# Pre-Readers at the Alien Zoo: A Preregistered Study of the Predictors of Dyslexia and Linguistic Sound Symbolism in 6-year-olds

**Fei Ting Woon (woon0039@e.ntu.edu.sg)[1], Yap-Seng Chong (obgcys@nus.edu.sg) [2,3], Lourdes Mary Daniel (mary.daniel@kkh.com.sg)[4], Birit F. P. Broekman (b.broekman@vumc.nl)[3,5], Shirong Cai (obgcais@nus.edu.sg)[2,3], Suzy J. Styles (suzy.styles@ntu.edu.sg)[1]**

[1]Psychology, School of Social Sciences, Nanyang Technological University, 14 Nanyang Drive, S(637332), Singapore
[2]Department of Obstetrics & Gynaecology, Yong Loo Lin School of Medicine, National University of Singapore, National University Health System, Singapore
[3]Singapore Institute for Clinical Sciences, Agency for Science, Technology and Research (A*STAR), Singapore
[4]Department of Child Development, KK Women's and Children's Hospital, Singapore
[5]Department of Psychiatry, VU Medical Centre, VU University, Amsterdam, Netherlands

**Abstract**

Recent studies suggest that multisensory linkages between speech and vision are implicated in the development of dyslexia. Current data only address a relationship in adults with existing diagnoses, but do not inform us about the developmental trajectory of the association. We conducted a pre-registered study of multisensory matching in 388 pre-readers in Singapore (Age: 5y 10m) using an adaptation of the bouba-kiki task (the Alien Zoo), and compared children's performance on this task to their earlier scores on measures known to predict dyslexia: phonological awareness, vocabulary size and letter knowledge. As reported elsewhere, children's Alien Zoo scores were lower than adults'(Woon & Styles, 2017a). The language measures were strongly inter-correlated, suggesting persistent language skills across multiple domains, However we found no significant relationship between performance on the Alien Zoo task and any of the predictors of dyslexia. This may mean that the relationship is yet to emerge in this population. The children in this cohort will be tracked and tested at a later time point to establish the developmental trajectory of this relationship.

**Keywords:** Dyslexia; Pre-Readers; Multisensory Processing; Sound Symbolism; Phonological awareness; bouba-kiki

## Introduction

A key process in reading is the ability to link up visual word forms with the phonological representations of the words they represent. This process relies on learned arbitrary multisensory mappings between visual symbols and auditory representations of speech. Recent research has suggested that people who suffer from reading difficulties may also exhibit differences in the multisensory mapping of novel speech tokens to novel visual stimuli.

In a sound-symbol matching task, known as the bouba-kiki test (Ramachandran & Hubbard, 2001), participants are asked to decide which of two linguistic strings (e.g., 'bouba' and 'kiki'), goes best with one of two visual shapes (e.g., spiky, rounded). Most adults prefer to match word forms containing phonemes such as /b, m, l, o, u/, to rounded shapes, and word forms containing phonemes such as /k, t, i, e/ with spiky shapes, and a recent meta-analysis has shown that on average 89% of people agree on which one is the best matching, or 'congruent,' choice between canonical shapes and sounds (Styles & Gawne, 2017). These effects suggest a common core of non-arbitrary (or iconic) multisensory processing for the sounds of speech, shared by the majority of adults. One possible offshoot of this might be that if the multisensory pathways supporting the bouba-kiki test are impaired, then other processes, like reading, may also be impaired. This makes the bouba-kiki test an interesting candidate for testing the relationship between general multisensory processing of speech sounds, and the specific multisensory linkages required for reading.

Recently, Drijvers, Zaadnoordijk, & Dingemanse (2015) investigated whether dyslexic adults make fewer congruent choices than typical readers. In their test, participants heard spoken pseudo words in Dutch, and saw pairs of complex outline shapes, one with jagged edges and one with rounded edges. For each pseudoword, participants selected the 'best matching' image from a pair. Adults diagnosed with dyslexia made fewer congruent choices than typical readers. The authors suggest that known cross-modal processing deficits in dyslexic adults may underlie both poor reading skills and fewer congruent sound-symbol matches.

Multiple possible causal relationships could explain this pattern over development. Children with weak or impaired non-arbitrary audio-visual processing may have difficulty acquiring the arbitrary audio-visual representations required for fluent reading (hence, weak multisensory processing *causes* later dyslexia). Alternatively, children who have difficulty learning to read may not reinforce the multisensory pathways that typical readers use in the bouba-kiki task (hence, weak reading *causes* later weakness in multisensory tasks). A third possibility is that both deficits arise from a common cause (e.g., differences in neural representation of language *cause both* deficiencies in reading, and in multisensory processing of speech). If the first of these possibilities is correct, then we would expect to see weak multisensory skills precede the onset of formal reading instruction in children who later develop dyslexia.

Studies on dyslexic children have revealed deficits in auditory and auditory-visual processing (e.g., letter/sound knowledge) (Blau et al., 2010; Blomert & Froyen, 2010). Since dyslexia manifests as a difficulty in fluent word

recognition and through weaker spelling and decoding abilities (Lyon et al., 1995), it can only be diagnosed after some formal instruction in reading, meaning little is known about the risk factors that could be detected earlier. Pre-literate children at risk for dyslexia have been shown to demonstrate difficulties in auditory processing (rise-time, phonetic discrimination) (Goswami, Fosker, Huss, & Mead, 2011). Phonological awareness, vocabulary size and letter knowledge are also known correlates of dyslexia (Nation 2009). However, no current tests investigate multisensory processing in pre-readers. The bouba-kiki paradigm provides a child-friendly possibility for evaluating audio-visual processing outside the domain of letter-sound knowledge.

## Methods

We conducted a preregistered test of the relationship between the best known predictors of reading (phonological awareness, vocabulary size, and letter knowledge) and sound symbolic matching, in a large cohort of pre-school aged children in Singapore. We developed a novel, child-friendly 16-item test, called the Alien Zoo task, and compared each individual's sound symbolic choices with their previously recorded scores on known predictors of reading.

### Participants

Children were recruited from the largest longitudinal cohort study in Singapore, Growing Up in Singapore Toward (healthy) Outcomes (GUSTO). 413 children were available for the study as part of the annual GUSTO testing schedule, of which a total of 388 attempted the task. Prior to analysis, results from 11 children were removed for failure to follow instructions (10), or dropout (1).

Of the 377 child participants whose results were analysed, 203 were male and174 were female. The children were aged between 5 years 10 months and 6 years 6 months (*A*ge: $M$ = 5 years 10 months; $SD$ = 3.36). The GUSTO study was approved by the National Healthcare Group Domain Specific Review Board (NHG DSRB) and the Sing Health Centralized Institutional Review Board (CIRB). Written consent was obtained from mothers at the time of the test.

As part of the GUSTO cohort study, children were tested on several measures that are known predictors of early reading: (i) the Singapore adaptation of the Communicative Developmental Inventory (CDI) (Tan, 2009) at 24 months; (ii) the Comprehensive Test of Phonological Processing (CTOPP-2) (Wagner, Torgesen, Rashotte, & Pearson, 2013) at 48 months; (iii) the Peabody Picture Vocabulary Test (PPVT-4) (Dunn & Dunn, 2007) at 48 months; (iv) and Lollipop Test (Chew, 1981) at 48 months. The CTOPP is a well-established measure of phonological awareness. The CDI and PPVT measure vocabulary size, and sophistication, respectively. The Lollipop Test evaluates general school readiness. We selected the letter identification and letter naming subscales from the Lollipop test. These data have not previously been published.

As reported in an earlier presentation, a comparison group of adult participants were asked to participate in the study through online invitations (Woon & Styles, 2017a). Of the 111 adult participants, 80 were undergraduates enrolled in an introductory psychology course and were given course credits for their participation. 2 participants did not indicate age or gender. The rest of the participants were aged between 18 years and 40 years (Mean age bracket: 21-30 years), there were 39 male participants and 70 female participants. The adult wave of testing was approved by the IRB of Nanyang Technological University, Singapore. Digital consent was obtained from adults prior to the task.

### Stimuli

Previous bouba-kiki studies involving children have used simple line drawings or coloured blobs (Maurer, Pathman, & Mondloch, 2006; Occelli, Esposito, Venuti, Arduino, & Zampini, 2013). To maintain children's attention over multiple trials, we adapted colourful 'Virus' images from stimuli used in a previous adult studies (Styles & Lai, 2017).

The original Viruses stimuli were created from photographs of pollen and microscopic organisms and then artificially coloured red, blue, green or purple. A separate group of adults rated the Viruses on dimensions of Shape (Round-Spiky), Texture (Rough – Smooth), and Plasticity (Hard-Soft) and their responses fell into two categories: a spiky-rough-hard category and a round-smooth-soft category (Styles & Lai, 2017). To make the stimuli appealing to children, we added googly eyes. The 32 images were yoked into 16 round/spiky pairs, each of which was presented in a single colour.

We used auditory stimuli from Styles & Lai (2017) – pseudo-words created from phonemes widely recognised as 'round' /m, o, u, b, l/ and 'spiky' /k, t, p, i, e/. The pseudo-words were randomly generated to follow alternating consonant-vowel structures like CVCVCV (c.f., *maluma*). Half of the auditory pseudowords were 'sharp' sounding (e.g., *tikit*) and half were 'rounded' sounding (e.g., *mobom*). Pseudowords were recorded by a Singaporean female.

Each pair of visual stimuli was matched with one auditory token creating 16 unique yoked trials. The order of the trials and the position of the spiky and rounded shapes were randomised. None of the shapes were repeated. The study was configured and presented on a computer screen using an online programme for surveys (Qualtrics, 2005).

### Procedure

To increase task interest, children were told that they had arrived at the Alien Zoo where the 'aliens' were loose. Children were asked to help Zookeeper Clarice (depicted in Lego) to sort the aliens. Onscreen prompts were read aloud by a Research Assistant.

As shown in Figure 1, in each trial, the participants saw a pair of visual stimuli side by side. The investigator read aloud the onscreen prompts (e.g., "Which alien do you think

has this name?"), and initiated the audio token. A detailed protocol described the kinds of prompts that were allowed (e.g., repeating or rephrasing the question). When children pointed to their choice on the screen, the research assistant highlighted the onscreen image, and confirmed the child's choice before moving to the next trial.


Figure 1: Example trial in the Alien Zoo task

At halfway, and at three-quarters through the study, encouraging messages were provided (e.g., "Good work! You have sorted half of Clarice's aliens!"). After the last trial, a message thanked participants for their effort. Children concluded the task by answering questions about their language use with their family, teachers, and friends. They chose from a list of languages common in Singapore: English, Mandarin, Malay, Tamil, Hokkien, Teochew, Cantonese, Hakka, and Others (to be specified). Adult participants moved on to another online task. At the end of the task, participants had made 16 forced-choice bouba-kiki matches.

### Predictions

If multisensory processing deficits are a critical factor in the emergence of dyslexia, such deficits should be evident before the onset of reading. We therefore predicted a positive correlation between the best known risk factor for dyslexia (phonological awareness) and sound symbolic sensitivity (as measured in the Alien Zoo task). Further, as rates of dyslexia are reported to be higher in males than females, we also predicted that if correlated, the strength of the effect may differ by gender. For preregistration, see Woon & Styles (2017b). We also preregistered a secondary *exploratory* interest in the relative strength of other language assessments taken at earlier times (2y; 4y) and their predictive power on the number of congruent matches made on the Alien Zoo task.

### Data-handling and Analysis

For the Alien Zoo task, the number of congruent responses for each participant was totalled. A total score of 16 indicates that the participant chose the expected Alien for every trial. A total score of 8 indicates responding at chance level.

We followed the preregistered decision pathway for analysis (Woon & Styles, 2017b),: In our **Primary Analysis**, we planned to test a positive correlation between phonological awareness (as measured by the Normalized Composite CTOPP Scores at 48m) and Alien Zoo scores at age 5y 10m. If a correlation was observed, the decision pathway allowed an ANCOVA to further test the influence of gender (M, F) on Alien Zoo scores, with CTOPP as a co-variate. The Analysis Pathway for the **Secondary Analysis** also described a check for inter-correlation among language assessments (CTOPP, CDI, PPVT, Lollipop test), followed by a Stepwise regression of the predictive power of these language measures on the Alien Zoo Score.

Given the longitudinal nature of the data used in analyses, and the variable dropout rate within and between test waves, all children for whom a pair of measures was available were considered in each analysis.

## Results

As reported elsewhere, children's scores on the Alien Zoo task were above chance (N = 377; $M = 9.48$; $SD = 2.54$), and lower than the scores of adults from the same linguistic community performing the same task (N = 111; $M = 12.52$; $SD = 3.14$). The range of the children's scores was wide (Max = 16, Min = 3) and normally distributed, giving a good range for analysis of individual differences (Woon & Styles, 2017a). We note that adults' scores are marginally lower than would be predicted by adult norms for this kind of maluma/takete task (Styles & Gawne, 2017), which may be due to the unconventional visual stimuli used.

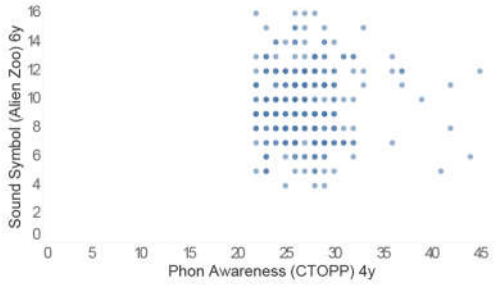


Figure 2: Scatter plot of CTOPP and Alien Zoo Scores.

### Phonological Awareness & Sound Symbolism

304 children were administered both the CTOPP task ($M = 27.0$, $SD = 3.65$) and the Alien Zoo task ($M = 9.60$, $SD = 2.51$). Figure 2 shows the relationship between an individual's score on the CTOPP at age 2y and the Alien Zoo at age 5y 10m. Contrary to the primary hypothesis, no significant relationship was observed ($\rho(304) = .007$, $p = .91$). As CTOPP and the Alien Zoo Score were not correlated, the ANCOVA with Gender was not performed. Instead, a *t*-test revealed that Alien Zoo Scores were slightly lower for boys than for girls ($t(375) = 2.40$, $p = .017$,

d = .249), however this result should be treated with caution since it was somewhat underpowered (1-β = .67), despite the size of the sample.

## Vocabulary Size, Letter Knowledge & Sound Symbolism

Figure 3 shows the relationship between children's individual scores on the language assessments performed at different ages. Inter-correlations between archival language measures were checked.

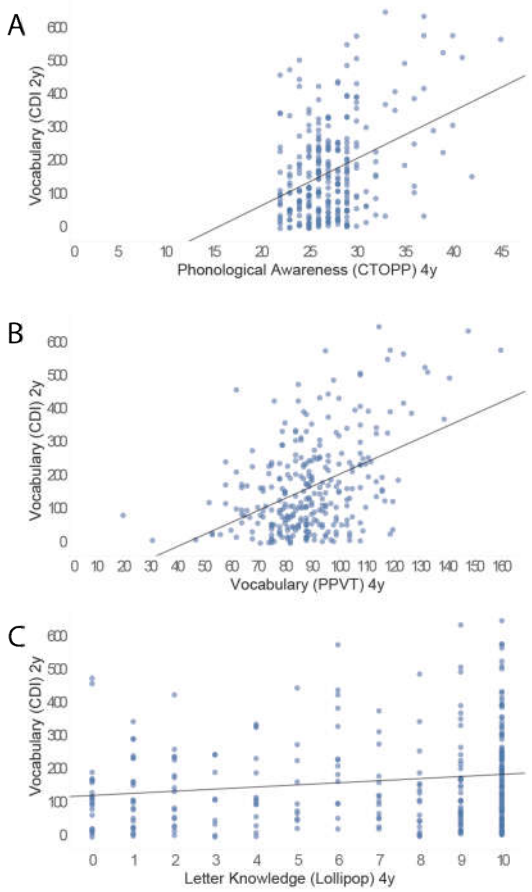


Figure 3: Scatter plots of the relationship between individuals' scores on different archival language measures. A. CDI (2y) and CTOPP (4y); B: CDI (2y) and PPVT (4y); C. CDI (2y) and Lollipop (4y)

Each individual's score on the earliest language measure (CDI at 2y) was correlated with their later scores on all language assessments at age 4y (CDI/PPVT: $\rho(291) = .34$, $p < .0005$; CDI/CTOPP: $(\rho(285) = .28$, $p < .0005$; CDI/Lollipop: $\rho(291) = .17$, $p = .004$), and the language assessments at age 4 were inter-correlated (CTOPP/PPVT: $(\rho(697) = .46$, $p < .0005)$; CTOPP/Lollipop: $(\rho(697) = .35$, $p < .0005)$; PPVT/Lollipop: $(\rho(716) = .47$, $p < .0005)$. These relationships demonstrate that children with an early English language advantage (age 2 years) tend to sustain that advantage over time (age 4 years), and in multiple language domains. As the language variables were heavily inter-correlated, the planned regression was not performed. However, as is evident in Figure 4, none of the earlier language measures correlated with scores on the Alien Zoo task. (CDI/Alien Zoo: $(\rho(187) = .71$, $p = .33)$; PPVT/Alien Zoo: $(\rho(313) = .69$, $p = .33)$, CDI/Lollipop: $(\rho(310) = .16$, $p = .77)$.

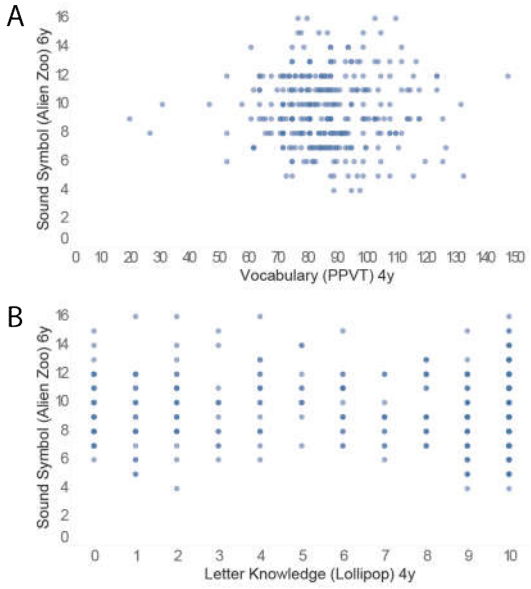


Figure 4: Scatter plots of individuals' archival language scores and Alien Zoo Scores on the test of sound symbolism. A: PPVT (4y) and Alien Zoo (6y); B. Lollipop (4y) and Alien Zoo (6y)

## Discussion

We wanted to know if the number of congruent choices made by children at age 6y correlated with known predictors of early reading skills. This was largely motivated by Drijvers et al (2015) who tested dyslexic adults on a two-alternative forced choice bouba-kiki task and found that they made significantly fewer sound-symbolic matches (60%) compared to typically reading adult controls (73%).

Dyslexic individuals have auditory processing deficits (Goswami et al., 2011) and exhibit deficits in auditory-visual temporal coordination (Meyler & Breznitz, 2005) as well as letter-speech matching and integration (Froyen, Willems, & Blomert, 2011). However, many of these audio-visual tasks are reading-related or require reading skills, making it difficult to assess children with different levels of reading instruction i.e. before formal schooling.

If the multisensory deficit seen in the Drijvers et al.'s study (2015) precedes the onset of reading instruction, we expected that known predictors of early reading ability (e.g. phonological awareness and vocabulary size) would

correlate with results from our Alien Zoo task. Our predictions were not borne out, even though the standardized language measures were strongly positively correlated with one another.

Since learning to read requires the linkage of two low-level sensory processes – auditory (speech sounds) and visual (letters/orthographic representations) – measures such as phonological awareness may tap into different aspects of reading, that are unrelated to our Alien Zoo task: The CTOPP investigates auditory processing and manipulation of speech sounds, which may be discrete from how these phonemes are connected to other sensations via cross-modal congruence (i.e., iconic matches) or arbitrary associations (i.e., letter sound matches); The CDI and PPVT assess higher level linkages between auditory word forms and semantic representations, but these associations may be discrete from more general audio-visual linkages; The subscales of the Lollipop test provide an indication of early literacy exposure, which may not be related to an individual's multisensory coordination of the letter shapes with sounds. Thus, while each of these measures has individually been linked with reading (Nation, 2009), these processes may be discrete from bouba-kiki style crossmodal congruence in prereaders.

At the time of test, the children in our study had not entered primary school, nor been evaluated directly for their reading skills, so it remains to be seen whether children in this group will show relationships between reading and the Alien Zoo task. Children in this sample were not selected for their risk of reading disorder, however the GUSTO cohort remains the largest longitudinal study of Singaporean children, and the large sample provides sufficient power to detect a moderate effect if around 10% of these children go on to have reading difficulties.

We investigated the developmental trajectory of sound-symbolism and dyslexia with a prediction that sound-symbolism deficits may precede, and possibly contribute to reading deficits, since sound-symbolic matching involves low-level sensory processing systems that are evident before the onset of reading (Maurer et al., 2006). Recent research has suggested that sound-symbolism provides a bootstrap for language learning (c.f. Imai & Kita, 2014), but we found no evidence that higher scores in the Alien Zoo task are related to larger vocabulary size in this age group. Future research involving more implicit measures of sound-symbolic processing (e.g., implicit associations) will be valuable to unpack these relationships.

However, we do not rule out the possibility that learning to read actually strengthens sound-to-symbol matching, hence a better reader will eventually also make more sound-symbolic choices in a bouba-kiki task. Adults in our study made significantly more congruent choices than children (Woon & Styles, 2017a). Adults had received years of formal reading instruction in English and more than a decade of reading practice, hence, undergoing countless rehearsals for sound-symbol cross-modal sensory rehearsal. Synaptic plasticity allows for strengthening and increasing connections of synapses whose neurons co-activate regularly and the countless rehearsals of speech-sound/letter would require co-activations of neurons processing audio and visual representations, thus altering and strengthening these connections in brains of literate adults (Owens & Tanner, 2017). Adults may make more congruent sound-symbolic choices *because they are fluent readers*.

At this stage, it looks as though the sound-symbolic deficit shown by Drijvers et al.'s (2015) dyslexic adults is not related to known predictors of dyslexia in this group of pre-reading children. It may be the case that after the onset of reading instruction, the strong readers enhance their multisensory processing, leaving the dyslexic children behind in both reading and the Alien Zoo. This would be evidence of fluent reading generating enhancements outside the domain of linking auditory and visual word forms. On the other hand, it may be the case that the children who performed at the lowest level in our Alien Zoo task go on to be those who do poorly in the acquisition of reading skills. This would be evidence that the multisensory skills required for our Alien Zoo task are indeed important for the early stages of reading. Indeed, our test may identify a previously unrecognized dyslexia subtype of children with unimpaired phonological awareness, but impaired multisensory processing. Further follow-up with the GUSTO cohort will be critical to tease apart these possibilities. To this end the next stage of this project will revisit the children after the onset of formal reading instruction, to find out whether the Alien Zoo task at age 6 has predictive value in identifying which children will go on to exhibit difficulties in the early stages of reading.

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## Author Contributions

Designed the GUSTO study: GUSTO; Designed and coded the Alien Zoo Sub-task: FTW & SJS; Tested the participants: GUSTO & FTW; Pre-registered the analysis, and analysed the data: FTW & SJS; Contributed language measures resources: GUSTO. Wrote the paper, FTW & SJS.

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