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SHORT REPORT

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Improving non-native duration contrast with dichotic training in dyslexic and non-dyslexic individuals

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Perceiving and producing English phonemic vowel length contrasts is challenging for non-native speakers. According to multi-time resolution models, endogenous slow/fast rhythms contribute, respectively, in the right/left hemispheres, to long/short acoustic cue processing. This study introduced a perceptual training method implementing dichotic stimulation to improve /iː/-/ɪ/ processing by promoting hemispheric complementarity. Twenty non-dyslexic and 20 dyslexic French adults received 1 hr-training over 3 days. Productions were evaluated with pre-/post-tests. Training enhanced vowel duration contrast in word production by /iː/ lengthening and /ɪ/ shortening in both groups. Adults with dyslexia compensated fewer /iː/ lengthening by /ɪ/ shortening than did non-dyslexic adults. Transfer from perceptual training to production seems possible for foreign-language learning even in dyslexic adults. The extent to which dichotic presentation contributed to training effectiveness cannot be evaluated here, but the triggering of lengthening and shortening mechanisms suggests that lateralized complementary skills have been enhanced by dichotic stimulation.

KEYWORDS
dichotic listening, dyslexia, foreign language learning, language training, vowel processing

1 | INTRODUCTION

Late second language (L2) learners typically misperceive non-native phonemes as instances of the closest native phonemes of their first language (L1) and produce them accordingly (Flege, Bohn, & Jang, 1997). For instance, the English short/long vowel contrast is irrelevant in French and is rarely perceived and produced by French speakers. However, L2 vowel perception and sometimes vowel production can improve with perceptual training (Lengeris & Hazan, 2010; Wong, 2013). Our study addressed this issue with a new training program based on assumptions of the Asymmetric Sampling in Time model (AST, Poeppel, 2003), according to which speech is decoded in the auditory cortex through a large temporal integration window (125–300 ms) relevant to syllables in the right hemisphere (RH), and a narrow integration window (20–80 ms) relevant to phonemes in the left hemisphere (LH) (Poeppel, Idsardi, & Van Wassenhove, 2008). This difference may be subserved by the dominance of slow theta oscillations (4–8 Hz) in the right auditory cortex and faster gamma cerebral oscillations (>30 Hz) in the left auditory cortex. In contrast to consonants, results about hemispheric asymmetry for vowels are mixed. For instance, bilateral multifocal motor neuropathy (MMN) emerged for long deviant vowels in electroencephalography (EEG) measurements (Asano, Shiga, Itagaki, & Yabe, 2015), and right-dominant activation occurred in the anterior superior temporal gyrus in functional magnetic resonance imaging (fMRI) for the perception of long German vowel (duration 333 ms; Obleser et al., 2006). This result pattern might be explained by (1) the rich spectral content of vowels and the spectral fine-tuning of the right auditory cortex (Warren, Jennings, & Griffiths, 2005; Zatorre, Belin, & Penhune, 2002) and (2) the long duration of many vowels (>150 ms). Indeed, RH dominance of cerebral activation has been reported for vowel discrimination, specifically in the case of long vowel pairs (Britton, Blumstein, Myers, & Grindrod, 2009), which reconciles the RH involvement in some phoneme perception with the assumptions of the AST model. The present study proposed a training that builds on the potential difference in hemispheric asymmetry related to the processing of short and long vowels.

According to the temporal sampling framework (TSF) (Goswami, 2011), the different cerebral modulation frequency ranges (cerebral oscillations) are not unimpaired in dyslexia (DYS), resulting in impaired temporal sampling of the acoustic speech signal, leading to phonological deficits. Consistent with this framework, an atypical absence of significant rightward lateralization for low frequencies and a rightward lateralization for high frequencies have been showed in children and adults with DYS (Lizarazu et al., 2015). The TSF specifically postulates that a difficulty with slower temporal modulations—including the theta range—takes a large part in the origin of speech processing impairments in DYS. This is in agreement with atypical RH activity during speech processing in children and adolescents with DYS (Heim, Eulitz, & Elbert, 2003). For instance, abnormal activity in the right supramarginal gyrus during 2 Hz modulation processing has been shown in dyslexic children (Cutini, Szűcs, Mead, Huss, & Goswami, 2016). In addition, Di Liberto et al. (2018) reported impaired low-frequency cortical tracking to phonetic features, and a correlation between this disorder and phonological skills in the case of DYS. Despite accumulating evidence for atypical processing of slow rate changes during speech processing in DYS, temporal processing in the high-frequency ranges has also been documented. For instance, a lack of LH-specialization for fast oscillations (Lehongre, Morillon, Giraud, & Ramus, 2013) and reduced leftward lateralization for high-frequency entrainment (Dushanova, Lalova, Kalonkina, & Tsokov, 2020) have been reported in developmental DYS.

Dichotic stimulation might be an appropriate method to improve the English long/short vowel contrast (e.g., /iː/—/ɪ/) processing in French speakers, notably by promoting hemispheric complementarity for duration processing. Dichotic listening provides participants simultaneously with two different sounds, one to each ear (Kimura, 1967). This method was designed to increase the dominance of contralateral hemisphere projections. Similar dichotic stimulation has been used successfully in Bouhon (2022) to help French dyslexic and typical-reading adults improve identification, discrimination, and pre-attentional sensitivity to another phonemic contrast based on temporal acoustic cues: the voicing of English stop consonants. In contrast to French (i.e., L1 of the participants), voiced stops have a short Voice Onset Time (VOT) and voiceless stops have a long VOT in English (Bouhon, 2022). In the present training targeting vowel perception, words containing /iː/ (i.e., long vowel) were presented to the left ear with white noise in the right ear, whereas words containing /ɪ/ (i.e., short vowel) were presented to the right ear concurrently with white noise in the left ear. The aim was to specifically involve the most efficient hemisphere for vowel duration processing. The training effect was evaluated with two pre-post word production tasks (i.e., reading aloud tasks with or without auditory model) in French adults with typical development or with DYS. Dyslexic individuals have been reported to frequently demonstrate a lower level of oral proficiency in L2 (Crombie, 1997; Sparks, Patton, Ganschow, Humbach, & Javorsky, 2006).

2 | METHODS

2.1 | Participants

Forty monolingual French native speakers (Table 1) from Lyon University with an English level (L2) inferior to B1 (Common European Framework of Reference for Languages, CECRL) participated: 20 adults who suffered from DYS in childhood (DYS) (16 females; $M = 22.80$ years; $SD = 3.62$) and 20 controls (CTR; 18 females; $M = 21.28$ years; $SD = 2.57$), with more participants in the latter group having a slightly higher English level. Thirty-four were right-handed (≥80% "right hand" responses in the Edinburgh test, 16 DYS and 18 CTR). They had to exhibit a right ear advantage (REA) to process short phonetic features according to a dichotic listening test in French introduced by (Bedoin, Ferragne, & Marsico, 2010). In one of the conditions, two words differing by the place of articulation of their initial plosive consonant (i.e., a short acoustic difference in formant transition, e.g., /pas/—/tas/) were simultaneously presented to the right ear and the left ear, respectively. Better identification of stimuli presented to the right ear (i.e., REA) was assumed to reflect better processing of short phonetic features by the LH. Exclusion criteria were uncorrected auditory or visual disorders known neurological or neurodevelopmental disorders other than DYS (e.g., attention deficit hyperactivity disorder [ADHD]). The experiment was approved by the French Ethics Committee (*Comité de Protection des Personnes*); participants provided written informed consent.

2.2 | Materials

Thirty-four English minimal pairs of monosyllabic words opposed by /iː/—/ɪ/ (e.g., *sheep-ship*) were recorded by a native English speaker. Thirty pairs were used for training and testing; four additional pairs were included in the production tests. The mean durations were 150 ms for /iː/ and 60 ms for /ɪ/. Pictures under creative commons license were used for training. Due to COVID-19, training and tests were performed remotely under the supervision of the experimenter, using OpenSesame (Mathôt, Schreij, & Theeuwes, 2012); participants used their headphones, dictaphones, and computers. Participants' setup was tested with a specialized video with left and right stereo channel isolation (#Stereo: Left and Right Stereo Sound Test, 2018).

2.3 | Procedure

A pre-test (T1)—training—post-test (T2) design was used. Two speech production tests have been designed to assess the duration of /iː/ and /ɪ/ in monosyllabic words at T1 and T2. In the first one (reading test), the participant had to

TABLE 1 Characteristics of the control (CTL) and dyslexic (DYS) participants.

Group	Mean age (years)	Age (*SD*)	Parity	Edinburgh laterality test	Mean right ear advantage (*SD*)	English level
CTL	21.28	2.57	18 females 2 males	18 right-handed 2 ambidextrous	0.50 (0.47)	4 A2 16 B1
DYS	22.80	3.62	16 females 4 males	16 right-handed 4 ambidextrous	0.80 (0.92)	12 A2 8 B1

read a series of words without an auditory model. In the second one (repetition test), the printed word and an auditory model were presented, and the participant had to imitate the word.

The training was presented as a lexical enrichment program over three consecutive days (20 min/day). Words containing /i:/ were presented to the left ear concurrently with white noise to the right ear to specifically involve the RH in /i:/ processing; the reverse lateralization was used for words containing /ɪ/. Participants did not receive explicit instructions about vowel durations. Exercises *A* and *B* were done on the first two days, and Exercises *B* and *C* on the third day. In Exercise *A* (word-learning), participants listened twice to an English word illustrated by a picture and English and French spellings to promote learning of both lexical representations (specific phonological-orthographic-semantic associations) and general grapheme-phoneme correspondences. In Exercise *B* (orthographic judgment), participants saw a new picture, listened to an English word, and had to select its orthographic form out of a minimal pair. Although the task can be performed based on lexical knowledge, the two printed words were designed to repetitively drive attention to focus on reliable grapheme-phoneme relations (1 letter = /ɪ/, short; 2 letters = /i:/, long), favoring the acquisition of these rules. In Exercise *C*, participants heard an English word spoken without spelling information, then they selected one of two novel pictures to illustrate it. Feedback was provided after each response in Exercises *B* and *C*. Exercise *B* underlined grapheme-phoneme relations between spelling and vowel duration, while Exercise *C* encouraged the acquisition of lexical phonological representations.

2.4 | Data analysis

Produced vowel durations were measured using Praat (Boersma & Weenink, 2021), and /i:/ minus /ɪ/ differences at T1 and T2, respectively, as well as /i:/ lengthening and /ɪ/ shortening from T1 to T2, were calculated. As residuals were not normally distributed for T1 and T2 differences, they were compared using Wilcoxon signed rank tests. *Vargha-Deleney* (*A*) effect sizes were reported for significant effects Cohen (1988).

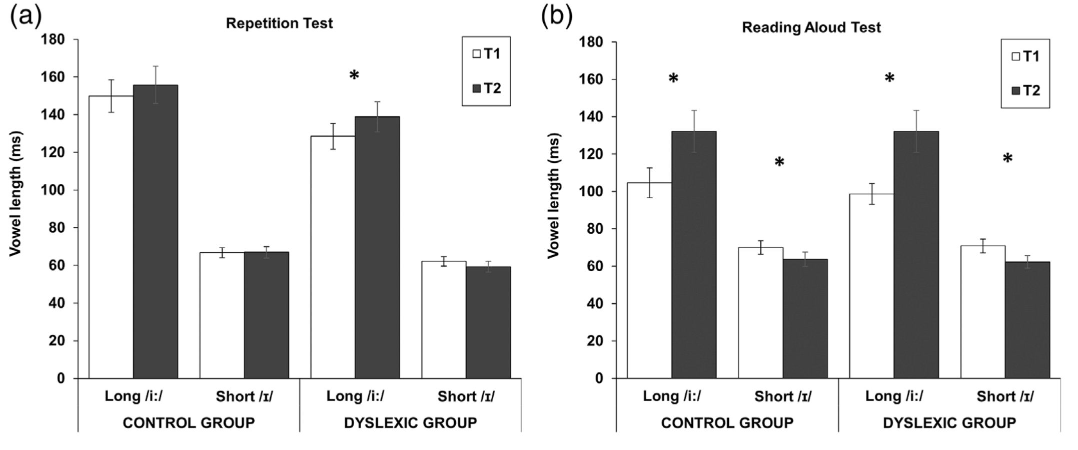

FIGURE 1 Left: duration difference produced at T1 (white) and T2 (black) by the control group (CTR, left side) and the dyslexic group (DYS, right side), for the repetition test (a), and for the reading aloud test (b). Error bars represent the standard error. *Significant differences ($p < .05$) between T1 and T2. Right: duration difference produced at T1 (white) and T2 (black) by the control group (CTR, left side) and the dyslexic group (DYS, right side), for the repetition test (panel a), and for the reading aloud test (panel b). Error bars represent the standard error. *Significant differences ($p < .05$) between T1 and T2.

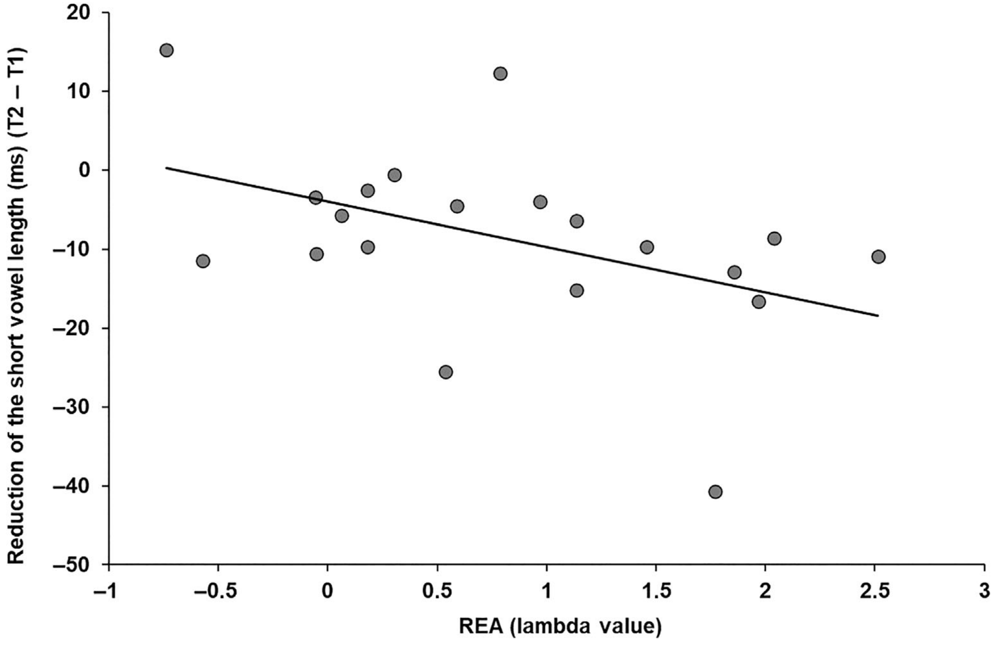

FIGURE 2 Scatterplot showing the correlation between the right ear advantage and the reduction of /ɪ/ duration from T1 to T2 for the dyslexia group.

3 | RESULTS

Repetition test: The /i:/–/ɪ/ duration difference tended to be smaller in DYS than in CTR at T1 ($W = 269$, $p = .064$), but not at T2 ($W = 222$, $p = .561$). It increased from T1 to T2 only in DYS ($V = 40$, $p = .016$, $A = 0.36$), due to /i:/ lengthening ($V = 49$, $p = .036$, $A = 0.60$) (Figure 1, left).

Reading test: For /i:/–/ɪ/ duration difference, the production of the two groups did not differ at T1 ($W = 197$, $p = .947$) and T2 ($W = 241$, $p = .277$). From T1 to T2, this difference increased in CTR and DYS ($V = 3$, $p < .001$, $A = 0.76$; $V = 8$, $p < .001$, $A = 0.81$). Its effect size was large for trained and untrained words in CTR ($V = 9$, $p < .001$, $A = 0.78$; $V = 21$, $p < .001$, $A = 0.73$) and DYS ($V = 17$, $p = .002$, $A = 0.78$; $V = 12$, $p < .001$, $A = 0.81$). In CTR, /i:/ lengthening ($V = 11$, $p < .001$, $A = 0.71$) surpassed /ɪ/ shortening ($V = 167$, $p = .019$, $A = 0.61$), whereas in DYS, /i:/ lengthening ($V = 41$, $p = .015$, $A = 0.68$) was slightly surpassed by /ɪ/ shortening ($V = 180$, $p = .004$, $A = 0.70$) (Figure 1 right). Additionally, correlation revealed that the stronger the REA (i.e., left-hemisphere dominance in the dichotic test (Bedoin et al., 2010)) was, the higher was the /ɪ/ shortening at T2 only in DYS (*Spearman*, $r = -0.45$, $p = .047$, $N = 20$; CTR: *Spearman*, $r < -0.01$, $p = .993$, $N = 20$) (Figure 2).

4 | DISCUSSION

Dichotic stimulation was used in perceptual training to promote appropriate hemispheric asymmetry for English vowel processing in agreement with the vowel duration. Transfer to speech production was assessed with two tests. Before training, /i:/–/ɪ/ duration difference was already present in productions in both groups, but it significantly sharpened after training. This improvement occurred whether the auditory model was available (i.e., repetition task) or not (i.e., reading aloud) in DYS, but not in the repetition test in CTR, probably due to ceiling performance.

This progress was generalized to novel words in both groups, although L2 learning has been reported to be challenging for dyslexics (Crombie, 1997; Sparks et al., 2006). Our findings suggest that improvements can transfer from perception to production, and new phonological contrasts can be learned by adults without explicit teaching. As training with the dichotic device has been previously shown to improve learning of consonant voicing based on VOT duration in English (Bouhon, 2022), future research could test its adaptation to other languages with duration contrasts for vowels (e.g., German). The tasks used in the present study suit particularly well for languages with grapheme-phoneme rules for vowel duration.

For the reading test, /i:/ lengthening and /ɪ/ shortening contributed to increasing the duration difference in both groups after training. This result pattern is consistent with the assumption that dichotic training could reinforce associations between right-lateralized slow oscillations (Poeppel et al., 2008) and long vowel processing, on the one hand, and fast left-lateralized oscillations and short vowel processing, on the other hand.

Detailed analyses have suggested long vowel lengthening to be the default mechanism after training to produce vowel duration contrast, as (a) in the repetition test, it was the source of /i:/–/ɪ/ difference increase; and (b) in the reading test, the effect size of /i:/ lengthening exceeded that of /ɪ/ shortening in CTR.

In the DYS group, the large effect size of /ɪ/ shortening in the reading test after dichotic training may seem surprising in light of the previously reported atypical reduced leftward lateralization of fast oscillations in DYS (Dushanova et al., 2020; Lehongre et al., 2013). However, typical beta power—a rhythm that is well-suited for short vowel processing—has been reported in the LH for dyslexic adults (Chang et al., 2021), which could allow for processing the /ɪ/ brevity after appropriate stimulation by dichotic training, at least as well as for control adults. The correlation between the REA and the shortening of /ɪ/ after training, observed only in the DYS group, is consistent with the hypothesis that improved processing of short phonetic events by the LH might be a key progress triggered by dichotic training in the DYS group.

The correlation between /ɪ/ shortening and REA in dyslexic adults suggests that the greater the typical dominance of fast oscillations in the LH, the higher was the compensatory mechanism based on /ɪ/ shortening in this group. This correlation has to be investigated in a larger scale study, but replicating this result would encourage further perspectives for practitioners to consider a training program with dichotic stimulation, notably by exploiting the REA for short acoustic cues, as measured by dichotic listening tests (e.g., in English, Rimol, Eichele, & Hugdahl, 2006; in French, Bedoin et al., 2010). Individual differences in hemispheric asymmetry could potentially help predict whether dichotic training for duration contrast learning could lead to both appropriate long vowel lengthening and short vowel shortening.

Two main limitations have to be acknowledged for this pilot study. First, the potential test–retest effect will need to be evaluated with an untrained group of normal-reading students at T1 and T2. Second, the effect of dichotic presentation has to be disentangled from the classical effect of perceptual training, for example, by adding a control condition using binaural presentation of the stimuli during training. A higher increase in performance from T1 to T2 is hypothesized in the case of dichotic training than in binaural training, as previously reported for consonants (Bouhon, 2022).

5 | CONCLUSION

In sum, short perceptual training using dichotic listening can improve new duration contrast production in late foreign-language learners with or without DYS. Due to the lack of binaural training conditions, the extent to which dichotic presentation contributed to training effectiveness cannot be evaluated here, but the triggering of lengthening and shortening mechanisms suggests that lateralized complementary skills have been enhanced by dichotic stimulation (see also Bouhon, 2022). The findings are consistent with multi-time resolution models (Poeppel et al., 2008), and, if replicated with larger participant groups, they could provide promising training perspectives to address L2 learning difficulties.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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