RAPID VISUAL PROCESSING DEFICITS IN CHILDREN WITH DYSLEXIA

by

Remington Cole Crossnoe

Submitted in partial fulfillment of the

requirements for Departmental Honors in

the Department of Psychology

Texas Christian University

Fort Worth, Texas

May 2, 2022

RAPID VISUAL PROCESSING DEFICITS IN CHILDREN WITH DYSLEXIA

Project Approved:

Supervising Professor: Tracy Centanni, Ph.D

Department of Psychology

Shawna McGillivray, Ph.D

Department of Biology

Brent Cooper, Ph.D

Department of Psychology

ABSTRACT

Developmental Dyslexia (DD) is a heritable disorder that effects approximately 5-12% of children (Shaywitz et al, 1990) and persists in 4-6% of adults (Schulte-Korne & Remschmidt, 2003). In those with dyslexia, reading dysfunction is caused by phonological impairments that may result from neurological low-level sensory-processing mechanisms. Previous research suggests that rapid autonomized naming (RAN) deficits are the most reported deficit in adults with dyslexia (Araújo et al, 2019), however it is unknown whether the RAN deficit is caused by general rapid processing deficits or a specific letter-sound binding problem. This experiment was designed to address this unknown question by measuring rapid visual processing deficits and their relation to reading skills in children with dyslexia. Children (N=103) were recruited during the COVID-19 pandemic as part of a larger study of rapid stimulus processing in dyslexia. Out of the 103 children screened, 77 qualified for the study (33 neurotypical, 33 dyslexia, and 11 compensated dyslexia). Children completed two visual processing tasks online. The first was a rapid serial visual perception task (RSVP; Amador-Campos et al, 2015) which evaluates rapid stimulus processing of one or more symbol and letter. The second was a visuo-spatial working memory task (VSWM; Sander, Werkle-Bergner, & Lindenberger, 2011) that evaluates working memory and visual acuity at different speeds. Accuracy and reaction times were measured for each task. While we found no group differences on any task or condition, there were main effects of target number for RSVP accuracy and of set size and speed for VSWM. These results demonstrate that the tasks were adequately difficult but that those with dyslexia did not exhibit specific deficits on either task, even when the stimuli were printed letters. This suggests that RAN deficits in children with dyslexia may not originate from rapid visual perception deficits, but some other neural mechanism.

INTRODUCTION

Developmental Dyslexia (DD) is neurodevelopmental disorder classified by an inability to acquire reading and writing skills at a typical rate, despite having adequate education and an average nonverbal IQ (Williams et al, 2006). Dyslexia is thought to be approximately 40-60% heritable (Fulker et al, 1987; Gialluisi et al, 2020) and affects approximately 5-12% of children (Shaywitz et al, 1990) and up to 15% of the American population (Peterson & Pennington, 2012). Despite its prevalence, many children with dyslexia go underdiagnosed. In one study they found that 2 out of 3 children with dyslexia were undiagnosed. (Barbiero et al, 2012). This is a serious issue, because reading ability is an important skill in many aspects of daily life, including academic and vocational success. Being able to accurately identify and diagnose dyslexia from an early age can help reduce the negative impact of this disorder, it has been shown that an understanding of dyslexia can help identify at risk children before senses of academic failure sets in (Snowling, 2013). Not only does this help the mental health of these children, but it is also an opportunity for early intervention such as phonic, orthographic (phonological spelling rules), and morphological instruction which have been shown to significantly improve spelling performances in children with dyslexia (Glauschka et al, 2020).

Reading dysfunction, such as just described, is not caused by an independent deficit, but by multiple deficits that may work independently or together to cause increased reading impairments. This is referred to as the double-deficit hypothesis (Wolf & Bowers, 1999). This theory states that Phonological Awareness (PA) deficits and naming-speed deficits represent separate core sources of reading dysfunction (Wolf & Bowers, 1999). In the current study, we focused on naming speed deficits because it relates to reading ability beyond the contribution of phonological awareness (Manis et al, 2000; Wolf & Bowers, 1999) and remains a reliable predictor of reading ability for at least a decade (Adlof et al, 2010).

The most common way to measure naming speed deficits is by using the Rapid Automatized Naming (RAN) task (Denckla & Rudel, 1976)). In these tasks, participants are instructed to name a group of letters, digits, colors, or shapes as quickly as possible. RAN is a reliable predictor of future reading ability in children (Norton & Wolf, 2012), and RAN deficits are the most widely reported deficit in children with dyslexia (Araújo, et al, 2019). Despite this, the precise neural mechanisms that link RAN to reading ability are unknown, and widely disputed. Some suggest that it relates to reading because of shared underlying cognitive processes such as serial processing, object recognition, phonological retrieval, and articulation (Georgiou & Parrila, 2020; Norton & Wolf, 2012), while others suggest RAN and reading are linked via serial visual processing and orthography (Sunseth & Bowers, 2002).

This study was designed to try and bridge that gap in knowledge. Since it is unclear how much serial visual processing and orthography are related to the RAN deficit, we designed our study to measure those factors. We focused on how RAN is affected by rapid stimulus processing and orthography, specifically rapid serial visual processing and letter-shape orthography in children with and without dyslexia. We hypothesized that participants with dyslexia will have deficits in rapid visual processing as well as exhibit orthographic deficits. Rapid serial visual perception, visual acuity, working memory, and orthographic representation will be measured in two tasks. The first task is the Rapid Serial Visual Perception (RSVP) task which measures rapid serial visual perception and orthographic representation. The second task is the visuospatial working memory (VSWM) task, which measures working memory and visual acuity. If any significant main effects between groups are identified for either of the tasks, we will have found evidence to support a relationship between rapid visual processing or orthography and RAN deficits for children with dyslexia. Finding supporting evidence will help us get closer to identifying the mechanisms by which the RAN deficit impacts reading ability in children with dyslexia and allow us to better identify and help children with dyslexia in the future.

METHODS

Participants:

For this study, we enrolled 102 children between the ages of 7 and 12 to participate in a virtual study of rapid stimulus processing. Participants were recruited by an online advertisement. Parents completed an online consent form, and background questionnaire to establish eligibility. Researchers conducted an initial zoom session with each eligible child to administer a series of standardized assessments. All children provided their verbal assent to begin the study. The initial session lasted approximately 40 minutes, and the researcher administered the Matrices subtest of the KBIT-2 (Kaufman & Kaufman, 2004) as a measure of nonverbal IQ ability. Then, the Word Identification and Word Attack (WRMT-3; Woodcock, 2011) and Sight Word Efficiency and Phonemic Decoding Efficiency (TOWRE-2 Torgesen, Wagner, & Rashotte, 2012) subtests were administered to measure timed and untimed real word and pseudoword reading. Children also completed the Rapid Digit Naming and Rapid Letter Naming subtests of the RAN/RAS (Wolf & Denckla, 2005) and Non-Word Repetition task (Dollaghan & Campbell, 1998). All standard English assessments were administered in the same serial order for each participant. If a participant had a KBIT nonverbal IQ of greater than 85 or scored less than 90 on two or more of the four single word reading measures (which ones here), they were classified in the dyslexia group. To qualify in the typically developing group, participants exhibited a KBIT nonverbal IQ of greater than 85 and scored greater than 90 on all four single word reading measures. The compensated dyslexia group consisted of participants who had a prior diagnosis of dyslexia but tested as typically developing as described above. Based on these criteria, a total of 77 children were eligible for the remainder of the study as typical readers (N=33), those with dyslexia (N=33), or compensated dyslexia (N=11). Following the initial assessment session, children completed two visual tasks online at their own pace: a rapid serial visual processing (RSVP) task and a visuospatial working memory (VSWM) task. Children were compensated for their time with a $20 Amazon gift card. All procedures were approved by the Institutional Review Board at Texas Christian University.

Task Design:

In the VSWM task, children saw an array of two, four, or six ladybugs for 1000 ms, a fixation cross for 1000 ms, and then a second array of ladybugs for 1000 ms (Sander, Werkle-Bergner, & Lindenberger, 2011). Children were then prompted to press a button to indicate whether the two arrays were identical (i.e., no changes in the two arrays) or different (i.e., the color of one ladybug changed from the first array to the second array). Accuracy and reaction time for the same/different judgment were collected. The number of ladybugs presented (two, four, or six) in an array was randomized per block. Half of the trials were identical, and half of the trials had one color change. Participants completed five practice trials with feedback and 84 test trials without feedback. After the first test block with a 1000 ms exposure time, children then completed a second test block of 84 trials where exposure time was decreased to 500 ms and a third test block of 84 trials with exposure time of 100 ms.

The RSVP task evaluated whether children could detect a target in a rapidly presented stream of stimuli (e.g., print letters and shapes; Amador-Campos et al, 2015). In each trial, 18 capital letters (A, C, E, F, H, I, J, K, L, N, P, R, S, T, U, V, Y, and Z) were presented for 100 ms each and a blank inter-stimulus interval of 50 ms. In the single task, children saw 18 letters, but in half of the trials, one letter was substituted with a target letter (X) which appeared in the seventh, eighth, ninth, or tenth position. After each trial, children reported if they saw the target letter or not. Each child completed five practice trials with feedback and 20 test trials without feedback. The dual task followed a similar procedure, except the first target, X, was present in all trials, and a second target, O, was present in half of the trials, occurring one, two, three, or four letters after X. Children completed five practice trials with feedback and 40 test trials without feedback of the dual task. The procedure was then repeated using shapes as the stimuli, including an arrow, bolt, heart, hexagon, moon, square, star, trapezoid, triangle, cross (target for single task), and circle (target for dual task). Accuracy and reaction time data were collected for all trials. Both measures were based on published tasks of rapid visual processing and were coded and administered on PsyToolKit (Stoet et al, 2010; Stoet et al, 2017).

Statistical Analysis Plan:

Reaction time and accuracy data were quantified for each participant using custom MATLAB code. Outliers were defined as data points that exceeded three standard deviations from the mean of the group and were excluded from the dataset. For RSVP accuracy we had two typically developing outliers, one for the single letter condition, and the other for the double shape. There was also a compensated participant who did not respond to large portions of trial prompts for any condition. For the reaction time, in addition to the previous three outliers there was also a dyslexia outlier for the double letter condition. For the VSWM reaction time, three typically developing outliers were identified for the slow medium and fast condition for the small and large set sizes. One dyslexia outlier for reaction time was identified for the medium speed medium set size condition. Cleaned data were then transferred to SPSS for statistical analysis. A three (group: neurotypical vs. dyslexic vs. compensated) x two (stimulus: letters vs. shapes) x two (count: 1 vs. 2) mixed design ANOVA was used for the RSVP task. A three (group: neurotypical vs. dyslexic vs. compensated) x three (speed: slow vs. medium vs. fast) x two (set size: 2 vs. 4 vs. 6) mixed design ANOVA was used for the VSWM task.

RESULTS

No rapid visual processing deficits in dyslexia

We utilized two three (group: typically developing vs. dyslexic vs. compensated) x two (stimulus: letters vs. shapes) x two (target count: 1 vs. 2) mixed design analysis of variance (ANOVA), one each for participant accuracy and reaction times. With respect to accuracy, there was a main effect of target count (F (1, 71) = 16.103, $p \leq .001$, $\eta_p^2 = 0.185$), such that performance was worse on the two-target condition compared to the one-target condition (Figure 1). There were no main effects with respect to reaction time, but there was a trend in the interaction between target count and stimulus (F (1, 71) = 3.398, $p = .070$, $\eta_p^2 = 0.048$). These results demonstrate that the RSVP task was sufficiently difficult to challenge all participants but there were no differences between the groups.

No rapid visuospatial working memory deficits in dyslexia

For the VSWM task, we utilized two three (group: neurotypical vs. dyslexic vs. compensated) x three (speed: slow vs. medium vs. fast) x three (set size: 2 vs. 4 vs. 6) mixed design analysis of variance (ANOVA), one each for participant accuracy and reaction times. With respect to accuracy, there was a main effect of set size, (F (2, 122) = 87.396, $p \leq .001$, $\eta_p^2 = 0.589$), and speed (F (2, 122) = 37.041, $p \leq .001$, $\eta_p^2 = 0.378$). There was also a significant interaction of set size and speed (F (4, 244) = 2.405, $p = 0.050$, $\eta_p^2 = 0.038$) on accuracy. With respect to reaction time, there was a main effect of speed (F (2, 114) = 3.723, $p = 0.040$, $\eta_p^2 = 0.061$) These results demonstrate that with respect to accuracy, the set size and presentation rate affected the performance of our participants, regardless of group. This result suggests that the task was adequately difficult and replicates prior behavioral data from this task (Sander, Werkle-Bergner, & Lindenberger, 2011). The interaction between set size and speed indicates that as the interstimulus speed increases (slower presentation of stimuli) that performances on increasing set sizes decreases for participants regardless of group.

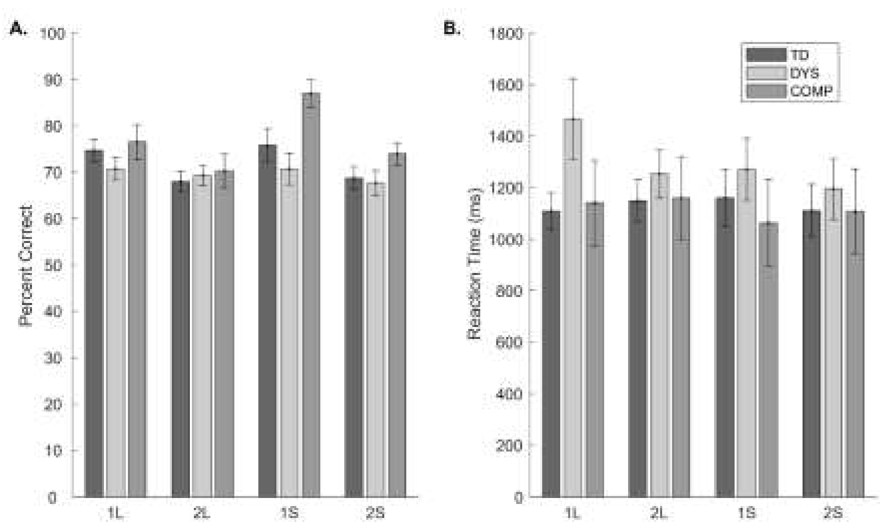
DISCUSSION

In this experiment, we tested the hypothesis that children with dyslexia have deficits in rapid visual perception and visual acuity, and that these deficits will be specific to orthographic stimuli. If these changes were found, they would help us to learn more about the mechanisms responsible for RAN deficits by linking it to rapid serial visual processing, or a specific letter-shape orthography deficit. In this study, we found no differences between the typically developing and dyslexia groups for visual processing, or from changes in orthography. This is contrary to our hypothesized results, as well as other papers in the field (Galaburda et al, 2006; Manis et al, 1999). However, this is not too unexpected with deficits in dyslexia. Just as the Double Deficit theory of dyslexia, proposes that varying levels of reading dysfunction is caused by interactions between phonological awareness deficits and naming speed deficits (Wolf & Bowers, 1999), it is also proposed that there are multiple different diagnostic subtypes of dyslexia (Manis et al, 1999). Individuals in the phonological dyslexia group performed poorly in phoneme awareness and expressive language, whereas individuals in the delayed dyslexia group were slower at processing printed letters. This variability in the dyslexia group would cause deficits to present themselves more prominently depending on the ratios of participants with a given subtype in the group. Because of this there may be a subcategory of dyslexia that when isolated would lead to a significant difference between the dyslexia and typically developing groups.

In the RSVP task, there was a main effect of target count (1 vs 2 stimuli), such that as the number of stimuli increased, accuracy decreased. These results suggest that the task itself was adequately difficult and there was likely no ceiling effect (Amador-Campos et al, 2015). Further, there was no main effect of stimulus type (letter vs. shape) on accuracy. We would expect to see a group difference here if there was evidence of a letter-shape orthographic processing deficit in dyslexia. Although we expected to see a difference here based on papers that found orthographic deficits (Badian et al, 1997; Badian, 2005), there are also sources that are unsure if orthographic deficits are associated with visual processing deficits (Georgiou et al, 2012). In the VSWM task, there were significant main effects of presentation rate and set size (2 vs. 4 vs. 6). These findings make sense in the context of this task. For presentation rate, as the duration that the arrays are displayed for decreases, the accuracy decreases. For set size, as the number of stimuli increase the accuracy decreases. The lack of main effect for group indicates that rapid visual processing in children with dyslexia is not significantly different than that of typically developing children. These findings indicate that rapid visual processing may not be the main contributor to the RAN deficit. Further research into other forms of rapid stimulus processing such as auditory may be beneficial for uncovering more about the mechanism the RAN deficit works through. Even though we were unable to find any connection between groups for rapid visual processing or orthographic representation in this study does not exclude the possibility that there is a visual component to dyslexia for certain subpopulations. Although, as researchers, we do our best to minimize factors in studies that would affect repeatability and compromise the validity of the experiment, sometimes things happen that are out of our control. Data were collected for this study at the onset of the Covid-19 pandemic. Because of this, there are a few limitations for the study. First, the nature of the virtual study meant that there was little experimental control over the testing environment. There was not a researcher in the room to monitor the testing process and keep them focused. This may have led to non-representative data being collected from environmental factors. Second, this project was one part of a larger study participants were undergoing, and they may have experienced burnout during this process. This burnout, coupled with our lack of control over the testing enviroment, would cause any potential group differences we should have seen to be masked by variability in responses and could be a source of error in the study. The other tasks in this study were focusing on auditory speech sounds, music perception, rhythm, and genetic markers. Once these datasets have been analyzed there may be more information regarding the nature of RAN deficits in children with dyslexia.

Figure 1

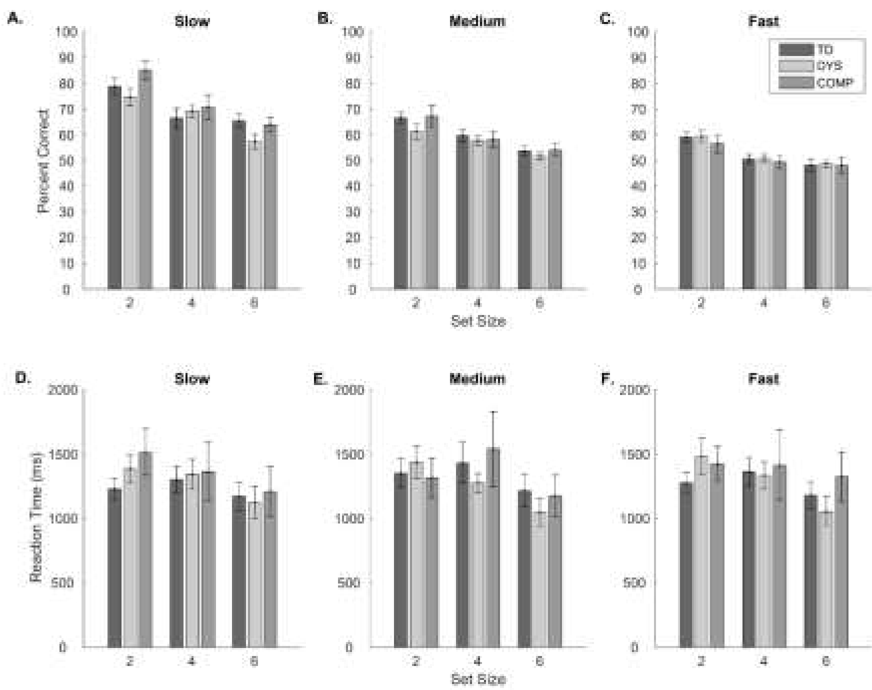
RSVP data results



Accuracy (**A**) and reaction time (**B**) data for the RSVP task across groups. There were no significant main effects of group but there was a significant main effect of count ($p \leq 0.001$) on accuracy.

Figure 2

VSWM data results



Accuracy (**A,B,C**) and reaction time (**D,E,F**) data for the VSWM task across presentation rates (slow, medium, fast) and set sizes (2, 4, 6). There was a main effect of set size, ($p \leq .001$), and speed ($p \leq .001$) and a significant interaction of set size and speed ($p = 0.050$,) on accuracy. For reaction time, a main effect of speed ($p = 0.040$).

REFERENCES

Adlof, S. M., Catts, H. W., & Lee, J. (2010). Kindergarten predictors of second versus eighth grade reading comprehension impairments. *Journal of Learning Disabilities*, *43*(4), 332-345.

Amador-Campos, J. A., Aznar-Casanova, J. A., Bezerra, I., Torro-Alves, N., & Sánchez, M. M. (2015). Attentional blink in children with attention deficit hyperactivity disorder. *Brazilian Journal of Psychiatry*, *37*, 133-138.

Araújo, S., & Faísca, L. (2019). A meta-analytic review of naming-speed deficits in developmental dyslexia. *Scientific Studies of Reading*, *23*(5), 349-368.

Badian, N. A. (1997). Dyslexia and the double deficit hypothesis. *Annals of Dyslexia*, 47(1), 69-87.

Badian, N. A. (2005). Does a visual-orthographic deficit contribute to reading disability?. *Annals of dyslexia*, *55*(1), 28-52.

Barbiero, C., Lonciari, I., Montico, M., Monasta, L., Penge, R., Vio, C., ... & for the Epidemiology of Dyslexia of Friuli Venezia Giulia working group (FVGwg). (2012). The submerged dyslexia iceberg: how many school children are not diagnosed? Results from an Italian study. *PloS one*, *7*(10), e48082.

Centanni, T. M., Beach, S. D., Ozernov-Palchik, O., May, S., Pantazis, D., & Gabrieli, J. D. (2021). Categorical perception and influence of attention on neural consistency in response to speech sounds in adults with dyslexia. *Annals of Dyslexia*, 1-23.

Denckla, M. B., & Rudel, R. G. (1976). Rapid 'automatized'naming (RAN): Dyslexia differentiated from other learning disabilities. *Neuropsychologia*, *14*(4), 471-479.

DeFries, J. C., Fulker, D. W., & LaBuda, M. C. (1987). Evidence for a genetic aetiology in reading disability of twins. *Nature*, *329*(6139), 537-539.

Galuschka, K., Görgen, R., Kalmar, J., Haberstroh, S., Schmalz, X., & Schulte-Körne, G. (2020). Effectiveness of spelling interventions for learners with dyslexia: A meta-analysis and systematic review. *Educational Psychologist*, *55*(1), 1-20.

Georgiou, G. K., Papadopoulos, T. C., Zarouna, E., & Parrila, R. (2012). Are auditory and visual processing deficits related to developmental dyslexia?. *Dyslexia*, 18(2), 110-129.

Georgiou, G. K., & Parrila, R. (2020). What mechanism underlies the rapid automatized naming–reading relation?. *Journal of Experimental Child Psychology*, *194*, 104840.

Gialluisi, A., Andlauer, T. F., Mirza-Schreiber, N., Moll, K., Becker, J., Hoffmann, P., ... & Schulte-Körne, G. (2019). Genome-wide association scan identifies new variants associated with a cognitive predictor of dyslexia. *Translational psychiatry*, *9*(1), 1-15.

Manis, F. R., Doi, L. M., & Bhadha, B. (2000). Naming speed, phonological awareness, and orthographic knowledge in second graders. *Journal of learning disabilities*, *33*(4), 325-333.

Manis, F. R., Seidenberg, M. S., Stallings, L., Joanisse, M., Bailey, C., Freedman, L., ... & Keating, P. (1999). Development of dyslexic subgroups. *Annals of Dyslexia*, *49*(1), 105-134.

Neef, N. E., Müller, B., Liebig, J., Schaadt, G., Grigutsch, M., Gunter, T. C., ... & Friederici, A. D. (2017). Dyslexia risk gene relates to representation of sound in the auditory brainstem. Developmental cognitive neuroscience, 24, 63-71.

Norton, E. S., & Wolf, M. (2012). Rapid automatized naming (RAN) and reading fluency: Implications for understanding and treatment of reading disabilities. *Annual review of psychology*, *63*, 427-452.

Peterson, R. L., & Pennington, B. F. (2012). Developmental dyslexia. The lancet, 379(9830), 1997-2007.

Sander, M. C., Werkle-Bergner, M., & Lindenberger, U. (2011). Binding and strategic selection in working memory: A lifespan dissociation. *Psychology and Aging*, *26*(3), 612.

Schulte-Körne, G., & Remschmidt, H. (2003). Legasthenie-Symptomatik.

Shaywitz, S. E., Shaywitz, B. A., Fletcher, J. M., & Escobar, M. D. (1990). Prevalence of reading disability in boys and girls: Results of the Connecticut Longitudinal Study. *Jama*, *264*(8), 998-1002.

Snowling, M. J. (2013). Early identification and interventions for dyslexia: a contemporary view. *Journal of Research in Special Educational Needs*, *13*(1), 7-14.

Stoet, G. (2010). PsyToolkit - A software package for programming psychological experiments using Linux. *Behavior Research Methods, 42(4)*, 1096-1104.

Stoet, G. (2017). PsyToolkit: A novel web-based method for running online questionnaires and reaction-time experiments. *Teaching of Psychology, 44(1)*, 24-31.

Sunseth, K., & Greig Bowers, P. (2002). Rapid naming and phonemic awareness: Contributions to reading, spelling, and orthographic knowledge. *Scientific studies of reading*, *6*(4), 401-429.

Tallal, P. (1980). Auditory temporal perception, phonics, and reading disabilities in children. *Brain and language*, *9*(2), 182-198.

Wolf, M., & Bowers, P. G. (1999). The double-deficit hypothesis for the developmental dyslexias. *Journal of educational psychology*, *91*(3), 415.