Running head: Memory trace formation in SLI or Dyslexia

Auditory short-term memory trace formation for non-speech and speech in SLI and Dyslexia as indexed by the N100 and Mismatch negativity (MMN) electrophysiological responses

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None declared

Abstract

This study investigates non-speech and speech processing in Specific Language Impairment (SLI) and dyslexia. We used a passive Mismatch Negativity (MMN) task to tap automatic brain responses and an active behavioural task to tap attended discrimination of non-speech and speech sounds. Using the roving standard MMN paradigm, we varied the number of standards ('few' vs 'many') to investigate the effect of sound repetition on N100 and MMN responses. The results revealed that the SLI group needed more repetitions than the dyslexics and controls to create a strong enough sensory trace to elicit MMN. In contrast, in the behavioural task, we observed good discrimination of speech and non-speech in all groups. The findings indicate that auditory processing deficits in SLI and dyslexia can be dissociable and that memory trace formation may be implicated in SLI.

Keywords: Auditory and speech perception; Specific Language Impairment, Dyslexia, Mismatch negativity (MMN); Memory trace formation; Repetition effects; event-related potentials (ERP).

1. Introduction

Specific Language Impairment (SLI) is an impairment in acquiring spoken language despite normally developing cognitive, articulatory and social abilities [1]. Developmental dyslexia is an impairment in acquiring reading and writing skills despite normal sensory and cognitive abilities and adequate instruction [2]. Despite apparent differences, substantial overlap (up to 50%) has been reported between SLI and dyslexia [3].

To account for this overlap it has frequently been claimed that individuals with SLI and dyslexia have similar auditory processing problems. However, there has been much controversy about what these problems are and to what extent they cause *both* oral and written language deficits. [3,4]

Neural correlates of auditory processing has been extensively studied in SLI or dyslexia by measuring the mismatch negativity (MMN) component of auditory ERPs which is especially useful in the clinical setting because MMN can be measured in the absence of attention or a verbal or motor response from the participant. The MMN reflects the brain's automatic change-detection where the infrequent sound (deviant) is compared to the sensory memory representation for the frequently occurring sound (standard) [5]. The MMN is elicited by any discriminable auditory change and is, therefore, considered as a neurophysiological measure of auditory discrimination accuracy [6].

In support of the auditory deficit theories of SLI or dyslexia, several studies have reported attenuated MMN amplitudes or delayed MMN peak latencies for non-speech sounds [7,8,9] or for both non-speech and speech sounds in the clinical groups [10,11]. Other evidence, however, contradict the auditory deficit theories by reporting age-appropriate MMN amplitudes or peak latencies for non-speech sounds but attenuated or delayed MMN responses for speech sounds [12,13] suggesting that the primary deficit in SLI or dyslexia is not auditory but speech-specific in nature.

However, because at least two factors influence the MMN elicitation: detection of regularities (i.e., memory trace formation for the standard sound, e.g., via sound repetition) and detection of deviance in the incoming signal (i.e., comparison between the incoming sound and the standard stimulus trace, e.g., via a sound change) [14,15], we argue that problem in either one of these mechanisms may result in attenuation of MMN amplitudes in SLI or dyslexia. Moreover, since memory traces are formed faster for familiar speech sounds than for other sounds [16] attenuated MMN amplitudes may also reflect the differential mechanisms in the dynamics of short-term memory trace formation for non-speech and speech sounds. Furthermore, recently it has been suggested that weaker stability at the brainstem could lead to deficits in how cortical neurons adapt to sound repetition in children with dyslexia [17]. Thus, further research onto the neural mechanisms underlying attenuated MMN responses in SLI or dyslexia is warranted.

Here we investigate auditory processing in SLI and dyslexia to see if they have a deficit in i) sound discrimination (MMN and behavioural discrimination); ii) the dynamic operation of auditory sensory memory (N100 response and memory trace formation for the standard sounds) iii) in non-speech auditory or speech-specific processing, and iv) if auditory processing differs between SLI and dyslexia.

2. Methods

This study was approved by UCL research ethics committee. A total of thirty-four young adults divided into three groups volunteered for the study. Eleven of them were diagnosed with

SLI (SLI: 8 male, mean age 18.8, 15-25 years old); eleven were diagnosed with dyslexia (DYS: 7 male, mean age 19.3, 14-25 years old); twelve controls (CA: 10 male, mean age 19.5, 15-25 years old) were matched with SLI and dyslexia groups on chronological age [F(2,31)=.121, p=.886] and non-verbal intelligence [RPM, [18]; F(2,31)=1.132, p=.335]. Participants in the clinical groups had all been diagnosed by educational psychologists or speech and language therapists, and they received support in school/higher education or attended (or had previously attended) special speech and language schools in the UK. All participants were right-handed native speakers of English and they all reported normal hearing. All participants (or their parents/guardians) gave informed consent and were financially recompensed for their time.

Two sets of synthetic stimuli, speech and non-speech (closely resembling those used by [19]), were created by using a Klatt type cascade-parallel formant synthesizer (HLsyn, Sensimetrics Inc., 1.0). Speech stimuli were English nonwords /bot/ and /bod/ that are distinguished by voicing of the syllable-final consonant. The voiceless and voiced speech stimuli were created by manipulating (i) the duration of the vocalic portion and (ii) the F1 offset frequency during the final 50 ms portion of the vowel [20]. However, in order to create variation for the MMN paradigm, two within-category variants of the syllables (/bot/$_2$ and /bod/$_2$) were synthesized where the primary cue (vowel duration) remained unchanged but the secondary cue (F1 offset) was changed to create acoustically different variants of the same phoneme. Stimulus parameters are presented in Table 1.

For all sounds, the vocalic portions were preceded by 50 ms of silence signalling the initial stop consonant [b] during which the amplitude of voicing (AV) parameter was interpolated from 40-60 dB. Fundamental frequency (F0) was set to increase from 100-130 Hz during the initial 50 ms after which it linearly decreased to 95 Hz to imitate natural pitch contour in speech. A 15 ms linear onset and offset ramp was used to remove clicks.

Non-speech stimuli were based on the four synthetic speech stimuli and they were synthesized by replacing the three lowest formants with sinusoids (Praat, version 4.4.16,) creating four non-speech control stimuli that acoustically resemble the speech sounds but are not perceived as speech unless the participant is informed about their speech-like nature [21]. Finally, the amplitudes of the speech and non-speech sounds were RMS normalized using CoolEdit96 software and all formant frequencies were checked using Praat.

TABLE 1 ABOUT HERE

In the EEG testing, the speech and non-speech stimuli were presented (E-prime software, SOA 800 ms; 2160 stimuli in total) in a roving-standard paradigm [16] in separate blocks. In this paradigm, once the infrequent target sound (deviant) is presented, it immediately starts a new train of frequent standard sounds, and all four non-speech/speech stimuli alternate as standards and deviants.

As in [16], the number of standards preceding the deviants was fixed to either ‘few’ (2-3 standard repetitions; N=240) or ‘many’ (4-6 standard repetitions; N=240). During the EEG recording participants were seated in a comfortable chair in Faraday cage and they were watching silent cartoons and they were instructed to relax, ignore the auditory stimuli, and to avoid any unnecessary movements. The EEG recording took approximately 90 minutes.

EEG was recorded with a 128-channel electrode net (Electrical Geodesic Inc.) using NetStation acquisition software (version 4.1.2) and an EGI amplifier (sampling rate 250 Hz, online band-pass filter of 0.1-100 Hz). The recording reference was at the vertex (Cz). Electrode impedances were kept below 30 kΩ as recommended by EGI guidelines.

Off-line analyses were performed using NetStation analysis software (version 4.1.2). The following procedure is applied: (i) band-pass filtering at 1-30 Hz (ii) epoching from -100 to 600 ms relative to stimulus onset (iii) artefact rejection (+/-70 mV) (iv) re-referencing to the common average voltage of all electrodes (v) baseline correction with respect to -100 ms prestimulus time period. Furthermore, those standards immediately following a deviant are removed from the averages [16].

Behavioural testing took place after the EEG testing in all participants. In the behavioural task non-speech and speech sounds were presented in separate blocks and in a pseudo-random order (190 stimuli in total in each block, incl. 40 deviants; SOA 1000 ms). The stimuli were played at a laptop computer via headphones (Sennheiser) at a comfortable level. As with EEG, the stimuli were presented in a roving standard paradigm but the number of standards preceding a deviant varied (between 3 and 7; M= 5) to avoid the change being predictable. Participants were asked to press a button on a keyboard as quickly as possible when they heard a change in the stimulus train (go/no-go task). A short practice session (a total of 34 stimuli, 5 deviants) consisting of easily discriminated trials preceded the experiment to establish that the participants had understood the instructions and participants had to achieve at least 4/5 correct before proceeding to the actual experiment. The experiment took approximately 10 minutes to complete. In the behavioural task, data from one dyslexic subject was excluded due to technical problems during testing and one SLI participant did not finish the task due to motivational reasons.

All analyses were conducted using SPSS (version 21.0, SPSS Inc., Chicago, IL). Main effects were considered significant for $p < .05$ and approaching significant at $p < .10$. When the assumption of sphericity is violated, we report corrected p-values and Greenhouse-Geisser epsilon values along with uncorrected degrees of freedom. Bonferroni correction to the critical significance level is applied to all follow-up analyses.

3. Results and discussion

The ERP data analyses were done separately for the MMN and N100 responses at nine Regions of Interest (ROIs: Anterior-Medial-Posterior; Left-Central-Right) where each ROI represents average voltage across six to eleven electrodes. The N100 response was quantified as the mean amplitude within a 50 ms time-window occurring 150-200 ms after the stimulus onset (i.e., 100-150 ms after vowel onset) for standard sounds only. The MMN response was quantified as the mean amplitude within a 100 ms time-window occurring at 250-350 ms after stimulus onset (i.e., 200-300 ms after vowel onset) for the three different stimuli (deviant ‘few, deviant ‘many’ and standard sounds). The selection of these time-windows was based on visual inspection of the individual and group-level grand-averaged data. Furthermore, for MMN, none of the time windows before and after the 250-350 ms time-window produced a statistically significant MMN response ($p>.10$).

3.1. Auditory discrimination (MMN and behavioural)

Fig. 1A and B display the grand average ERPs for deviants (after ‘few’ and ‘many’ repetitions) and standards at an anterior-central ROI (AC) where the ERPs were largest for all groups, and the topographical voltage distribution of the MMN difference responses for non-speech and speech sounds for the three groups. Table 2 displays the response amplitudes for the three stimuli in the nine ROIs.

A Four-way repeated measures mixed ANOVA comparing the mean amplitude of the MMN response for Mode (2: non-speech, speech), Stimulus (3: deviant few, deviant many, standard), ROI (9: AL, AC, AR, ML, MC, MR, PL, PC, PR) and Group (3: CA, SLI, DYS) revealed a significant three-way interaction between Stimulus, ROI and Group (F(32,496)=1.59, p=.023, η_p^2=.093).

Repeated measures ANOVA for the CA group showed a significant interaction between Stimulus and ROI [F(16,176)=7.892, p<.001, η_p^2=.418, ε=.214]. To follow up the significant interaction, paired-sample t-tests between the three stimuli (deviant 'few', deviant 'many', standard) was conducted individually for each of the nine ROIs. The t-tests revealed that deviants after 'many' repetitions differed significantly from standard sounds in five anterior/medial ROIs (AL, AC, AR, MC, MR, all comparisons p<.017), and that deviants after 'few' repetitions differ significantly from standard sounds in two anterior/medial ROIs (AR, MC, all comparisons p<.017, see Table 2).

Repeated measures ANOVA for the SLI group showed only a significant main effect of ROI [F(8,80)=24.532, p<.001, η_p^2=.710, ε=.205], and no other significant main effects or interactions were found.

Lastly, for the dyslexia group we found a significant interaction between Stimulus and ROI [F(16,160)=3.845, p<.001, η_p^2=.278, ε=.165]. Again, paired-sample t-tests for the three stimuli individually for each nine ROIs was conducted. The t-tests revealed that deviants after 'many' repetitions differed significantly from standard sounds in four anterior/medial ROIs (AL, AC, MC, MR, all comparisons p<.017) and deviants after 'few' repetitions differ significantly from standard sounds in the anterior left ROI (AL, p<.017, see Table 2).

FIGURE 1A AND 1B ABOUT HERE

TABLE 2 ABOUT HERE

To analyse the behavioural discrimination data, the d-prime (d') measure of discrimination sensitivity and response bias (c-criterion; [22]) were calculated to account for both the discrimination performance and for the possible differences in the response strategies between participants.

Repeated measures ANOVAs were run separately for discrimination sensitivity and response bias measures for Group (3: CA, SLI, DYS) and for Mode (2: non-speech and speech). For discrimination sensitivity, no significant main effects or interactions involving the factor Group were found (all comparisons p>.10). The response bias measure showed a marginally significant interaction between Group and Mode [$F(2,29)=3.070$, $p=.062$, $\eta_p^2=.175$]. The dyslexia group adopted a more careful response strategy for speech than for non-speech (Speech: M=1.11, SD=0.25; Non-speech: M=1.26, SD=0.23; p=.021) whereas in controls and SLIs the bias for non-speech and speech did not differ (both comparisons, p>.10). The main effect of Group was not significant (p>.10).

3.2. N100 response and memory trace formation for the standard sounds

Three-way repeated measures mixed ANOVA comparing the mean amplitude of the N100 response for Mode (2: non-speech, speech), ROI (9: AL, AC, AR, ML, MC, MR, PL, PC, PR) and Group (3: CA, SLI, DYS) revealed no significant main effects or interactions involving the factor Group (all comparisons, p>.10; see Fig. 1). Overall, the amplitude of N100 response did not differ between non-speech and speech, nor did it differ between the three groups (CA, SLI and dyslexia).

Moreover, one-way ANOVA comparing the responses to standard sounds between the three groups at each of the nine ROIs revealed no significant main effects or interactions with the factor Group (all comparisons, p>.1).

Overall, these results indicate that both controls and dyslexia groups elicited a MMN response both after ‘few’ and ‘many’ repetitions of standard sounds in the fronto-central ROIs. For the SLI group, however, the two deviants did not differ from standards in any of the nine ROIs. In behavioural discrimination task all three groups achieved relatively high detection sensitivity indicating intact behavioural discrimination for both non-speech and speech sounds in SLI and dyslexia. The N100 results and the comparison of standard sounds between the three groups revealed no significant group differences. Taken together, present findings support and extend previous research by showing attenuated MMN amplitudes to both non-speech and speech sounds in the SLI group [10], even after ‘many’ repetitions of standard sounds. Furthermore, the present results also suggest that, when measuring repetition effects in auditory processing, SLI and dyslexia are dissociable disorders.

4. Conclusions

Our results suggests that individuals with SLI, but not with dyslexia, need more standard sound repetitions for MMN elicitation than controls indicating a deficit in forming accurate short-term memory traces for sounds. However, our findings suggest that the attenuated MMN response in SLI is not due to differences in how their brains extracts regularities in the ongoing auditory signal. However, further research on sub-cortical and cortical auditory responses to sound repetition in both SLI and dyslexia is needed.

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Table 1. Stimulus parameters for synthezing English nonwords /bɔt/ and /bɔd/. Formant frequencies in Hertz and vowel duration in milliseconds.

Table 2. Stimulus*ROI*Group Interaction: the mean amplitudes (in µV) for deviants after few repetitions, deviants after many repetitions and standard sounds for the three groups at nine Regions of Interest (ROIs). Standard Errors are indicated in parenthesis. Highlighted areas indicate statistically significant difference from standards (p<.017, Bonferroni correction of the significance level applied within each ROI).

Table 1.

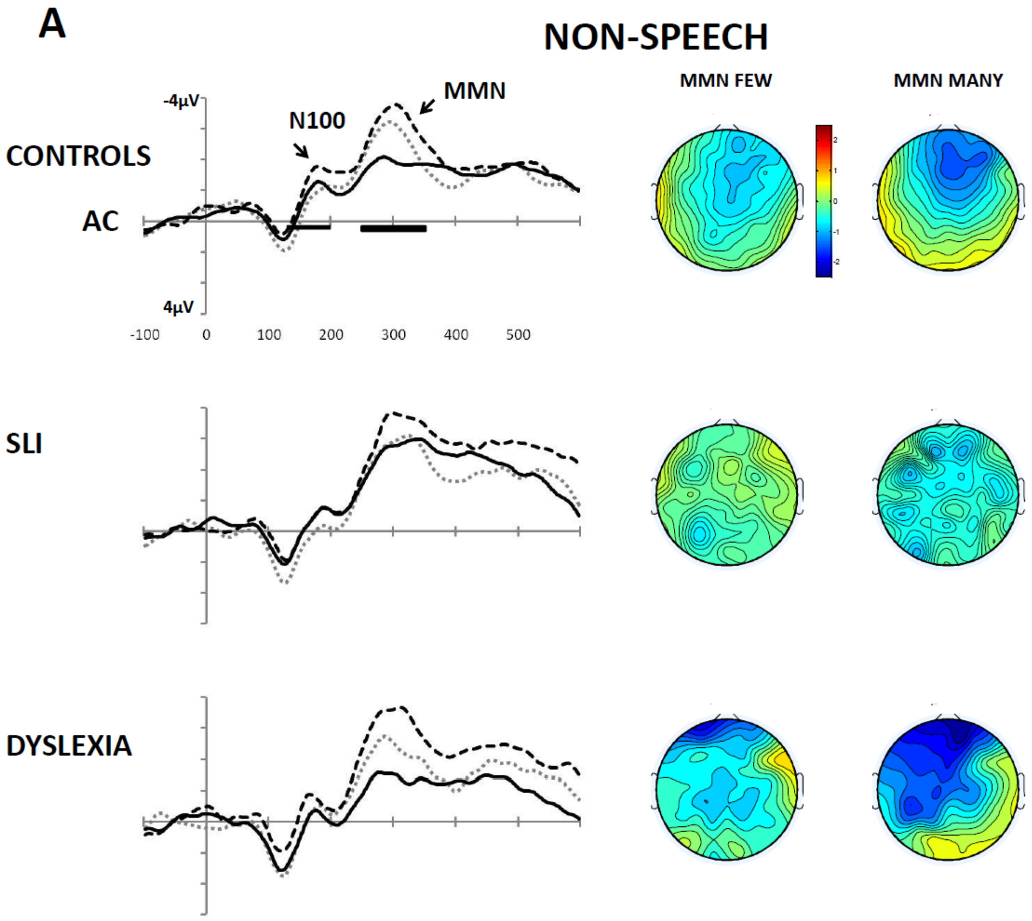
	/bɔt/$_1$	**/bɔt/$_2$**	**/bɔd/$_1$**	**/bɔd/$_2$**
Vowel duration	120	120	220	220
F1 -offset*	570-570	570-250	570-250	570-570
F2 -offset*	1000-1500	1000-1500	1000-1500	1000-1500
F3 frequency	2650	2650	2650	2650
F4 frequency	3500	3500	3500	3500
F5 frequency	4500	4500	4500	4500
F6 frequency	4990	4990	4990	4990

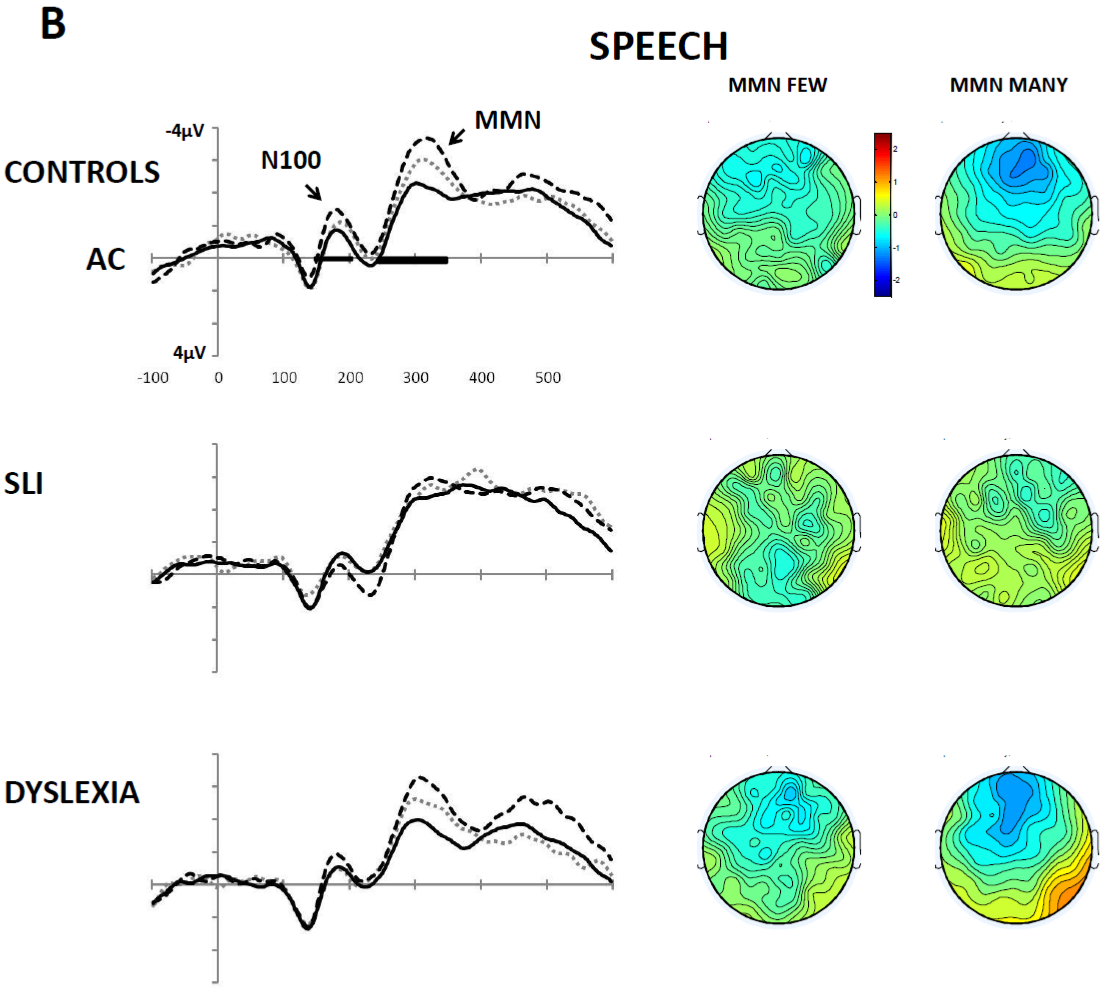
*Start and end frequency during the final 50 ms of the syllable (linear increase/decrease).

Table 2.

GROUP	**STIMULUS**	**REGIONS OF INTEREST**									
		AL	**AC**	**AR**	**ML**	**MC**	**MR**	**PL**	**PC**	**PR**	**TOTAL**
CONTROLS	**DEVIANT FEW**	-1.95 (0.38)	-2.52 (0.49)	-1.79 (0.40)	-0.99 (0.24)	-2.06 (0.35)	-0.75 (0.24)	0.45 (0.18)	0.88 (0.22)	0.57 (0.17)	**-0.99 (0.20)**
	DEVIANT MANY	-2.13 (0.30)	-3.07 (0.37)	-2.15 (0.32)	-0.92 (0.23)	-2.49 (0.32)	-0.82 (0.22)	0.71 (0.19)	0.46 (0.19)	0.84 (0.16)	**-1.04 (0.17)**
	STANDARD	-1.52 (0.34)	-1.86 (0.43)	-1.21 (0.29)	-0.78 (0.17)	-1.53 (0.26)	-0.40 (0.17)	0.45 (0.17)	0.25 (0.18)	0.66 (0.19)	**-0.66 (0.12)**
SLI	**DEVIANT FEW**	-1.66 (0.39)	-2.44 (0.39)	-1.83 (0.39)	-0.76 (0.32)	-1.79 (0.41)	-0.83 (0.36)	0.36 (0.20)	0.18 (0.10)	0.57 (0.12)	**-0.91 (0.24)**
	DEVIANT MANY	-1.72 (0.34)	-2.82 (0.42)	-2.19 (0.34)	-0.97 (0.27)	-1.91 (0.30)	-1.04 (0.29)	0.36 (0.19)	0.34 (0.24)	0.62 (0.22)	**-1.04 (0.18)**
	STANDARD	-1.45 (0.45)	-2.33 (0.49)	-1.83 (0.38)	-0.70 (0.31)	-1.63 (0.40)	-0.78 (0.27)	0.58 (0.25)	0.43 (0.26)	0.58 (0.26)	**-0.79 (0.24)**
DYSLEXIA	**DEVIANT FEW**	-1.29 (0.48)	-2.20 (0.70)	-1.23 (0.48)	-0.46 (0.35)	-1.56 (0.49)	-0.37 (0.38)	0.51 (0.34)	0.05 (0.29)	0.45 (0.30)	**-0.68 (0.30)**
	DEVIANT MANY	-1.84 (0.52)	-2.90 (0.76)	-1.59 (0.71)	-0.85 (0.28)	-1.87 (0.50)	-0.35 (0.52)	0.45 (0.26)	0.59 (0.43)	1.11 (0.43)	**-0.81 (0.29)**
	STANDARD	-0.79 (0.42)	-1.47 (0.59)	-0.99 (0.40)	-0.06 (0.28)	-0.99 (0.36)	-0.22 (0.18)	0.61 (0.18)	0.33 (0.17)	0.56 (0.17)	**-0.33 (0.21)**

Figure 1. Grand-averaged ERP responses for control, SLI and dyslexia groups. The Left column depicts the ERP waveforms for non-speech and speech and for the three stimulus conditions at anterior central (AC) Region of Interest (ROI). The individual waveforms represent ERP responses to deviants after ‘few’ repetitions (grey dashed line), deviants after ‘many’ repetitions (black dashed line) and standard sounds (thick black line). The black bars in the time axis indicate the analysis time-windows for the N100 (150-200 ms) and MMN (250-350 ms) responses. The right column depicts the scalp topography of the MMN difference wave in the 250-350 ms time-window across the nine ROIs.




B
SPEECH
MMN FEW
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CONTROLS
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-4µV
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SLI
DYSLEXIA