Sound-Symbolism is Disrupted in Dyslexia: Implications for the Role of Cross-Modal Abstraction Processes

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Abstract

Research into sound-symbolism has shown that people can consistently associate certain pseudo-words with certain referents; for instance, pseudo-words with rounded vowels and sonorant consonants are linked to round shapes, while pseudo-words with unrounded vowels and obstruents (with a non-continuous airflow), are associated with sharp shapes. Such sound-symbolic associations have been proposed to arise from cross-modal abstraction processes. Here we assess the link between sound-symbolism and cross-modal abstraction by testing dyslexic individuals' ability to make sound-symbolic associations. Dyslexic individuals are known to have deficiencies in cross-modal processing. We find that dyslexic individuals are impaired in their ability to make sound-symbolic associations relative to the controls. Our results shed light on the cognitive underpinnings of sound-symbolism by providing novel evidence for the role —and disruptability— of cross-modal abstraction processes in sound-symbolic effects.

Keywords: sound-symbolism; bouba-kiki effect; dyslexia; cross-modal abstraction

Introduction

A common view in theoretical linguistics is that linguistic signs are essentially arbitrary, i.e. there is no intrinsic relation between the sound of a word and the meaning it represents (Hockett, 1960; Saussure, 1983). However, humans readily treat sound as a cue to meaning, as shown in a line of experiments initiated by Köhler (1929), in which participants consistently matched certain pseudo-words to sharp shapes (e.g. *takete* or *kiki*), and others to round shapes (e.g. *maluma* or *bouba*). These effects have been placed under the banner of sound-symbolism: the existence of non-arbitrary, systematic relations between the sounds and meanings of words (cf. Westbury, 2005). Such relations also exist in natural languages, as, for example, in the phonaesthemes of English (Bergen, 2004), and in the major word classes of ideophones or mimetics in languages like Japanese, Korean, Zulu or Quechua (Dingemanse, 2012; Imai et al., 2008).

The robust effect of sound-symbolism has been replicated (e.g. Nielsen & Rendall, 2011) and extended by using different visual stimuli (e.g. Maurer et al., 2006; Nielsen & Rendall, 2012). Other studies showed similar sound-symbolic effects using different auditory stimuli, focusing on consonants (e.g. Westbury, 2005) or vowels (e.g. Nielsen & Rendall, 2011). Furthermore, the bouba-kiki effect has been found cross-linguistically and cross-culturally (Davis, 1961; Tarte, 1974; Tarte & Barritt, 1971). To rule out the potential effect of orthography, sound-symbolism has been investigated and found in young children before they have learned to read (Maurer et al., 2006; Ozturk et al., 2013). Although it has been suggested that preliterate orthographic intuitions could still have an effect on the formation of sound-symbolic associations (Cuskley, 2013), the effect remains when the phenomenon is tested with participants who have a different or no alphabet such as Tamils (Ramachandran, 2004) and Himba (Bremner et al., 2013). These studies strongly indicate that the shape of the letters does not drive the effect.

As an underlying mechanism for this phenomenon, it has been suggested that the intuitive associations between the pseudo-word *kiki* and the sharp shape of, for example, a star may be explained by certain phonetic characteristics of the word (Marks, 1978; Ramachandran, 2004; Spence, 2011). Ramachandran (2004) argued that our brain recognizes 'sharpness' in both modalities, and that these cross-modal abstractions from both types of stimuli are coupled together. It was proposed that the bouba-kiki effect might occur due to the multi-modal combination of abstraction of the nonsense stimuli, the abstraction of the shape of the mouth and lips, and the inflection of the tongue (Ramachandran & Hubbard, 2001). However, these claims have mostly been supported by correlational evidence. The nature of the relation between the underlying cross-modal abstraction processes and the occurrence of sound-symbolism remains to be clarified.

To obtain insight in the nature of this relation, we investigated sound-symbolic associations in dyslexic and non-dyslexic participants. Dyslexia is a specific neurobiological learning deficiency (Lyon et al., 2003) that typically manifests in impaired written word recognition and poor spelling abilities, among other co-morbid symptoms (Bruck, 1990).

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The language deficit is independent of cognitive and intellectual abilities, and affects approximately 4 percent of the population (Blomert, 2004; Shaywitz, 1998).

There are several reasons to expect that the performance of dyslexic individuals can shed light on cognitive processes underlying sound-symbolism. Previous research has suggested that dyslexic individuals show deviant cross-modal processing (McNorgan et al., 2013; Sela, 2014), as seen in deficiencies in reading abilities. Reading is an intrinsically cross-modal process that requires successful mapping between visual (orthographic) and auditory (phonological) representations (McNorgan et al., 2013). Deficits in cross-modal processes may lead to reading problems, and have been suggested to underlie many of the difficulties found in dyslexic individuals (Froyen et al., 2011; Meyler & Breznitz, 2005). If these deficits affect their ability to make sound-symbolic associations, this would point towards cross-modal abstraction as a potential underlying mechanism of sound-symbolism. This in turn would lead to specific hypotheses for the possible types of deficits in this mechanism in dyslexic individuals. If cross-modal abstraction processes underlie sound-symbolic effects in normal individuals, a disruption of the same processes in dyslexia should affect performance in sound-symbolic tasks (see Occelli et al. (2013) for a similar argument and evidence from individuals with Autism Spectrum Disorders).

We hypothesized that dyslexic individuals will deviate from non-dyslexic controls by making fewer sound-symbolic associations. This hypothesis is strengthened by the results from a pilot, which showed that both dyslexic children and dyslexic adults made significantly fewer sound-symbolic associations (in fact, they scored at chance level) compared to controls (Drijvers, 2013). In the current study, which is based on the pilot, changes have been made to improve the stimuli and the measurements. Drijvers (2013) did not find an effect of age, hence our choice to conduct this experiment with adult participants only. It is our expectation that the pilot results will be replicated, and provide evidence for the role of cross-modal abstraction processes as a mechanism underlying sound-symbolic associations.

Methods

Participants

Twenty-eight Dutch participants (14 dyslexic individuals, 14 controls) were recruited (13 males; mean age: 22.50 (SD = 2.12); all right-handed) and gave informed consent before the start of the experiment. All of the participants reported normal or corrected-to-normal vision and no auditory problems or neurological disorders. The participants were naive to the purposes of the experiment. The participants in the dyslexia group were all diagnosed with dyslexia in their youth.

To confirm reading problems associated with dyslexia, we administered the 'Een-Minuut-Test' (EMT: Brus & Voeten, 1972), in which existing words have to be read out loud as quickly and accurately as possible within one minute, and the 'De Klepel' (Van den Bos et al., 1994), in which pseudo-words have to be read out as accurately and quickly as possible in two minutes. We administered a verbal competence test (Analogies) from the Dutch Wechsler Adult Intelligence Scale (Uterwijk, 2000), to confirm that the impairment of our dyslexic participants was a reading impairment, rather than a language-competence impairment (EMT: $t(26)$ = 3.748, p = .001, De Klepel: $t(26)$ = 4.249, p < .000, WAIS: $t(26)$ = -.609, p = .548).

Ethical approval for the study was given by the Ethics Board of the Faculty of Social Sciences of the Radboud University Nijmegen.

Stimuli

The participants were presented with 100 stimuli: 40 experimental items and 60 fillers in pseudo-randomized order. The auditory target words consisted of 20 pseudo-words that had no resemblance to real words in Dutch, with phonetic features associated in previous work with being 'pointy' (10 words) and 'rounded' (10 words) (Nielsen & Rendall, 2011; 2012). To achieve an equal balance between segments that might be associated with pointy and round figures, we used voiced obstruents and voiced sonorants as the consonantal segments for the target words. Obstruents are articulated with a closure of the vocal tract, stopping or interfering airflow, whereas sonorants are produced with a continuous, non-turbulent airflow in the vocal tract. Therefore, obstruents can be classified as more 'jagged' than sonorants. The continuous airflow in sonorants causes a more 'round' characteristic. 'Round' words were formed by sonorants and round vowels, whereas 'pointy' words were constructed of obstruents and unrounded vowels (as in previous research, such as Maurer et al. 2006; adjusted to Dutch pronunciation). For the 'round' stimuli, we included /r/ in addition to /m/, /n/ and /L/ to keep an equal balance between nasals and liquids. For the 'pointy' stimuli, we included both stop consonants and fricatives to keep a similar balance over subcategories within voiced obstruents. All consonants in the stimulus items are voiced to rule out differences due to consonant voicing. See Table 1 for an overview.

Table 1: Overview of consonants and vowels that formed the target words

Obstruents	Sonorants	Unrounded vowels	Round vowels
/z/	/m/	/i/	/u/
/g/	/n/	/e/	/o/
/v/	/l/		
/b/	/r/		

All target words were bi-syllabic, had a CVCV-structure and a trochaic stress pattern, congruent with the dominant Dutch stress pattern. Counter-balancing and equally distributing vowels and consonants led to the following twenty tar-

get words: *Pointy*: /zige/, /gebi/, /vebi/, /bive/, /vivi/, /zeze/, /zebi/, /vegi/, /gigi/, /bege/, and *Round*: /mumo/, /lonu/, /nuro/, /romu/, /lumo/, /nolu/, /molo/, /rulu/, /roro/, /nunu/.

A female speaker recorded the auditory stimuli in a sound-attenuated booth. These sound files were edited and standardized with Adobe Audition & Praat (Boersma & Weenink, 2014). All of the target words were preceded by a sentence that asked the participant to look or search for one out of two of the displayed visual stimuli. The auditory fillers consisted of 60 words for everyday objects (e.g. 'gitaar' (guitar)) that were neither specifically round nor pointy. Specifically because our filler items were neither round nor pointy, we included more filler items (60) than experimental items (40), to keep our participants from developing an answering strategy. Each experimental item and filler item was presented twice, with randomly selected shapes per participant.

The visual stimuli consisted of 100 randomly generated figures that were either round (50) or jagged (50). We wrote a Matlab script that generated random points on a 1000 by 1000 grid, with an adjustable density parameter to generate a predefined number of points. Then, one or multiple of the generated random points were selected, based on an object parameter that could be set to a certain number of figures that needed to be generated and an edging parameter where the number of edges could be predefined. The center of gravity of the generated figures was based on the mean of the figure. This was done to ensure that all the figures were generated in the middle of the grid (see Figure 1 for examples).

This method ensures the randomized generation of a wide range of properly balanced, contrasting stimuli, constructed according to the best practices outlined in recent work (Nielsen & Rendall, 2011; Westbury, 2005). We made sure all of the figures were single *Gestalt* shapes, uniformly filled and without holes. All figures had a non-significant difference in the number of pixels to rule out size-effects on sound-symbolic associations and were presented in black to avoid color confounds. To control for perceived size, we piloted a simple test where 5 participants were asked to indicate which of two (1 pointy, 1 round) shapes was larger. Here, answering options included 'left', 'right' and 'same size'. The results showed that perceived size does not confound our stimuli. Another pilot (10 participants) confirmed that our round and pointy stimuli were indeed perceived as round and pointy. These pilot-participants did not participate in the actual experiment.

Experimental considerations

A common risk in sound-symbolism research (though not specific to it) is experimenter bias in the process of stimuli selection. In this study, we attempt to avoid this by using computer-generated visual stimuli as opposed to selecting or creating them manually. Similarly, the auditory stimuli have been created based on the phonetic properties of the sounds (as established in prior work) as opposed to our own judgment of their round or sharp features.

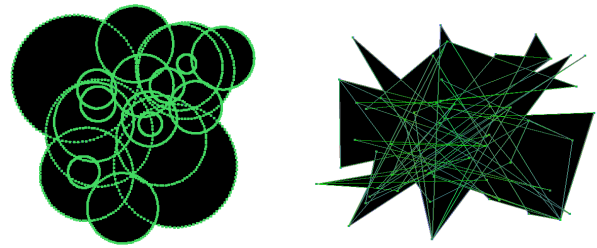Our experimental setup investigates the capacities of par-

Figure 1: Schematic overview of superimposed circles and polygons and their internal lines, generated by the algorithm. Inner lines are shown for clarification; they were not visible to the participants during the experiment.

ticipants to make sound-symbolic associations in a two-alternative forced choice task. Natural language use may not require such polarized choices, yet we expect any sound-symbolic patterning in language to be constrained by human capacities for cross-modal abstraction we aim to investigate here.

Procedure

Participants were placed in a sound-attenuated booth, and fitted with headphones that played the auditory stimuli at a 70 dB SPL rate. The experiment started with five test trials, to familiarize the participants with the experimental paradigm. A trial started with a 500 ms fixation cross. For each trial, one pointy figure and one round figure was randomly selected. In every trial, two pictures (one left, one right, randomized and counterbalanced) were presented next to each other. After 2000 ms the auditory stimulus was presented: *"Kijk naar de [target word/filler]"* (Look at the [target word / filler]) / *"Welke van deze twee plaatjes is [target word/filler]"* (Which of these two pictures is the [target word/filler] / *"Waar is de [target word/filler]"* (Where is the [target word/filler]).[1] When the auditory stimulus stopped playing, the participants had 4000 ms to indicate their choice on a button box.

Design and analysis

Responses that were given too late or were missing were removed (4 missing, 0.14%). The results were contrasted between the groups on the basis of their button-press responses. We characterized button-presses as "correct" when the auditory stimulus was associated with the visual stimulus on the basis of their sound-symbolic characteristics. The total number of correct responses per participant was contrasted between groups, as well as the total number of correct scores on pointy and round items to test for any differences in complexity per figure type. Lastly, we compared the reaction times per participant per group and per figure type.

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[1]These sentences were chosen to optimize our design for eye-tracking. The eye-tracking results are not presented here.

Results

An independent t-test revealed a significant difference between the dyslexic and control group on the number of sound-symbolic associations ($t(26) = 2.444$, $p = .034$, Cohen's $d = 0.88$; see Figure 2). The control group scored well above chance (73% correct), whereas the dyslexic participants scored slightly above chance (60% correct). A MANOVA revealed no difference between the dyslexic and control group on the number of correct answers per stimulus type (round/pointy) (independent variable: dyslexia (yes/no), dependent variables: total number of correct answers on 'round' items vs. total number of correct answers on 'pointy' items ($F(2, 25) = 2.818$, $p = .079$)). An independent t-test on the reaction times did not yield a significant difference between the dyslexic group and the control group on reaction times ($t(26) = .554$, $p = .585$). Additional item-based analyses showed no effects for specific items in our dataset (all items n.s.): there was no item that yielded significantly more or less correct answers compared to other items.
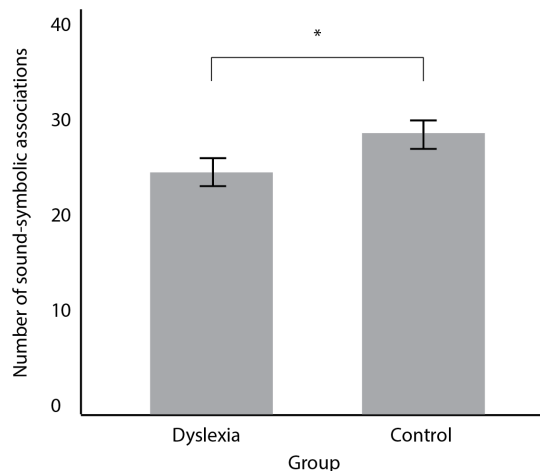

Figure 2: Mean number of sound-symbolic associations per group.

Discussion

We investigated the cross-modal abstraction processes that are claimed to underlie sound-symbolic associations. To test this, we contrasted a control group with a group of dyslexic individuals who are known to have deficiencies in their cross-modal abstraction processes. We hypothesized that dyslexic individuals would make fewer sound-symbolic associations than controls. The data showed a pattern that matched our hypothesis: Dyslexic individuals made signicantly fewer sound-symbolic associations than the control group. These results provide further evidence for a disrupted cross-modal processing mechanism in dyslexic individuals, and strengthen the hypothesis that cross-modal abstraction may lay at the basis of sound-symbolic associations (Marks, 1978; Ramachandran &

Hubbard, 2001; Spence, 2011).

Even though we found only a small difference between the number of sound-symbolic associations made by both groups, it is possible that a more extreme difference between stimulus items (e.g. by opposing voiceless obstruents and voiced sonorants, as suggested by Nielsen & Rendall (2011)) might have resulted in a larger effect. The results from our MANOVA showed a trend towards more expected answers in response to auditory stimuli predicted to invite matches with round shapes vs. the sharp shapes for the control group. Since we used voiced obstruents instead of voiceless obstruents, our stimuli may have been less 'sharp' than the stimuli that have been used in previous research. However, item-based analyses did not reveal any items that yielded more correct answers than other items. We will address this matter in future research, where we aim to systematically test the contributions of different phonetic factors (e.g. voicing, manner of articulation, place of articulation, vowel quality).

Our findings might have implications for research on dyslexia. Making abstractions and coupling them has a strong resemblance to analogical reasoning in terms of structure (Emmorey, 2014; Gentner, 1983; Tufvesson, 2011). When we consider the sound-symbolic association process in this way, it immediately becomes clear that there are several steps (i.e. the abstraction from two modalities as well as the coupling of them) in the process that could be disrupted. Although we suggest that a deficit in cross-modal abstraction processes in dyslexic individuals causes them to make fewer sound-symbolic associations, this experiment does not yet show which part of the process might be disrupted. The deficit could be in the abstraction of the visual stimuli, in the abstraction of the auditory stimuli (e.g. due to or related to dyslexic individuals difficulties in phonemic category formation (Serniclaes et al., 2004), in linking the abstractions, or in a combination of these processes. Moreover, considering the complex nature of the difficulties in dyslexia, it seems unlikely that the deficit in the cross-modal abstraction process is of a simple nature. From a neuroscientific perspective, the angular gyrus (AG) seems to be a potential neurobiological locus for the difference that we observe between the control group and the dyslexic individuals. The AG is thought to be involved in sound-symbolism (Ramachandran, 2004; Ramachandran & Hubbard, 2001), and has been shown to have a disrupted function and connectivity pattern in dyslexic individuals (Horwitz et al., 1998; Pugh et al., 2000; Shaywitz, 1998). Future research may tap into this in order get a step closer in understanding the underlying deficient mechanisms in dyslexia and its neurobiological basis.

Conclusion

Sound-symbolism, long thought to be a marginal phenomenon in language, is increasingly appreciated for the insights it may provide into vocabulary structure, language evolution and cross-modal processing. A wide range of recent studies have shown sound-symbolic effects to be strongly

consistent across age groups and cultures, suggesting it is a robust and universal phenomenon. Just as important as showing its robustness is understanding the conditions under which it may be broken. Here we have shown that sound-symbolism may be disrupted in dyslexic individuals. We found that dyslexic individuals make fewer sound-symbolic associations than controls. We suggest that this difference is caused by a deficit in cross-modal abstraction processes that leads to a disrupted facilitation of sound-symbolic associations. More research on the precise deviation of cross-modal abstractions in dyslexic individuals is necessary to understand why and how these mechanisms produce deviating associations in this population, and how this can be viewed within the broader context of the difficulties experienced in dyslexia. This study has taken sound-symbolic research into the domain of language impairments, and the results suggest that this approach provides a fruitful way to shed light on the human abilities to match sound and sense.

Acknowledgements

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