonga, and modified after a pilot study. Two subtests (Reading Recognition and Reading Comprehension) were used in the present study.

**Reading Recognition (ZAT-RR):** This version of ZATRR included 39 multiple-choice items of pre-reading skills (alphabet knowledge and phonological awareness). Students were instructed to select the most appropriate response by pointing to one of four answer choices provided on an answer page. For example, children were shown a letter and then asked to find the same letter from a set of four letters. Assessment was discontinued after eight consecutive incorrect responses. The total score is the sum of all correct responses (Cronbach's α = .90).

**Reading Comprehension (ZAT-RC):** The version of the ZAT-RC included 21 items. Students were asked to read a stimulus and then choose a response by pointing to one of the listed options. The items varied in difficulty from single word recognition to single sentence instructions and short paragraph comprehension. The total score is the sum of all correct responses (Cronbach's α = .93).

**Phonological Memory (PM)—**PM is a short-term phonological memory measure including 20 items designed to assess the capacity to memorize the sounds of Chitonga. All stimuli and responses were verbal. Although this task may seem rather easy, especially for older children, no participant in this study reached maximal performance (20), and the total score was not significantly related to age ($r = .006$, $p = .917$). Similar non-word repetition assessments have proved to be valid indicators of phonological memory (e.g. Gathercole & Baddeley, 1990; Michas & Henry, 1994). For each item, students were asked to listen to a non-word (English example: *chuff*; Chitonga example: *centwe*) and then repeat it. The non-words increased in length and difficulty (in this study, item difficulty ranging from $p = .96$ to $p = .01$, mean $p = .63$). The total score is the sum of all correct responses (Cronbach's α = .82).

**Universal Non-verbal Intelligence Test: Symbolic Memory (UNIT-SM)—**UNIT-SM (Bracken & McCallum, 1998) included 30 items of increasing difficulty. Students were instructed to look at an array of one to six images of people differing in age, gender, and color (green, black). This array was then covered and the students were instructed to reproduce it from memory using tiles with the same images. UNIT-SM was discontinued after seven consecutive incorrect responses. The total score is the sum of all correct responses (Cronbach's α = .79).

**Kaufman Assessment Battery for Children, Second Edition: Triangles (KABC-II-T)—**The KABC-II-T (Kaufman, 2004) included 29 items used to measure simultaneous visual processing. Students were asked to use physical foam and plastic shapes (mainly triangles) to reproduce images shown to them. The assessment was discontinued after five consecutive incorrect responses. Due to this stop rule, two items with null variance were discarded in the computation of the total sum score (Cronbach's $\alpha$ = .89 for the 27 remaining items).

**Letter-Digit Spans (LD-Spans)—**The LD-Spans assessment was adapted from the Wechsler Intelligence Scale for Children, Fourth Edition, WISC-IV (Wechsler, 2003) for use in Chitonga. Each of the four subtests (Letters Forward, Letters Backward, Numbers Forward, Numbers Backward) included 16 items. For each item, students were asked to repeat sets of numbers or letters either forward or backward, depending on the subtest. All stimuli and responses were verbal. Each subtest employed a stop rule of four consecutive incorrect responses, yielding 12 items across all subtests with null variance excluded for computing the respective sum scores for each subtest. Because the four LD subtest scores shared a substantial amount of variance (range of $r$ = .43 to .75), we derived a composite LD-Spans score as the sum of the four subtest scores (Cronbach's $\alpha$ = .80).

## Procedure

Informed consent was collected from parents or guardians. In addition, children themselves assented to participate in the study. Measure completion time ranged between two minutes (PM) and 13 minutes (PA). Completing the full battery of measures took several hours, with breaks given in between assessments. All measures were administered individually at schools. The screening phase and subsequent testing phase were completed in a time frame that was as short as possible and all testing was completed within a few months for each student. Participating schools received gifts (e.g. donations of soccer balls). Snacks, stickers, and pencils were offered as tokens of appreciation to students. No schools, families, or children received financial compensation in exchange for participation.

## Data analyses

The FLLT was modeled as an eight-trial LGCM including two latent variables: the *intercept* represents participants' baseline level (i.e. number of words recalled at the first trial), and the *slope* captures learning (i.e. the average learning growth from one trial to the next). Residuals for each trial were freely estimated, and correlations between residuals from one trial to the following trial were freely estimated to account for dependency of observed variables resulting from repeated measurements and the increasing task difficulty across trials. The intercepts of the observed variables were fixed to zero to freely estimate the mean of the latent factors along with variance parameters and covariance between intercept and slope. In order to examine a potential confounding effect of age, we also correlated age with intercept and slope.

Following recommendations by Grimm and colleagues (2011), linear and non-linear growth curves were estimated in order to consider different functional *patterns of learning* and to find the curve that best described the population's average learning pattern. By fixing the loadings of the slope (i.e. time scores or ‘shape factors’) to different values, various functional patterns of growth across the eight trials were tested (Gross et al., 2012). First, a linear *change model* was estimated (i.e. time scores were fixed at 0 to 7 with an increment of 1 for trial 1 to trial 8). Second, in a *quadratic change* model, we assumed a larger rate of change at the beginning of the task and a deceleration in learning towards the end of the task (see e.g. Preacher et al., 2008). Loadings of the slope factor were fixed accordingly. Third, the *logarithmic change* model tested a logarithmic learning curve function, similar to other multiple-trial cumulative learning tasks studies (Jones et al., 2005). Accordingly, time scores were fixed using the logarithmic function of 1 to 8 for trials 1 to 8, respectively. Finally, the *free change* (or 'latent basis') model (Grimm et al., 2011; Meredith & Tisak, 1990) was used to estimate the average learning pattern without constraint on time scores (freely estimated) except for the first trial (fixed to 0) and the last trial (fixed to 7). Because such a model is atheoretical regarding the structure of change as it rescales time for optimal fit (Grimm et al., 2011), we expected that the free change model would yield the best fit, and would thus serve as the baseline for comparison with the linear, quadratic and logarithmic curve models.

Because females comprised a large percentage of the -SRD group, we tested measurement invariance of the LGCM across males and females using the usual procedure of invariance testing in which models with additional sets of invariance constraints were successively tested and compared to an unconstrained model (Byrne, 2010). This step was conducted to ensure that the same measurement model was valid for both genders. Based on the identification of the best fitting learning curve for the full sample and the test for measurement invariance across gender, the best fitting model was then used as a basis of multi-group analyses for exploring potential differences between +SRD and -SRD groups. In order to isolate group differences in the means of intercept and slope as well as time score differences, other sources of variation in LGCM parameters were maintained invariant across groups in a model with equal structural covariance and measurement residuals (*structural equivalence* model).

All analyses were conducted with AMOS 18 (Arbuckle, 2009) using the full information maximum likelihood algorithm in the estimation of all model parameters (Schafer & Graham, 2002). The overall goodness-of-fit of the models to the observed data was evaluated based on established criteria for tests and cutoff values of indices in the literature (Bentler, 1990; Schermelleh-Engel, Moosbrugger & Müller, 2003). Accordingly, a non-significant chi-square test ($\chi^2$), a proportion for $\chi^2/df \leq 2$, a Comparative Fit Index (CFI) higher than .95, a Tucker-Lewis-Index (TLI) in the same range as the CFI, and a Root Mean Square Error of Approximation (RMSEA) lower than .08 indicate an adequate overall model fit. As recommended by Jones and colleagues (2005), decisions on the best functional form were made by comparing the Akaike Information Criterion (AIC; Akaike, 1974) of non-nested models testing different functional forms (e.g. linear vs. quadratic), favoring the model with the smallest AIC. Invariance decisions in favor of the more constrained models were based both on the nonsignificance of the $\Delta\chi^2$ between the unconstrained and the constrained models, as well as a difference in CFI (ΔCFI) lower than .01 (Byrne, 2010; Cheung & Rensvold, 2002).

## Results

### Preliminary analyses

Missing FLLT values ranged from 0% (trials 1, 3, and 4) to 5% (trial 8) with an average of 1.14% across trials. The observed pattern of missing values was not completely random

(MCAR) as indicated by Little's MCAR test ($\chi^2[29] = 362.478$, $p < .001$). The mechanism of missingness was mostly determined by the FLLT stop-rule, according to which the task ends (and therefore no data are recorded) when a student recalls 16 words correctly. However, this missingness pattern does not imply ceiling or censored data beyond the 16 words threshold as individuals with maximum FLLT performance in any given trial between trials 5 to 8 may possibly decrease, or slow down, subsequent performance. Distributional data features obtained across the eight trials, and the properties of the correlation matrix were explored to confirm the suitability of input data for planned analyses. Table 2 presents intercorrelations between the eight trials and the distributional properties of the data at each trial. A distributional analysis suggested trial features close to normal distributions, while properties of the correlation matrix appeared suitable for planned analyses (Bartlett's test of sphericity = 6475.75, $df = 28$, $p < .001$; KMO = .92 [MSAs =.91–.95]).

## General learning trend and measurement invariance across gender

Table 3 presents the fit indices for the four LGCM (*linear, logarithmic, quadratic,* and *free change*) tested with the complete sample. As indicated by the fit indices and the AIC values for each model, the general growth trend across the eight trials is poorly described by *quadratic* and *logarithmic* functions. The linear model appears closer to the average growth of the sample, while still yielding a fit below the acceptable cut-offs. Only the *free change* model indicates adequate goodness-of-fit (Figure 2). Unstandardized factor loadings suggest, on average, a relative apex in performance at trial 6 followed by a relative plateau in the following trials. The means and variances of intercept and slope were significantly different from zero ($p < .001$), suggesting substantial interindividual differences in (1) the number of words recalled in the first trial and (2) the rate of learning across subsequent trials. Similar to the estimates obtained with the *free change* model (Figure 2), the latent means estimates of the linear model were examined to facilitate the interpretation of the slope. On average, children recalled 2.72 words in the initial trial and an average rate of learning of .74 words per trial. The correlation between intercept and slope was .43 ($p < .001$). Hence, there was about 19% commonality between the initial performance and the average rate of change, denoting a relative independence between both learning indicators. The correlation of age with the intercept was .06 ($p = .15$), and .13 ($p < .01$) between age and slope.

Next, we tested for measurement invariance of the *free change* model across gender (males: $n = 449$; females: $n = 456$). Results yielded an acceptable goodness-of-fit of the most constrained model (equal time scores, means of intercept and slope, covariance structure, and residual variance across boys and girls; $\chi^2(30) = 179.68$, $p < .01$, $\chi^2/df = 2.30$, CFI = .986, RMSEA [90%-CI] = .038 [.031–.045]), and a marginal decrease in fit ($\Delta\chi^2(30) = 43.17$, $p = .057$, DCFI = .002) as compared to the congeneric model, suggesting that the learning trend outlined for the entire sample did not differ significantly by gender.

## Group differences in learning profiles of +SRD and -SRD groups

Building upon the *free change* model derived from the complete sample, a multi-group LGCM was applied to explore differences between the +SRD and SRD groups in the pattern and rate of change across trials, testing for the hypothesis of group differences in the functional pattern of change across the trials, while keeping other sources of variation constant (i.e. residual variance and covariance structure). The *time scores invariance* model, which tested the hypothesis of an identical pattern of learning (time score equality across groups), fitted the data reasonably and was not associated with a significant degradation in model fit, suggesting that both groups may be described by the same average learning pattern. The level of invariance stringency reached in this model allowed for a meaningful comparison of latent means between groups. To this end, the *structural means* invariance model rejected the hypothesis of equal means in the initial level and learning rate across groups, and was clearly associated with degradation in model fit. Consequently, the *structural equivalence* model was retained to derive parameter estimates for both groups regarding the functional pattern of learning, and the time *scores invariance* model was used to examine latent means differences across groups.

Table 4 provides the *structural equivalence* model parameter estimates for both groups and the respective critical ratios for parameter estimate differences between groups. Estimated latent means in the *time scores invariance* model are also displayed with their respective critical ratios for estimates difference. The most salient group differences resulting from the multi-group LGCM were not only the initial number of words recalled correctly (mean of the intercept), but also the speed of learning (mean of the slope) with an average of 1.13 words learned by trial for the -SRD group as opposed to an average of 0.38 words learned by trial for the +SRD group (similar estimates and group differences were obtained with a linear curve). These differences were significant at $p < .001$. Effect sizes (Cohen's $d$) for the intercept and the slope were .73 and 1.60, respectively. Using Guilford's formula (1965), these differences translate into 9% and 53% of variance explained by group membership for intercept and slope, respectively.

Regarding time scores (based on *structural equivalence model* estimates), the difference for the third time score loading was marginally significant between the groups. Moreover, both groups showed significantly different loadings on the sixth trial. Figure 3 depicts the estimated curves for the +SRD and -SRD groups as well as for the sample as a whole (based on the growth parameters obtained with the free change model for the full sample). Despite clear group differences in learning speed, Figure 3 also suggests a slightly more linear learning trend for the +SRD group. To further explore this trend, a set of complementary analyses was conducted to investigate the extent to which linear growth was a realistic condition when tested independently for each group. For the SRD group, linearity of learning was a constraint associated with poor fit ($\chi^2[30] = 86.91$, $p < .001$, $\chi^2/df = 2.90$, CFI = .96, RMSEA [90%-CI] = .10 [.076–.125]) and substantial degradation in model fit when compared to the free change model ($\Delta\chi^2[6] = 52.36$, $p < .001$, DCFI = .033). In contrast, the linear model for the +SRD group was within the acceptable range ($\chi^2[30] = 52.71$, $p = .006$, $\chi^2/df = 1.76$, CFI = .967, RMSEA [90%-CI] = .075 [.039–.107]) and was associated with a better fit than the free change model ($\Delta\chi^2[6] = 4.13$, $p = .66$, DCFI = .002).

### Predicting initial level and learning speed in the FLLT

The *free change* LGCM was extended into a structural model in which intercept and slope were predicted simultaneously by a set of reading-related measures to examine the unique contribution of each predictor over and above the set of remaining predictors. All predictors (PA, KABC-II-T, UNIT-SM, ZAT-RR, PM, ZAT-RC, and LD-Span) were regressed on age in the same model, and their residuals were allowed to intercorrelate. The model yielded an acceptable fit to the data ($\chi^2$[68] = 155.79, $p < .01$, $\chi^2/df = 2.29$, CFI = .991, RMSEA [90%CI] = .038 [.030–.046]). Table 5 presents the variance estimates of each predictor uniquely associated with either intercept or *slope* parameters. The *intercept* was mainly predicted by memory measures (LD-Spans and PM), confirming the hypothesis that performance on the initial trial mainly depends on memory skills. Specifically, one SD increase in PM and LD-Spans is associated with a 0.19 SD and 0.24 SD increase in the *intercept*, respectively. The *slope* was mainly predicted by UNITSM, PM and ZAT-RR, which partially confirms the hypothesis that memory skills play a comparable role in intercept and slope whereas phonological skills explain additional variation in learning rate. In particular, one *SD* increase in UNIT-SM, PM and ZAT-RR is associated with a 0.11 *SD*, 0.26 *SD*, and 0.17 *SD* increase in the slope, respectively. However, not all skills were important for either intercept or slope. PA, KABC-II-T, and ZATRC did not contribute significantly to performance. Combined, the seven predictors explained 14% and 31% of the variance of intercept and slope, respectively.[6]

## Discussion

Modeling FLLT learning patterns provides important insights into how children at risk for SRD learn and whether other areas of development are associated with – or may be impacted by – their learning deficits. Regarding the general process of learning, we found evidence that some functional learning patterns did not adequately describe the average learning trajectory. Quadratic and logarithmic patterns failed to represent the learning process underlined with the FLLT (see also Grimm & Ram, 2009). As recommended in the literature, the free change model was best suited to identify the average functional pattern, confirming its flexibility for modeling nonlinear change patterns (Grimm et al., 2011). The multi-group analysis yielded a much better fit than the overall sample model, confirming that there is also no 'one-size-fits-all' in microdevelopmental studies (Preacher et al., 2008), and suggesting group differences in the functional pattern of learning that we further explored.

Significant differences in the means of *intercept* and *slope* between -SRD and +SRD groups were found. As expected, the +SRD group recalled fewer words correctly in the first trial (initial level) and learned significantly slower than the -SRD group. The groups also differed on their average learning pattern. The -SRD group learned at a faster, but not constant, rate; they reached a plateau around the sixth trial, suggesting that they were close to their maximal performance (i.e. the maximum number of words across eight trials) by the end of the task. This plateau is not surprising, as by the time the -SRD group reached the sixth trial, students in this group recalled more words than the +SRD group, making it more difficult to learn and remember subsequent words. In contrast, the +SRD group learned more slowly,

6A set of complementary analyses of the 445 youngest students (49.2% of the study sample; min age = 8, max = 12.99; *M* = 10.99, *SD* = 1.05) compared to the 460 (50.8%) oldest students (min = 13, max = 19; *M* = 14.32, *SD* = 1.23) suggested a similar functioning of the predictor variable across groups, strict measurement invariance of the FLLT LGCM, and almost identical regression estimates of intercept and slope by the predictor measures.

but at a more constant rate (demonstrated by a more linear pattern), with no plateau reached across the eight trials.

This finding has important implications for education in +SRD populations: it does not necessarily suggest that -SRD and +SRD students fundamentally differ in the functional patterns of learning processes, but rather that the slower learning process of the +SRD group does not give them the opportunity to reach their maximal performance within the constraints of the task (i.e. eight trials). It is possible that an increased number of trials for the +SRD group may result in a similar learning curve as the -SRD group, with a plateau somewhere after the eighth trial, indicating nearly maximal performance. This hypothesis needs further investigations in aversion of the FLLT that spans the learning process until the participants learned all 16 words.

Regarding the related abilities assessed, children's memory capacities (LD-Spans and PM) were the only significant predictors for the number of words recalled at the first trial (*intercept*). This finding is consistent with the observation by Gross and colleagues (2012) that initial word recall provides a measure of memory span or attention control for verbal recall (Delis, Kramer, Kaplan & Ober, 2000; Jones et al., 2005; Lezak, Howieson & Loring, 2004). Confirming this hypothesis, +SRD children who are usually found to present memory deficits (Constantinidou & Evripidou, 2011) had, in our study, lower overall recall at the first trial. This finding is aligned with research showing that less skilled readers who perform low on measures of reading recognition tend to have low phonological short-term memory (Swanson & Berninger, 1995), and that working memory plays a role in pseudoword performance (Swanson & Alexander, 1997). In contrast, measures more closely associated with reading (ZAT-RR, ZAT-RC, UNIT-SM) predicted learning speed across the seven subsequent trials (*slope*). Hence, as anticipated, vocabulary acquisition relies on both memory capacities and phonological skills that make additional contributions towards explaining learning growth rate (Meschyan & Hernandez, 2002; Speciale et al., 2004), confirming that reading and vocabulary acquisition are interconnected skills. Illustrating this effect, students at risk for SRD performed less successfully in the FLLT even though responses were non-verbal (therefore eliminating the challenges of spelling; see Swanson, Trainin, Necoechea & Hammill, 2003).

As a whole, the results of this study in Zambia confirm and supplement studies of learning trends between +SRD and -SRD groups of children in other parts of the world, such as the United States (Pugh et al., 2008) and Greece (Constantinidou & Evripidou, 2011). However, contrary to previous research (e.g. Pugh et al., 2008), our +SRD group did not show spikes in performance, but rather portrayed a linear learning trajectory, suggesting that children at risk for SRD are potentially capable of reaching the level of their peers, if provided the opportunity to do so (e.g. more trials). Hence, when working with children at risk for SRD, an important advantage to using measures that allow a fine-grained examination of learning processes such as the FLLT is the possibility of identifying any false positives that other identification tools might fail to detect. Instruments like the FLLT provide qualitative information about learning patterns that traditional measures of academic competences (often borrowed from U.S. assessments) cannot capture (Bagenda, Nassali, Kalyesubula, Sherman, Drotar et al., 2006; Boivin, Bangirana, Byarugaba, Opoka, Idro et al., 2007; Lauchlan & Elliott, 2001).

This study also contributes to two underdeveloped research areas. First, our sample represents a vastly under-researched part of the world that constitutes a large proportion of all children worldwide (Pretorius & Mampuru, 2007). The Bala Bbala Project is one of the few large-scale studies of children in LMIC; the majority of scientific literature currently available on SRD in children comes from HIC. Second, this study focused on Chitonga-speaking children, whose language is largely under-represented in SRD studies even though it is spoken by over one million people (Lewis, 2009). Hence, this study supplements cross-linguistic research findings which provide important insight into language and reading acquisition on the language-specific and language-universal levels.

### Limitations and future directions

Despite these new insights, limitations should also be acknowledged. Because of prime interest in real-time learning process, we did not investigate long-term recall as in previous FLLT studies (Baddeley et al., 1995). Further, the phonologies of the foreign language being used in the adapted FLLT (Spanish) and the participants' native language (Chitonga) are well matched in their syllabic structure with both languages preferring open syllables. Related work indicated that participants in this study struggle with commonplace assessment of phonological awareness, but do comparatively well with first sound matching (Reich, Nedwick, Thuma & Grigorenko, 2010). Future studies should explore this link by considering phonological similarities and differences in foreign language selection. In addition, although learning pattern differences were identified between groups, future studies would benefit from using more trials to investigate whether the +SRD group could eventually reach the same level as the -SRD group in the number of words recalled, or whether they, too, would reach their plateau, and if so, at what point.

Finally, intervention methods could be informed by this study. Previous studies have already recommended using visual stimuli to help improve learning for children struggling with phonological awareness and reading-related skills (Constantinidou & Evripidou, 2011). Our study demonstrates that the +SRD group is indeed able to learn and acquire new vocabulary using a simple task that involves both auditory and visual stimuli. Developing new measures that take into account learning rates and patterns for children with SRD is essential for implementing appropriate reading interventions.

### Conclusion

This study explored SRD and vocabulary acquisition, involving a large and rarely studied sample of Chitonga-speaking children in Zambia. Using FLLT, a learning task requiring few resources and being easily adaptable to various cultural and language-specific contexts, we applied a LGCM technique to uncover the learning process of children with and without reading difficulties. This study and its analytical approach open promising perspectives for future microdevelopmental research by differentiating three components of the learning process: initial recall, learning rate, and functional pattern of learning. This approach revealed that low-performing readers showed lower initial recall (*intercept*) and learned at a slower but more constant rate (*slope*) than high-performing readers who learned faster at the beginning, then reached a plateau (indicating nearly maximal performance) by the last trial. Hence, LGCM appeared useful for exploring group differences in both rate and functional pattern of learning. In addition, learning parameter correlates were explored, and suggested that initial recall is mainly predicted by memory skills, whereas learning rate across subsequent trials was explained by both memory and reading skills. Understanding how and why children with diverse reading skill levels learn differently in a non-reading task can inform intervention development for children struggling with learning in general and with reading acquisition in particular. Easily adaptable and administrable in low-resource settings, the FLLT can assess learning potential and learning deficits in children whose native language is not one of the widely studied world languages.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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**Research Highlights**

- This study elucidates associations between Specific Reading Disability (SRD) and learning in an understudied population of 905 children from rural Zambia.
- Differences in learning patterns of vocabulary acquisition in children at risk and not at risk for SRD are explored.
- Multi-group Latent Growth Curve Model elicited 'real-time' learning process differences on such baseline variables as initial level of recall, rate of learning, and functional pattern of learning.

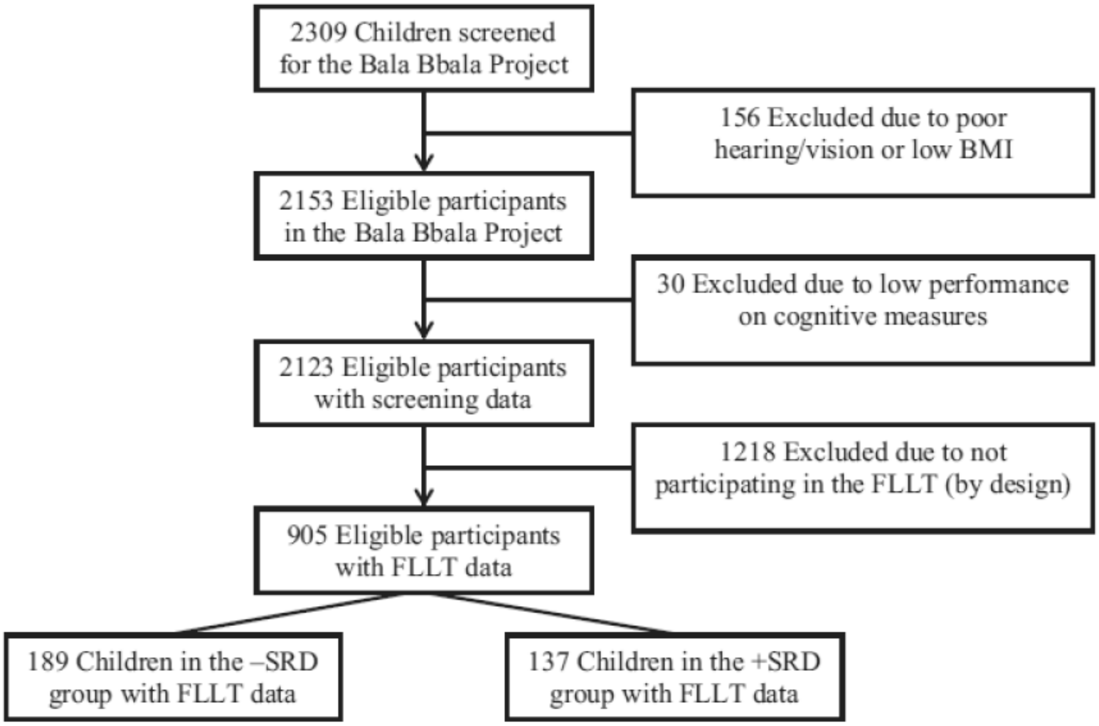


**Figure 1.**
Selection process for study participants.

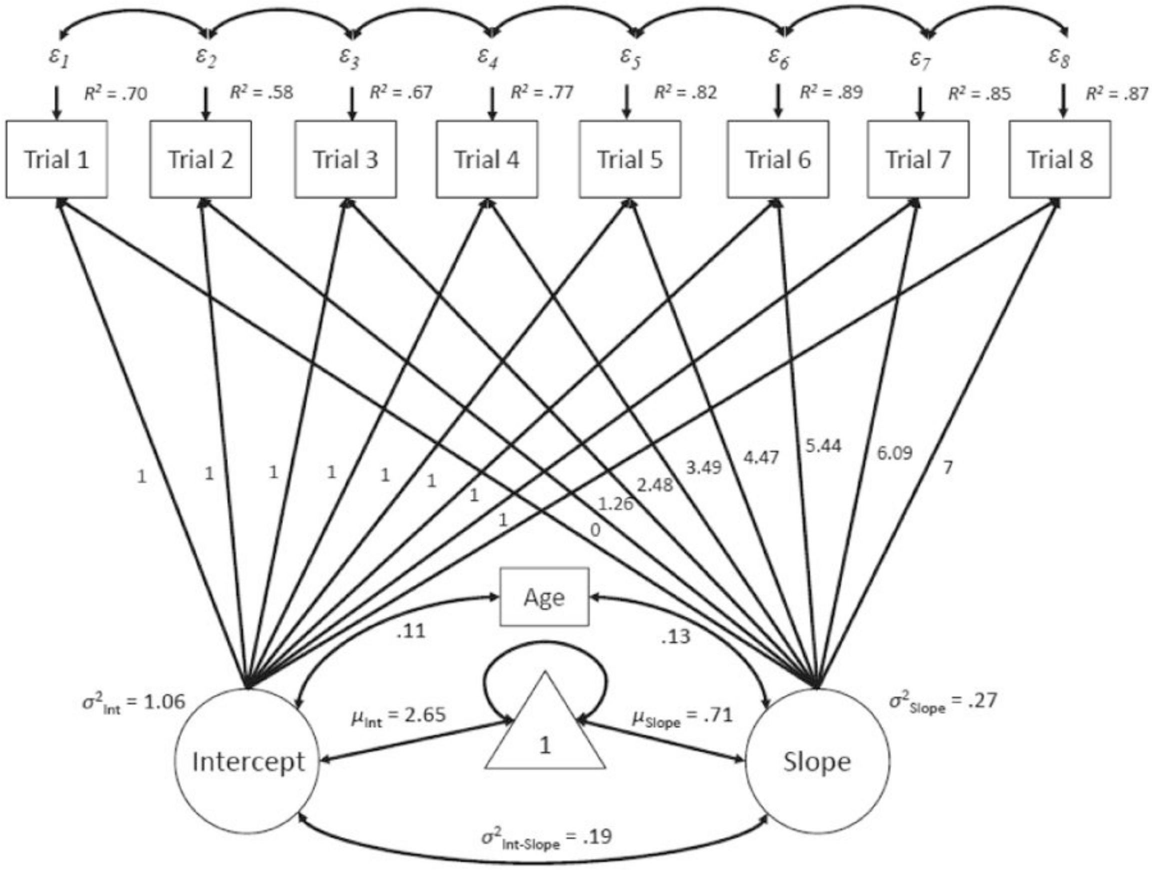


**Figure 2.**
Latent Growth Curve Model of the FLLT (numbers reflect unstandardized parameter estimates).

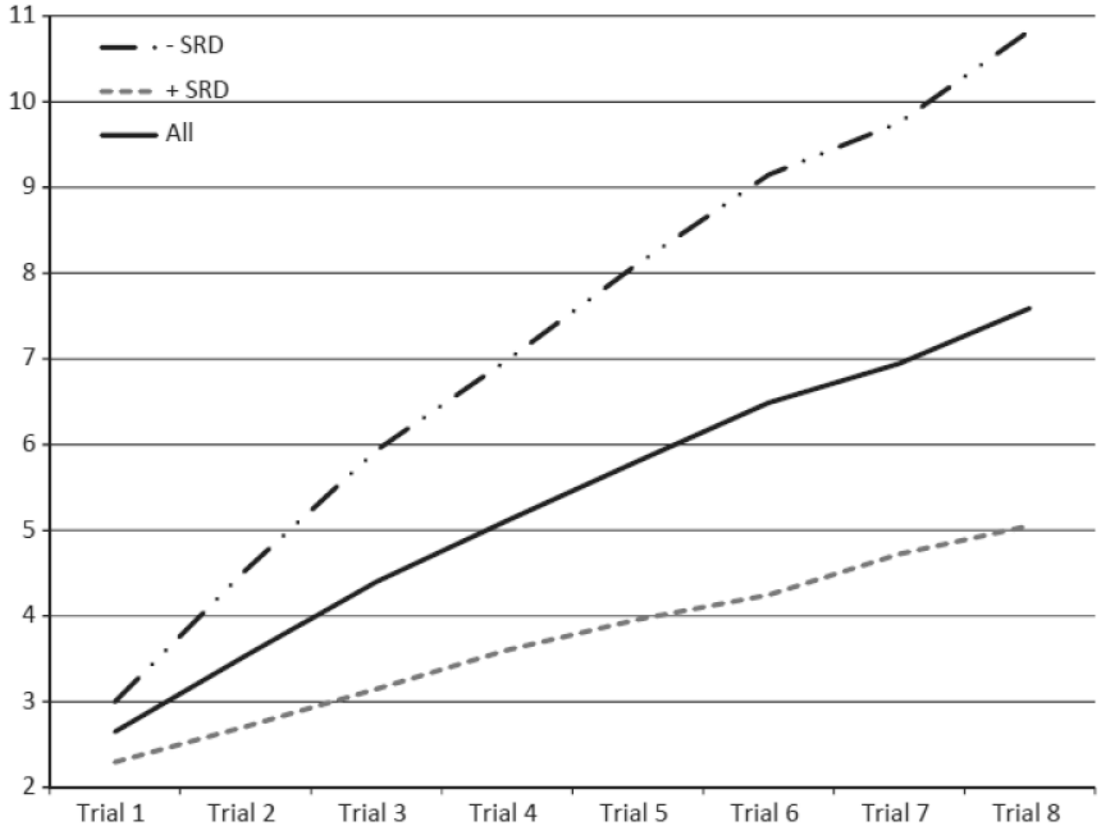


**Figure 3.**

Average trajectories of learning for the -SRD group (*n* = 189), +SRD group (*n* = 137) and the entire sample (*N* = 905).

## Table 1

**Sample breakdown by gender, age, and grade**

| | Gender | | Age | | | | Grade | |
|---|---|---|---|---|---|---|---|---|
| **Group** | **Male** | **Female** | **Min** | **Max** | ***M*** | ***SD*** | ***M*** | ***SD*** |
| Full sample ($n = 905$) | 449 | 456 | 8 | 19 | 12.7 | 2 | 5 | 1.4 |
| +SRD ($n = 137$) | 83 | 54 | 8 | 19 | 12.6 | 2 | 4.5 | 1.2 |
| -SRD ($n = 189$) | 81 | 108 | 8 | 17 | 12.7 | 1.8 | 5.5 | 1.3 |

*Notes*: Grade ranged from 3 to 7 for each group.

**Table 2**

**Correlations between trials and their distributional features for the analysis of a Latent Growth Curve Model of the FLLT**

| | | **1.** | **2.** | **3.** | **4.** | **5.** | **6.** | **7.** | **8.** |
|---|---|---|---|---|---|---|---|---|---|
| 1. | Trial 1 | – | | | | | | | |
| 2. | Trial 2 | .55*** | – | | | | | | |
| 3. | Trial 3 | .52*** | .76*** | – | | | | | |
| 4. | Trial 4 | .49*** | .69*** | .81*** | – | | | | |
| 5. | Trial 5 | .47*** | .66*** | .76*** | .86*** | – | | | |
| 6. | Trial 6 | .46*** | .64*** | .74*** | .82*** | .87*** | – | | |
| 7. | Trial 7 | .40*** | .57*** | .68*** | .75*** | .80*** | .87*** | – | |
| 8. | Trial 8 | .39*** | .55*** | .67*** | .74*** | .78*** | .84*** | .86*** | – |
| | *M* | 2.67 | 3.49 | 4.36 | 5.09 | 5.73 | 6.33 | 6.70 | 7.23 |
| | *SD* | 1.20 | 1.89 | 2.40 | 2.75 | 3.16 | 3.52 | 3.51 | 3.55 |
| Skewness | | -.66 | .51 | .53 | .62 | .60 | .68 | .49 | .37 |
| Kurtosis | | -.44 | -.02 | -.09 | .28 | .00 | .13 | -.13 | -.40 |

*Notes*: N = 905. Means are reported but not analyzed.

*** $p < .01$

## Table 3

### Fit indices of the LGCM

| Model | $\chi^2$ | *df* | *p* | $\chi^2/df$ | $\Delta\chi^2$ | CFI | AIC | ΔCFI | RMSEA (CI) |
|---|---|---|---|---|---|---|---|---|---|
| Complete sample | | | | | | | | | |
| Free change | 106.95 | 24 | .000 | 4.46 | – | .989 | 166.95 | – | .062 (.050-.074) |
| Linear change | 214.18 | 30 | .000 | 7.14 | .000 | .975 | 262.18 | – | .082 (.072-.093) |
| Logarithmic change | 584.62 | 30 | .000 | 19.49 | .000 | .925 | 632.62 | – | .143 (.133-.253) |
| Quadratic change | 1634.81 | 30 | .000 | 54.49 | .000 | .784 | 1682.81 | – | .243 (.233-.253) |
| Multi-group LGCM2 | | | | | | | | | |
| Congeneric | 83.175 | 48 | .001 | 1.73 | – | .983 | 203.18 | – | .048 (.030-.064) |
| Structural covariance[a] | 120.26 | 54 | .000 | 2.23 | .000 | .969 | 228.26 | .014 | .062 (.047-.076) |
| Structural equivalence[b] | 149.63 | 69 | .000 | 2.17 | .014 | .962 | 227.63 | .007 | .060 (.047-.073) |
| Time scores invariance[c] | 156.16 | 75 | .000 | 2.08 | .367 | .962 | 222.16 | .000 | .058 (.045-.071) |
| Structural means invariance[d] | 286.84 | 72 | .000 | 3.98 | .000 | .899 | 236.21 | .063 | .096 (.084-.108) |

*Notes*: 1 = General model based on the complete sample ($N = 905$). 2 = comparison between the +SRD ($n = 137$) and _SRD (n = 189) group.

[a]= invariance testing using the ‘Congeneric’ model as baseline;

[b]= invariance testing using the ‘Structural covariance’ model as baseline;

[c]= invariance testing using the ‘Structural equivalence’ model as baseline;

[d]= invariance testing using the ‘Time score invariance’ model as baseline;

$\chi^2$ = chi-square; *df* = degrees of freedom; *p* = *p*-value of the $\chi^2$ test; $\Delta\chi^2$ = *p*-value of the $\chi^2$ difference test; CFI = comparative fit index; DCFI = difference in the CFI value; RMSEA = root mean square error of approximation; CI = 90% confidence interval of RMSEA value.

## Table 4

**LGCM parameter estimates for +SRD and -SRD children**

| | -SRD | | | +SRD | | | Pairwise comparison | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **Unst.** | ***SE*** | **St.** | **Unst.** | ***SE*** | **St.** | **CR** | ***p*-value** |
| Time scores [1] | | | | | | | | |
| Trial 1 | 0 | – | .000 | 0 | – | .000 | – | – |
| Trial 2 | 1.371*** | .085 | .361 | 1.053*** | .201 | .289 | 1.465 | .142 |
| Trial 3 | 2.623*** | .095 | .553 | 2.164*** | .220 | .486 | 1.925 | .054 |
| Trial 4 | 3.562*** | .099 | .661 | 3.320*** | .228 | .637 | .984 | .325 |
| Trial 5 | 4.567*** | .108 | .735 | 4.222*** | .245 | .712 | 1.313 | .189 |
| Trial 6 | 5.495*** | .114 | .794 | 4.952*** | .249 | .768 | 2.033 | .042 |
| Trial 7 | 6.038*** | .110 | .777 | 6.162*** | .251 | .782 | -.460 | .646 |
| Trial 8 | 7 | – | .823 | 7 | – | .823 | – | – |
| Latent factor means [2] | | | | | | | | |
| Intercept | 3.007*** | .088 | – | 2.272*** | .100 | – | 5.564 | <.001 |
| Slope | 1.127*** | .039 | – | .377*** | .043 | – | 13.09 | <.001 |

*Notes*:

[1]= Parameters are estimated based on a free change model with equal covariances and measurement residuals across groups (*structural equivalence* model).

[2]= latent means estimated based on the *time scores invariance* model.

n+ $_{SRD}$ = 137. n- $_{SRD}$ = 189. Unst. = unstandardized estimates. St. = standardized estimates. *SE* = standard error. CR = critical ratio for unstandardized estimates difference between the +SRD and -SRD groups. Other parameters estimates: Intercept $\sigma^2$ (SE) = .988 (.156)***, Slope $\sigma^2$ (SE) = .219 (.021)***, $\Phi_{Intercept-Slope}$ = .119 (.040)**, $\Phi_{Age-Slope}$ = .021 (.055), $\Phi_{Age-Intercept}$ = .072 (.127). $\delta_{Trial1}$ (SE) = .491 (.137)***, $\delta_{Trial2}$ (SE) = 1.429 (.155)***, $\delta_{Trial3}$ (SE) = 1.814 (.158)***, $\delta_{Trial4}$ (SE) = 1.749 (.162)***, $\delta_{Trial5}$ (SE) = 1.806 (.199)***, $\delta_{Trial6}$ (SE) = 1.573 (.207)***, $\delta_{Trial7}$ (SE) = 2.827 (.354)***, $\delta_{Trial8}$ (SE) = 2.456 (.355)***.

** $p < .01$;

*** $p < .001$.

## Table 5

### Regression estimates of intercept and slope by the predictor measures

| | Descriptive | | Regression Est. Intercept | | Regression Est. Slope | |
|---|---|---|---|---|---|---|
| Predictor | *M* | *SD* | Unst. (*SE*) | St. | Unst. (*SE*) | St. |
| PA | 34.05 | 13.18 | -.007 (.006) | -.089 | .004 (.002) | .107 |
| KABC-II-T[a] | 13.80 | 5.37 | .013 (.010) | .069 | .001 (.004) | .005 |
| UNIT-SM[a] | 6.89 | 3.46 | -.019 (.013) | -.065 | .016** (.005) | .109 |
| ZAT-RR[a] | 28.44 | 7.28 | .014 (.008) | .096 | .018*** (.003) | .255 |
| PM[b] | 12.56 | 3.19 | .062** (.020) | .190 | .028*** (.008) | .171 |
| LD-Spans[c] | 18.82 | 6.10 | .042** (.015) | .240 | .005 (.006) | .063 |
| ZAT-RC[d] | 9.08 | 6.12 | .007 (.014) | .043 | .007 (.006) | .077 |

*Notes*: Parameters are estimated based on the free change model with complete sample. All predictors were regressed on age.

[a] $n = 905$,

[b] $n = 327$,

[c] $n = 319$,

[d] $n = 400$,

Unst. = unstandardized estimates, *SE* = Standard error, St. = standardized estimates. $R2_{\text{Intercept}} = .14$. $R2_{\text{Slope}} = .31$.

* $p < .05$;

** $p < .01$;

*** $p < .001$.