Short Research Article

Ability for Voice Recognition Is a Marker for Dyslexia in Children

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Abstract. A recent voice recognition experiment conducted by Perrachione, Del Tufo, and Gabrieli (2011) revealed that, in normal adult readers, the accuracy at identifying human voices was better in the participants' mother tongue than in an unfamiliar language, while this difference was *absent* in a group of adults with dyslexia. This pattern favored a view of dyslexia as due to "fundamentally impoverished native-language phonological representations." To further examine this issue, we conducted two voice recognition experiments, one with children with/without dyslexia, and the other with adults with/without dyslexia. Results revealed that children/adults with dyslexia were less accurate at identifying voices than normal readers and, importantly, this effect was independent of language. These data are more consistent with the assumption of dyslexia as due to a deficit in multisensory integration rather than a deficit based on impoverished native-language phonologically based representations.

Keywords: voice recognition, phonological deficit, dyslexia

Developmental dyslexia is a reading disorder that is commonly thought to originate from impaired phonological processing (see Peterson & Pennington, 2012, for a review). Dyslexia can be characterized as a core deficit in auditory processing, as proposed by leading theories of dyslexia (e.g., see Ahissar, Protopapas, Reid, & Merzenich, 2000; Goswami, 2011) or rather due to "impoverished native-language phonological representations" (i.e., language-specific). In a recent study, Perrachione, Del Tufo, and Gabrieli (2011; see also Perrachione, 2012) designed an experiment aimed at disentangling these two accounts. In their experiment, adult participants with/without dyslexia had to learn to associate five talkers' voices with their corresponding avatars in an initial training phase, whereas in a subsequent phase, they were presented auditory sentences and had to identify who of the talkers spoke on each sentence. The voices were either in the participants' native language (English) or in an unfamiliar language (Chinese), in separate blocks. Previous research has consistently found an advantage in voice identification in the mother-tongue language than in unfamiliar language (Goggin, Thompson, Strube, & Simental, 1991). This advantage depends on language phonology, as it has also been reported in seven-month-olds infants (see Johnson, Westrek, Nazzi, & Cutler, 2011, for discussion). Perrachione (2012, p. 28) reasoned that if dyslexia is characterized by a deficit in core auditory processing "individuals with this disorder would most likely have global deficits in voice recognition learning, due to the demanding auditory perceptual requirements of this task" (i.e., additive effects of Group and Language). Conversely, if dyslexia is characterized by impoverished native-language phonological representations, individuals with dyslexia "should demonstrate impaired native-language voice recognition, which is facilitated by implicit phonological processing, but unimpaired foreign-language voice recognition, which does not depend on phonological processing" (Perrachione, 2012, p. 28; i.e., an interaction effect between Group and Language).

The results from the Perrachione et al. (2011) experiment revealed that, in a group of adults with normal reading development, accuracy at identifying the voices was better in the participants' mother tongue than in an unfamiliar language (English vs. Chinese in a group of participants in the US; Chinese vs. English in a group of participants in China) (see Goggin et al., 1991, for a similar finding). But the critical finding was that this advantage of the mother tongue was *absent* in a group of adults with dyslexia – they only tested a group of dyslexic participants whose mother tongue was English, not Chinese. This null effect is even more remarkable when one considers that all sentences were completely legal (i.e., phonological representations that involved lexical representations) and still there was no advantage of familiar words in the native language. Perrachione et al. (2011) also reported some correlational analyses that showed that, for the individuals with dyslexia, a greater phonological impairment (as measured by phonological awareness) was associated with worse accuracy at detecting the voices in their native language.

Perrachione (2012) concluded that "the fact that individuals with dyslexia exhibit impaired voice recognition

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Table 1. Demographic characteristics and Digits span and PROLEC-R scores of the participants in Experiment 1 (means and standard deviations)

	Dyslexia	Control	*p*-value
Age	9.8 (2.3)	8.7 (2.4)	> .85
Gender (boys/girls)	5/9	5/9	> .85
Education (years)	7.7 (2.3)	7.8 (2.3)	> .85
Digits (WISC-R)	10.0 (2.5)	12.7 (2.9)	= .014
Phonological awareness	24.7 (4.1)	28.1 (2.2)	= .010
PROLEC-R			
Word accuracy	32.8 (5.1)	39.1 (1.3)	< .001
Word speed	97.9 (58.4)	37.9 (8.8)	< .001
Nonword accuracy	26.6 (5.6)	37 (3.1)	< .001
Nonword speed	124.4 (63.7)	52.5 (12.1)	< .001

abilities only in their native language and not a foreign one is inconsistent with the idea of a general, low-level auditory processing deficit in dyslexia (Ahissar et al., 2000; Goswami, 2011)" (p. 34), as this account would have predicted additive effects of Group and Language (see above). Instead, Perrachione favored an interpretation in terms of "fundamentally impoverished native-language phonological representations" in dyslexia. The significance of the Perrachione et al. (2011) experiment goes beyond the clarification of the nature of the phonological deficits associated with dyslexia. If their findings are easily replicable, the "avatar" task may also become an easy-to-run test to identify kindergarteners at risk of dyslexia: similar accuracy at identifying the talker's voice in familiar and unfamiliar languages could potentially be used as an early marker of dyslexia, thus helping early remediation strategies.

One limitation of the Perrachione et al. (2011) experiment is that the participants were English-speaking adults (dyslexia group: $N = 16$; mean age: 24 years: range 16–38). Thus, similar voice identification rates in familiar and unfamiliar languages could have been a consequence rather than a cause of dyslexia. To examine this issue, Experiment 1 was parallel to the Perrachione et al. (2011) experiment except that the sample was composed of children (either normally developing or children with dyslexia) and that the number of avatars was reduced to four (instead of the five) – this was done on the basis of pilot testing to reduce task difficulty/length. Furthermore, to test the generality of the Perrachione et al. findings across languages, the participants' mother language was Spanish rather than English – Mandarin Chinese was the unfamiliar language. For comparison purposes with the Perrachione et al. experiment, all sentences were grammatically correct.

The predictions are clear: If dyslexia can be characterized as a deficit in native-language phonological representations, as advocated by Perrachione et al. (2011), children with dyslexia – unlike normally developing young readers – wouldn't associate the talker's voices more accurately in their mother tongue than in an unfamiliar language. Alternatively, if the deficit in dyslexia occurs at a core auditory level (e.g., Ahissar et al., 2000; Goswami, 2011), the ability at recognizing voices should be impaired in children with dyslexia relative to normally developing young readers, and this should occur regardless of language (familiar/unfamiliar). Experiment 2 was a replication of Experiment 1 with adults (normal readers and readers with dyslexia), the only difference being that the number of avatars was reinstated to five (i.e., the same number of avatars as in the Perrachione et al., 2011, experiment).

Experiment 1

Method

Participants

Twenty-eight children between 7 and 15 years, all of them native speakers of Spanish, participated in the experiment. Fourteen were dyslexic and fourteen were normal readers. The dyslexic children had a history of difficulties in learning to read and attended several clinics in Oviedo for speech therapy. In two sessions prior to the experiment, all participants were assessed with the reading tests PROLEC-R (Cuetos, Rodríguez, Ruano, & Arribas, 2007; for children of 7–10 years) or PROLEC-SE (Ramos & Cuetos, 1999; for children older than 10 years), with the phonological awareness test PECO (Ramos & Cuadrado, 2006), and with the Spanish adaptation of the WISC-R intelligence test (Wechsler, 2001). The demographic characteristics, digits span, and PROLEC-R scores are displayed in Table 1. All the children in the dyslexia group obtained a normal score ($M = 108$, $SD = 6.6$, range: 90–120) in the WISC-R test and in the Digit subtest of the WISC-R, whereas all of them were more than 2.5 standard deviations below average in a combined measure of the word and nonword reading tasks of the PROLEC tests. The children in the control group belonged to a middle-class primary school and were also evaluated with PROLEC-R or PROLEC-SE, the phonological awareness test, and the Digit subtest of the WISC-R. All control participants had normal scores on these tests. The two groups were matched for age, sex, socio-familiar environment (middle-class families in all cases), and years of education – note that there was a small advantage in Digit subtest for the control versus the dyslexic group (see Table 1). None of the children indicated prior experience with Mandarin Chinese. No child had physical, neurological, or mental problems, and the experiment was conducted under the informed written consent of their parents and teachers.

Materials

Sixteen sentences were recorded for the experiment: half in Spanish and the other half in Mandarin Chinese. The Spanish sentences were taken from children's stories. The Chinese sentences were the same as those used by Perrachione et al. (2011). The two groups of sentences were matched in average duration (1.46–4.09 s, $M = 2.43$, $SD = 0.54$). The Spanish sentences were read by four native Spanish-speaking women (aged 25–29 years) and the Chinese sentences were read by four native Mandarin-speaking women (aged 23–27 years). The recordings of the sentences took place in a soundproof room with special equipment for voice processing. Given that the present experiment involves a speaker discrimination task, we computed the speakers' fundamental frequencies (f_0), as an index of discriminability of Spanish and Chinese speakers. The mean and the standard deviation f_0 were similar in Spanish (mean = 206 Hz, $SD = 20.1$) and Chinese (mean = 211 Hz, $SD = 15.5$), both ps > .50. Eight cartoon avatars were designed and each avatar was associated with a specific speaker. For each language, four sentences were used during the familiarization phase and four during test phase. Fourteen lists of stimuli were created to counterbalance the materials. Participants were randomly assigned to each list. Participants received 32 trials (4 Voices × 4 Sentences × 2 Repetitions) in each phase.

Procedure

Participants were tested individually in a soundproof room. The experiment was controlled by DMDX software (Forster & Forster, 2003) and the auditory stimuli were presented binaurally at a comfortable level over Sennheiser HD-205 circumaural headphones. The procedure mimicked that of Perrachione (2012). The instructions were presented visually on the computer screen and in an oral way by the experimenter. The experiment consisted of two language conditions conducted on different days, one day in Spanish, and the other day in Chinese. The two sessions were exactly alike except for the talker's language. Half of the participants performed the Spanish session the first day, and the other half the Chinese session the first day. These sessions consisted of two phases: an initial phase of training in the voice recognition task, and immediately after, there was the experimental phase (see Figure 1, for a depiction of the procedure). In the training phase, participants had to learn to identify the talkers by their voice. To do this, two avatars appeared on the screen in succession. At the same time that an avatar appeared, participants heard a sentence through the headphones, spoken by a specific voice. Then, the four avatars appeared on the screen along with one of the two previously spoken sentences. Children were instructed to press the number key that corresponded to the avatar that had said the sentence (numbers 1, 2, 3, and 4 appeared below the avatars). Next, visual feedback on the screen revealed if the selection was correct or not – if the participant's answer was wrong, the computer indicated the correct response. In the experimental phase, on each trial, children listened to a sentence and then the four avatars appeared on the screen. Again, children had to indicate who the speaker of the sentence was by pressing the 1, 2, 3, or 4 keys. In this second phase, children did not receive feedback on their performance. Each experimental session lasted for about 40 min.

Results and Discussion

As in the Perrachione et al. (2011) experiment, we conducted a 2 (Language: mother tongue [Spanish], unfamiliar language [Mandarin Chinese]) × 2 (Group: with, without dyslexia) ANOVA on the participant's accuracy in the voice recognition task, where Language was a within-subject factor and Group was a between-subjects factor. The averages per condition are displayed in Figure 2 (left panel).

The ANOVA revealed that children were more accurate at identifying the appropriate talker's voice in their native language than in an unfamiliar language (62% vs. 42%), $F(1, 26) = 32.06$, $\eta_p^2 = .55$, $p < .001$, and that, on average, control children were more accurate at identifying the appropriate talker's voice than the children with dyslexia (58% vs. 45%), $F(1, 26) = 6.74$, $\eta_p^2 = .21$, $p = .015$. There were no signs of an interaction between the two main effects, $F < 1$, $p > .37$. Given that the most critical claim of an account of dyslexia as a deficit at the level of "impoverished native-language phonological representations" made by Perrachione et al. (2011) relies on the null effect of Language in the individuals with dyslexia, we computed this planned comparison in the present experiment. Results were clear-cut: most of the children with dyslexia (11 out of 14: 79%) were more accurate at identifying voices in their mother tongue than in the foreign language and the resulting 17% advantage was statistically robust, $t(13) = 3.85$, $p = .002$. Likewise, the JZS Bayes Factor (BF_{01}; see Rouder, Speckman, Sun, Morey, & Iverson, 2009) for this test was 0.045, which indicates substantial support for H_1.

To examine if the ability at identifying human voices is related to phonological and reading abilities, we conducted the corresponding Pearson's correlation tests between the global scores in the voice recognition task (i.e., given the observed additivity pattern, we combined Spanish and Chinese data together) and the phonological and reading abilities of the participants. Reading abilities are typically

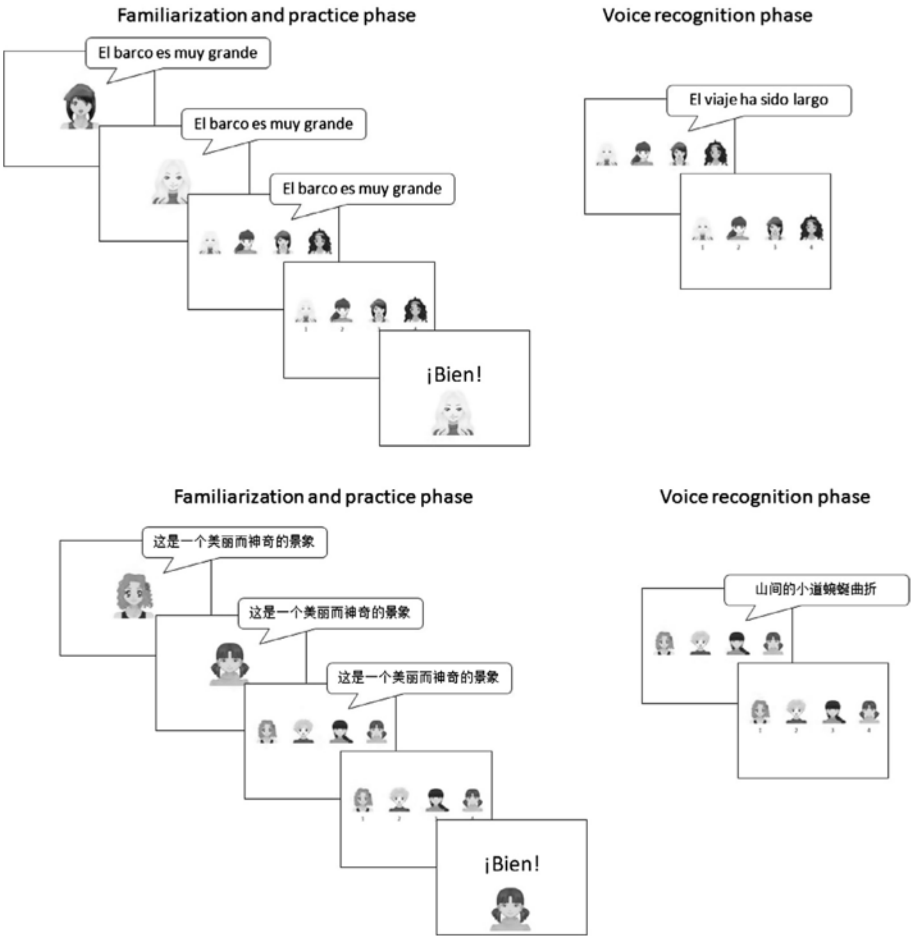

Figure 1. Description of the procedure with Spanish (top panel) and Chinese (bottom panel) sentences. In the training phase, listeners learned to associate the voices with their corresponding avatars. The accuracy of voice recognition was assessed in the final test.

measured with the accuracy/speed in reading words and pseudowords (e.g., see Davies, Rodríguez-Ferreiro, Suárez, & Cuetos, 2013; Di Betta & Romani, 2006; Hatcher, Snowling, & Griffiths, 2002). The correlation was significant in all cases: phonological awareness ($r = .42$, $p = .027$), reading accuracy ($r = .42$, $p = .029$) (i.e., children with higher scores in voice recognition read a greater number of words correctly in the PROLEC test), and reading speed ($r = -.48$, $p = .010$) (i.e., children with higher scores in voice recognition also had shorter latencies in the word reading test of the PROLEC test). Therefore, phonological and reading difficulties go together with worse abilities to identify voices.

One fair question to ask is whether the lower performance of dyslexics in the voice recognition task was due to encoding, retention, or retrieval. Although the design of the experiment is not completely suited to answer this question, one option is to examine the differences in accuracy in the final ten trials of the practice phase. For the children with dyslexia: the averages were 8.9 and 8.7 (out of 10) in the blocks with the familiar and unfamiliar languages, respectively. When computing the parallel analyses for the normally developing readers, the averages were 9.9 and 9.9 in the blocks with the familiar and unfamiliar languages, respectively. An ANOVA on this dependent measure with Language and Group as factors revealed that children with dyslexia had more difficulty learning the associations between avatars and voices than the normally developing children, $F(1, 26) = 12.61$, $\eta_p^2 = .33$, $p = .001$. Neither the effect of Language nor the interaction between the two factors approached significance, both Fs < 1.

In sum, the present experiment has revealed that children with/without dyslexia were more accurate in recognizing voices in their native tongue than in an unfamiliar language. In addition, there was an advantage of the control group over the group with dyslexia, regardless of language – this effect of Group was also noticeable at the end of the practice phase. Taken together, this pattern of data is inconsistent with a deficit in native-language phonological representations, as this account would have predicted a null effect of Language in developmental dyslexics.

The question now is whether the null effect of language reported by Perrachione et al. (2011) for individuals with dyslexia in the voice recognition task is specific to adult readers. Experiment 2 was designed to explore this possibility. The participants were adults with/without dyslexia whose mother tongue was Spanish. The procedure was exactly the same as in Experiment 1 except that there were five avatars to perfectly mimic the Perrachione et al. (2011) experiment.

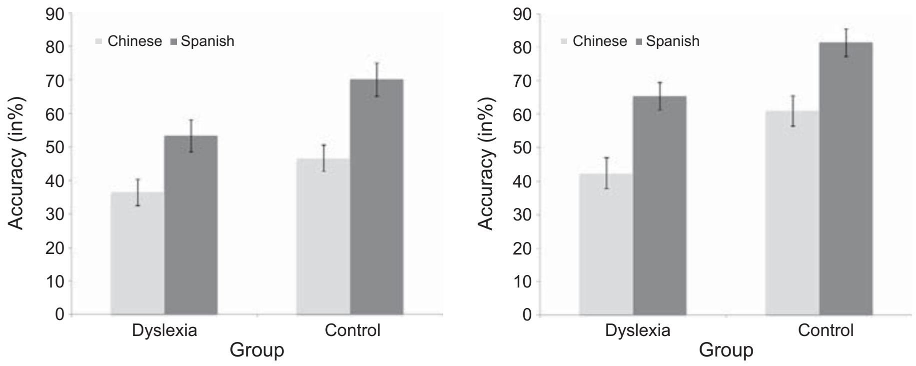

Figure 2. Mean voice recognition accuracy (in %) of dyslexic and control participants (error bars designate the standard error of the mean). The left panel corresponds to Experiment 1 (children) and the right panel corresponds to Experiment 2 (adults).

Table 2. Demographic characteristics and Digits Span, Phonological Awareness, Reading, Writing, an IQ scores of the adult participants in Experiment 2 (means and standard deviations)

	Dyslexia	Control	*p*-value
Age	33.6 (10.4)	29.5 (9.5)	= .29
Gender (men/women)	4/14	4/14	> .85
Education (years)	14.1 (2.2)	14.1 (2.1)	> .85
Digits (WAIS)	9.8 (1.9)	10.9 (1.1)	= .041
Phonological awareness (oral spelling)	10.5 (2.1)	13.3 (1.1)	< .001
PROLEC-SE			
Word accuracy	38.6 (1.2)	39.8 (0.3)	< .001
Word speed	31.9 (7.6)	22.1 (3.1)	< .001
Nonword accuracy	35 (3.1)	38.7 (1.0)	< .001
Nonword speed	55.7 (9.6)	36.1 (4.7)	< .001
PROESC			
Ruled spelling	21.8 (2.3)	24.4 (0.9)	< .001
Nonruled spelling	22.7 (1.8)	23.8 (1.6)	= .109
Pseudowords	20.3 (2.4)	23 (0.9)	= .003
WAIS			
Verbal IQ	108 (8.5)	113 (5.1)	= .042
Performance IQ	124 (9.1)	128 (5.9)	= .224
Total IQ	118 (6.7)	122 (5.7)	= .013

Experiment 2

Method

Participants

Thirty-six native Spanish-speaking adults participated in this experiment. Eighteen were dyslexic and eighteen were normal readers. All participants, dyslexics and controls, had a high level of education – in both groups half of them had university studies and the other half professional studies. The dyslexic participants had a history of difficulties in learning to read. In two sessions prior to the experiment, all these participants were assessed with the PROLEC-SE reading test (Ramos & Cuetos, 1999), a phonological awareness test, and four subtests of the Spanish adaptation of the WAIS intelligence test (two verbal: Similarities and Digit Span; two nonverbal: Picture Completion and Digit Symbol-coding) – as Fuentes-Durá, Romero-Peris, Dasí-Vivó, and Ruiz-Ruiz (2010) demonstrated, these four subtests provide high levels of reliability and validity of IQ scores for research purposes (see Blyler, Gold, Iannone, & Buchanan, 2000; Demsky, Gass, Edwards, & Golden, 1988). The demographic characteristics, digits span, phonological awareness, reading, writing, and IQ scores of the adult participants are presented in Table 2. All control participants had normal scores on these tests. The control participants were matched with the dyslexics in educational level, age, and gender. Both groups were also matched in Performance IQ, although there was a small advantage in Verbal IQ for the control versus the dyslexic group (see Table 1), as it occurs usually. No participant indicated prior experience with Mandarin Chinese. All participants signed an informed written consent before the experiment.

Materials

Ten sentences recorded in Spanish and Mandarin Chinese were used in this experiment. These sentences were the eight used in Experiment 1 plus two others of similar structure and length. These new sentences were recorded by two different women (a native Spanish speaker and a native Mandarin Chinese speaker) under the same conditions as in Experiment 1. The avatars were the same as in Experiment 1 – except for the addition of two new ones (one for the Spanish condition and another one for the Chinese condition). Eighteen lists of stimuli were created to counterbalance the materials. Participants were randomly assigned to each list. Participants received 50 trials (5 Voices × 5 Sentences × 2 Repetitions) in each phase.

Procedure

Participants were tested individually in a soundproof laboratory of the school of Psychology at the University of Oviedo. The overall procedure was the same as in Experiment 1. Each experimental session lasted for about 60 min.

Results and Discussion

The statistical analyses were parallel to those in Experiment 1, and the averages per condition are displayed in Figure 2 (right panel). Similarly to Experiment 1, we found main effects of Language, $F(1, 34) = 53.45$, $\eta_p^2 = .61$, $p < .001$ (higher voice recognition rates in the participants' mother tongue than in an unfamiliar language) and Group, $F(1, 34) = 25.23$, $\eta_p^2 = .43$, $p < .001$ (higher voice recognition rates in the control group than in the dyslexia group). Again, there were no trends of an interaction between the two factors, $F < 1$, $p = .67$. As in Experiment 1, the vast majority of the participants with dyslexia (16 out of 18: 89%) were more accurate at identifying voices in their mother tongue than in the unfamiliar language and the 23% advantage in accuracy was statistically robust, $t(17) = 4.80$, $p < .001$ – the JZS Bayes Factor (BF_{01}) for this test was 0.005, which represents extreme evidence for H_1.

We also conducted a conjoint ANOVA of the two experiments to examine the evidence in favor of the additivity of the effects of Language and Group across experiments – note that the performance in adults (Experiment 2) was not much better than in children (Experiment 1), but this was probably due to the increased task difficulty for the adults (five instead of four speakers). In particular, we computed the probability of the null hypothesis of the interaction being true, given the data obtained. The $p(H_0|D)$ value was 0.88, which represents positive evidence in favor of the null hypothesis (see Masson, 2011).

As in the Experiment 1, we conducted Pearson's correlation tests between the global scores in the voice recognition task and the phonological abilities and accuracy and speed in reading pseudowords. The correlation tests were significant in phonological ability ($r = .37$, $p = .027$), accuracy ($r = .39$, $p = .018$) and speed ($r = -.52$, $p = .001$): participants with higher scores in the voice recognition task had a more accurate reading, shorter latencies, and higher scores in the phonological test. Similarly to Experiment 1, we examined the accuracy in the final ten trials of the practice phase. Readers with dyslexia had averages of 9.7 and 9.1 (out of 10) in the blocks with the familiar and unfamiliar languages, respectively, while the controls had an average of 9.8 and 9.6 of correct trials in the familiar and familiar blocks, respectively. An ANOVA on this dependent measure with Language and Group as factors revealed that accuracy was higher when the voices were in the familiar than in the unfamiliar language, $F(1, 34) = 6.38$, $\eta_p^2 = .16$, $p = .016$. In addition, the individuals with dyslexia had more difficulties learning the associations between avatars and voices than the controls, although the effect did not reach the classical criterion for statistical significance $F(1, 34) = 3.59$, $\eta_p^2 = .10$, $p = .067$. There were no signs of an interaction between the two factors, $F < 1$.

In sum, the present experiment is a successful replication of Experiment 1 with an adult population. Participants with dyslexia are less accurate than control individuals in the voice recognition task, and this disadvantage occurs to a similar degree independently of the familiarity of the talker's language (see Figure 2). Furthermore, overall performance in the voice recognition task is related to the participants' reading abilities.

General Discussion

The main findings of the present experiments can be summarized as follows: (i) children and adults are more accurate at identifying the talker's voice in their mother tongue (Spanish) than in an unfamiliar language (Mandarin Chinese), thus replicating earlier research (e.g., Goggin et al., 1991); (ii) children and adults with dyslexia are less accurate at identifying the talker's voice than normal readers; (iii) this disadvantage is similar in magnitude in the two languages (Spanish vs. Chinese); and (iv) performance in the voice recognition task is correlated with the participants' reading abilities (both in children and adults) – that is, this task can potentially be useful to detect kindergarteners at risk of dyslexia.

The present data pose problems for an account of dyslexia based on a deficit at the level of "native-language phonological representations" (Perrachione, 2012; Perrachione et al., 2011). This account predicts a null difference between the accuracy at identifying the talker's voice in familiar and unfamiliar languages in dyslexics. Instead, the present experiments revealed a robust mother-tongue advantage at identifying the talker's voice in both adults and children with dyslexia. This was done using classical significant tests and Bayesian tests, and importantly, Spanish and Chinese voices in the present experiments were matched in terms of fundamental frequencies (i.e., a measure of voice discriminability). We acknowledge that the fundamental frequency is only one single aspect of a voice, and discriminability may depend on further measurable voice characteristics, such as jitter and shimmer but also accent or lisps – given the nature of the stimuli and recording/testing, they are unlikely to have played a major role, though we do not deny its potential impact in natural environments. It is unclear to us why Perrachione et al. (2011) failed to find a language difference in the recognition of voices in a group of adults with dyslexia: after all, the sentences in the native language were composed of phonological representations from words in grammatically correct sentences, while the sentences in the unfamiliar language would be completely unintelligible (i.e., there was actually a confound in their experiment that should have favored the identification of the talker's voice in the native language). One might argue, however, that the null effect reported by Perrachione et al. is language-dependent, perhaps in terms of some grain-sized measures in languages as different as English (Perrachione et al., 2011) and Spanish (the present experiments). Spanish has a more transparent orthography than English, and phonologically based reading impairment may be more prevalent in English than in Spanish (or other "shallow" orthographies). However, leaving aside that the deficits associated to dyslexia appear to be universal (e.g., see Goswami et al., 2011, for evidence in English, Spanish, and Mandarin Chinese), the conclusions from Perrachione and cols. were supposed to be general rather than language-specific.[1]

The advantage of normally developing readers over dyslexics at identifying voices, both with children and adults, can be readily accommodated by influential theories of developmental dyslexia (e.g., Ahissar et al., 2000; Goswami, 2011): The basic auditory perceptual deficits in readers with dyslexia would hinder the acquisition of stable representations, and hence, their performance would be lower than in normally developing readers regardless of linguistic content. The underlying idea is that the acoustic-phonetic characteristics of speech sounds may contribute to associate talker identification (see Belin, Fecteau, & Bédard, 2004, for a model of voice perception). Although the present design is not optimal to distinguish between deficits at encoding versus retrieval, the data from the final trials in the practice phase may be taken to suggest that the deficit already occurs during the phase of association learning – note that, in the present experiment (as in the Perrachione et al., 2011, experiment), both phases (acquisition and recognition) were run in close succession and this makes it difficult to differentiate between working memory and long-term memory effects.[2] As a reviewer pointed out, a nonexclusive (and more parsimonious) conclusion is that individuals with dyslexia have a general impairment in association learning across modalities. Indeed, a number of recent proposals that deficits in multisensory integration may underlie dyslexia (see Gori & Facoetti, 2014; Harrar et al., 2014, for recent evidence). That is, dyslexics may be impaired at learning to match voices (auditory modality) to avatars (visual modality). In particular, the present data may be taken to suggest that the individuals with dyslexia may have a general impairment of fine-grained memory representations. This might be present not only in the auditory domain (negatively affecting the representation of subtle acoustic differences between voices), but also in the visual domain (negatively affecting the representation of subtle differences between abstract visual orthographic representations, see Dehaene et al., 2010). This explanation in terms of deficits in multi-sensory integration avoids all the interpretive issues related to explaining why a low-level auditory deficit affects voice recognition but not other complex auditory abilities like speech perception which is essentially unimpaired in dyslexia. We must keep in mind that the causal connection between dysfunctional auditory processing and reading impairment does not account for other, preserved, complex auditory abilities in dyslexia, such as speech and music. Furthermore, a purely auditory account of dyslexia cannot explain why small increases in inter-character spacing while reading sentences is helpful for dyslexic readers, while the effect for normally developing readers is negligible (e.g., Perea, Panadero, Moret-Tatay, & Gómez, 2012; see McCandliss, 2012, for an explanation in terms of visual attention).

Can the "avatar game" be employed as an easy-to-run test to detect kindergarteners at risk of dyslexia? The present experiments (with children and adults) and the Perrachione et al. (2011) experiment (with adults) provide converging evidence of a relationship between reading and phonological abilities and performance in the "avatar game." Regardless of linguistic content, children (and adults) with dyslexia had a general impairment in the ability of associating voices with their corresponding avatar (see Figure 2) – this effect was restricted to the participants' mother tongue in the experiment of Perrachione et al. (2011). Furthermore, reading abilities correlated with the children's (and adult) performance in the voice recognition task, thus extending the correlational data reported by Perrachione et al. (2011) with adults. Thus, in conjunction with other tests, the "avatar game" can potentially be employed to detect kindergarteners at risk of dyslexia (i.e., low accuracy would be a marker of dyslexia).[3] A longitudinal study is necessary to examine in greater detail this issue.

[1] What we should also note here is that the underlying cause of the null effect of language in the group of dyslexics was not effectively pursued in the Perrachione et al. (2011) experiment, as they did not replicate the experiment with a comparison group of dyslexic individuals whose mother tongue was Mandarin Chinese – they did test a group of native speakers of Mandarin Chinese with no reading disorders.

[2] This way, learning performance would be comparable at the end of acquisition and the obtained effects could be attributed to recognition rather than learning.

[3] As a reviewer pointed out, the Perrachione et al. procedure could be refined by using pseudowords of the native language rather than words. The reason is that using real words in the children's own language in contrast to a foreign language that must sound like unfamiliar pseudowords has the "lexical status of the items" as a confound.

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