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Research Article

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Gaining Mismatch Negativity! Improving Auditory Phoneme Discrimination by Literacy Training – A Pre-Post Event-Related Potential Study

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Abstract

Illiteracy is still present in the society these days. Several studies have shown that illiterate individuals lack important cognitive prerequisites for literacy acquisition, such as auditory phoneme discrimination. Therefore, the current study investigated auditory phoneme discrimination in illiterate individuals before and after a one-year literacy course. We analyzed the characteristic event-related brain potential (ERP) marker for auditory phoneme discrimination, namely Mismatch Negativity (MMN).The results showed a significant enhancement of the amplitude of MMN from before to after a one-year literacy course. This finding indicates the close relationship between literacy acquisition and auditory phoneme discrimination. Further, it indicates the importance of considering discrimination training in literacy courses, especially for illiterate adults.

Keywords: Mismatch negativity (MMN); auditory phoneme discrimination; illiteracy; literacy training; pre-post study

Abbreviations: ERP: Event-Related Potential; MMN: Mismatch Negativity; DSM IV: Diagnostic And Statistical Manual of Mental Disorders; DRC-Model: Dual-Route Cascaded Model; BOLD: Blood Oxygen Level Dependency; EEG: Electroencephalography; CEFR: Common European Framework of References for Languages; HNT: Heidelberg Nonverbal Test; BISC: Bielefelder Screening zur Früherkennung von Lese-Rechtschreibschwierigkeiten; HSP: Hamburger Schreib-Probe; APA: American Psychological Association; SPL: sound-Pressure Level; Ag: silver; AgCL: silver Chloride; EOG: Electrooculogram; SPSS: Statistical Package for the Social Science; ANOVA: Repeated Measures Analyses of Variance; ANCOVA: Analysis of Covariance

Gaining Mismatch Negativity! Improving Auditory Phoneme Discrimination by Literacy Training – A Pre-Post ERP Study

Two of the most important cultural abilities are reading and writing. One can imagine how essential they are for addressing the challenges in everyday life. It is surprising that even in Germany, a highly developed country, there are still about 7.5 million individuals who cannot read or write sufficiently [1]. This large number of individuals without sufficient literal abilities highlights the importance of investigations concerning literacy acquisition in illiterate adults. Further, this special sample can give us more information about the importance of literacy acquisition in generaland its impact on the human brain, and its functions. Auditory phoneme discrimination is one of the most important cognitive abilities for literacy acquisition [2]. It has been shown that successful literacy acquisition is closely related to auditory phoneme discrimination. Schulte-Körne et al. [3] demonstrated that children with dyslexia show diminished Mismatch Negativity (MMN) in response to phonemes compared to normally developing children. The MMN is the characteristic event-related potential (ERP) marker for auditory phoneme discrimination. We investigated the MMN in illiterates before they took part in a literacy course [4] and did not find a discernible MMN in our illiterate sample. These results support the assumption that literacy acquisition has a great impact on the brain. In addition, they lead to the question whether the MMN in response to phonemes, which is already established in infants [5] and develops further during literacy acquisition, "is lost" in illiterate individuals and whether literacy training might help to enhance auditory phoneme discrimination again. Results would help to improve literacy acquisition in adults and further help to gain insights into the interplay between literacy acquisition and auditory phoneme discrimination. The study at hand aimed to investigate possible changes in auditory phoneme discrimination in illiterates by comparing the MMN before after a one-year literacy course.

A person is illiterate if his or her literal abilities are insufficient compared to those abilities that are normally required in the social context a person lives in. Illiteracy is present if adult individuals are not able to read and write sufficiently due to inadequate schooling [4]. Another well-known deficit regarding reading and writing is dyslexia. Familial frequency highlights genetic causes of dyslexia [DSM IV-R] [6]. When contrasting illiteracy and dyslexia, it becomes apparent that illiteracy is mainly caused by a lack of education whereas dyslexia is not. Many studies have investigated phonological awareness in children with and without dyslexia. Phonological awareness refers to "…one´s awareness of and access to the phonology of one´s language…" [7] and is the ability to manipulate and discriminate sounds in syllables and words. It encompasses awareness of the most basic speech units of a language. These basic units include phonemes as well as larger units such as rhymes and syllables. Phonological awareness is highly predictive of future success in literacy acquisition, that is, it is one of the most important cognitive prerequisites for literacy acquisition [8].

Phonological awareness is closely related to auditory discrimination [9]. Capabilities like language acquisition [10] and

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literacy acquisition [2,3] are known to be influenced by the auditory ability to discriminate phonemes. Perfetti [11] argued that during the process of literacy acquisition matching process takes places. Visual information is encoded into orthographic units (graphemes) and the encoding of auditory information to phonological units (phonemes) is stressed further. Orthographic and auditory units that correspond are then matched and stored in long-term memory. The encoding, matching, and consolidation of corresponding units require auditory phoneme discrimination [11]. A lot of evidence shows that auditory information is not only processed actively, but also unconsciously [12]. A well-known auditory ERP called MMN is thought to reflect the unconscious process of auditory discrimination [12]. The MMN can be described as negativity visible in the ERP in response to an occasionally occurring stimulus (deviant) in a sequence of standard stimuli. It provides an objective measure of the individual discrimination ability for simple (frequency, duration, pitch) as well as complex (phonemes, tone patterns) sound features [13]. Regarding the generation of the MMN, several hypotheses have been discussed in the past. The *model adjustment hypothesis*, first postulated by Näätänen et al. [12], explains the generation of MMN by a break of regularity in a sequence of standard stimuli. The actual sensory input is compared to a memory trace of the previously received stimuli [12,14]. In the broader sense, the MMN can be interpreted as an on-line modification of a perceptual model. If the previous prediction is not matched by the auditory input, the model needs to be updated [15]. In contrast, the *adaption hypothesis* is assuming that constant stimulation of the auditory cortex leads to the reduction of the responsiveness of neuronal elements. Consequently, the deviation of the former stimulation then leads to an enhancement of responsiveness of the neuronal elements [16]. The *predictive coding framework* encompasses these two distinct hypotheses [17] by suggesting a hierarchically organized cortical system. Levels within this system generate a compromise between bottom-up information (sensory input) and top-down predictions. Within this hierarchically organized cortical system, the inferior frontal gyrus (IFG) is thought to contribute to a top-down process modulating the deviance detection system in the superior temporal gyrus (STG) [18]. An MMN is elicited if bottom-up input is predicted incorrectly and, therefore, prediction errors cannot be suppressed [19]. The MMN is attractive for auditory research as it has been shown to be independent of attention [20-23]. However, more recent research has found an enhancement of the MMN amplitude when stimuli are attended [24]. This enhancement of amplitude was found to be associated to frontal generators of the MMN, namely IFG, but not to temporal generators of the MMN, namely STG [25,26].

The MMN has been reported to be helpful for investigating important prerequisites for literacy acquisition, such as auditory phoneme discrimination and long-term representations of phonemes [27,28]. The MMN was found to be reduced in children and adults with dyslexia in response to phonemes [3,29]. Other studies have shown deficits in children with dyslexia regarding the discrimination of frequency changes [30-32], duration changes [33] and complex tone patterns [2]. Thus, speech perception, especially the differentiation of phonemes, appears to be reduced in individuals with dyslexia. It has been shown that neural activation patterns change during the learning process provoked by training [22]. In consequence, training should also influence the amplitude of MMN Kraus et al. [34] investigated effects of discrimination training by analyzing the amplitude of MMN in adults before and after 1 week of discrimination training. They found that discrimination training enhances the MMN amplitude significantly. They could further show a significant transfer effect to stimuli that were not trained. Hence, independent of the stimuli used in the training sessions MMN amplitude was enhanced after training [34]. These results suggest auditory system plasticity associated to training. As mentioned above, we analyzed MMN in illiterate individuals and did not find a discernible MMN in individuals without sufficient literal abilities compared to literate controls [4]. In contrast, Schulte-Körne showed a discernible but reduced MMN in adults with dyslexia [29]. Therefore, written language is assumed to aid the development as well as the maintenance of auditory phoneme discrimination as monitored by MMN. This conclusion corresponds to the Dual-Route Cascaded Model (DRC-Model) by Coltheart et al. [35]. The model postulates three processing routes: the lexical non semantic route, the grapheme-phoneme correspondence route, and the semantic route. According to the DRC-Model the phoneme system and the phoneme units are activated during print exposure. If individuals lack print exposure, phoneme units are less activated and long-term representations of phonemes are consolidated less frequently. Therefore, the discrimination ability regarding phonemes is not stressed frequently enough.

If this conclusion is true, the question arises whether the illiterate brain can be altered after taking part in a literacy course. Dehaene et al. [36] found a significant alteration of the activity in the planum temporale in individuals that acquired literacy compared to individuals that did not acquire literacy. The Blood Oxygen Level Dependency (BOLD) signal to spoken sentences "essentially doubled" from illiterate individuals to literate individuals [36]. The planum temporale is responsible for the phonological coding of speech and sensitive to the congruity between speech sounds and simultaneously visually presented letters [37,38]. Hence, auditory processing appears to be altered by literacy acquisition. However, the study by Dehaene et al. [36] compared two groups of individuals with different educational background. Further, functional imaging studies are expensive and are not as promising as ERPs for diagnostic purposes, due to the reduced temporal resolution of fMRI data. Therefore, we aimed at investigating the development of MMN, the characteristic ERP marker for auditory phoneme discrimination [39,40] and an important prerequisite for literacy acquisition [31], in response to literacy acquisition. We recorded an EEG before [4] and after a one-year literacy course while participants listened to standard and deviant phonemes (oddball paradigm). We predicted that the amplitude of MMN of participants would enhance from before to after one-year literacy course as a consequence of literacy acquisition.

Method

Participants

Nineteen illiterates participated in the study. After the one-year literacy course eleven illiterates could be tested again. The group of illiterate participants consisted of people who did not acquire written language due to inadequate schooling and of secondary illiterates who lost their literal abilities due to the lack of practice. We controlled for the literacy status of the participants in the language of their country of origin. Only participants with rudimentary literal abilities regarding their mother tongue were included in the study.

Demographic data of participants were registered (age, gender, years in Germany, years of school attendance). There was only one male participant. Due to the possible confounding influence of gender on language processing, we excluded the male participant from further analyses. Before the one-year literacy course, the German language proficiency of participants was tested orally. German language proficiency is classified by the categorical system of the Common European Framework of References for Languages (CEFR). The German language proficiency of the illiterate sample ranged from A1 to B2 (Table 1). [1]Two participants had only elementary German language proficiency (A1) and were therefore excluded from further analyses. For the remaining eight participants, descriptive statistics for demographic variables are presented in Table 1.

Five participants had a migratory background (Arabian *N*=1, Bosnian *N*=2, Yugoslavian *N*=1, Serbian *N*=1) and three were of German origin. In a baseline assessment before a one-year literacy course, a battery of cognitive tests was administered at the cognitive science laboratory of the Humboldt-Universitätzu Berlin. We assessed the Heidelberg nonverbal test [HNT; [41] to control for nonverbal intelligence. It consists of four subtests–logical reasoning, reproduction, differentiation and creativity. All subtests use abstract patterns. The nonverbal intelligence of the illiterate group lies in the normal range (i.e., between 25 and 75 percentile ranks, (Table 1)). Thus, the nonverbal intelligence is comparable to the overall population. To exclude the risk for dyslexia, we assessed the Bielefeld Screening for the Early Recognition of the risk for dyslexia [42]. It is a standardized test for preschool children administered verbally to test important prerequisites for written language acquisition, namely working memory, attention, and phonological awareness [8]. Re-test reliability is moderate (up to.79). Overall test performance correlates significantly with reading (.58) and writing abilities (.52) in second graders, indicating high predictive validity. Test results show that illiterates' phonological abilities lie above the norm range (i.e., between 25 and 75 percentile ranks) of preschool children. Thus, our illiterate sample is not likely to develop dyslexia. The writing ability of the illiterate group was assessed with the Hamburger writing test for first to ninth graders [German: Hamburger Schreib-Probe 1-9 (HSP 1-9); [43], before (T1) and after (T2) a one-year literacy course. This test has a highre-test reliability; r =.92-.99. In addition, test performance correlates with school essay writing (r^2=0.78-0.82), indicating high predictive validity. The amount of correctly written words was assessed (Table 1). The results show that the writing abilities of our illiterate sample are similar to those of first graders, which allows us to speak of illiteracy. Illiterates improved significantly regarding their writing abilities from before to after the one-year literacy course, *t* (6) = -5.30, *p*<.01.

Participants were paid for their participation. The study followed APA standards in accordance with the Declaration of Helsinki from 1964 [44].

Stimulus material

To test auditory discrimination, a passive oddball paradigm was conducted. Participants was presented a frequently occurring standard phoneme, which was occasionally replaced by a deviant phoneme. The phonemes /ga/ and /da/ were used due to their appearance in the various languages of the participants' countries of origin (e.g., Arabian: /da/raga (walk) vs. /ga/lasa (sit)). Additionally, these phonemes are often used for investigating language and written language deficits such as specific language impairment and dyslexia [45]. The phonemes were recorded by a native German speaker. Figure 1 shows acoustic parameters of the stimuli. The phoneme stimulus /ga/ was 250 ms in length, while the phoneme stimulus /da/ was 200 ms in length.

N	10	
German language proficiency A1	2 participants (excluded)	
German language proficiency B1	4 participants	
German language proficiency B2	1 participant	
German mother tongue	3 participants	
N	8	
Gender	8F	
Age	37.75 (11.78)	
Years in Germany (n = 51)	14.40 (6.693)	
Years of school attendance	4.13 (3.04)	
HNT	55.00 (34.64)	
BISC	77.16 (8.70)	
		First grader comparison data
HSP *T*1 (n=7[2])	3.14 (3.39)	3.8 (2.3)
HSP *T*2 (n=7[2])	7.71 (2.16)	

* Note: N = number of participants; F = females; number in brackets = standard deviations; 1 three participants were of German origin; years in Germany were assessed before the one-year literacy course; HNT = Heidelberg nonverbal intelligence test (percentile rank is given); BISC = Bielefeld Screening for the early recognition of Dyslexia (percentile rank is given); HSP = Hamburger writing test, possible maximum of 10 correctly written words (raw score is given); 2 Participant did not take part in the baseline assessment (T1) and in the assessment after a one-year literacy course (T2)

Table 1: Demographic Information and test results of the cognitive baseline assessment of Illiterates.

Procedure

Participants were orally informed about the procedure and gave written consent. After preparation of the participants for the EEG recording, the oddball paradigm was conducted. Auditory stimuli were presented binaurally via loud speakers with an intensity of 64 dB sound-pressure level (SPL). Stimuli were presented by the Presentation software (Neurobehavioral Systems, Inc., Albany, USA). During the auditory presentation, participants watched a silent video of a train ride. Due to the calm characteristic of the train ride with no changes of perspective, level of arousal could be controlled for. Before the experiment started, participants were orally instructed to watch the silent video. This instruction was standardized. A blocked design was used. Every participant had to finish two experimental blocks. In one block, the phoneme /da/ was used as a standard and the phoneme /ga/ as a deviant; in the other block, the phoneme /da/ was the deviant and the phoneme /ga/ was the standard. Therefore, we could compare the phonemes as standards to themselves as deviants. Thus, we were able to control for effects that could have simply been attributed to different physical characteristics of the two phonemes (Figure 1), such as the different duration characteristics. Within one block, 1,000 stimuli were presented. The order of the two blocks was counterbalanced across participants. In total, 2,000 stimuli were presented. The presentation of the deviant was pseudo-randomized such that at least two standards had to be presented in between the deviants. There were 85% standard and 15% deviant stimuli. The ISI between two stimuli (offset to onset) was 350 ms. The experiment lasted for 20 min, and in total, the procedure lasted for about 60 min.

Illiterates were tested before and after a one-year literacy course. The literacy course consisted of a curriculum divided into three modules held in German, which was held five days per week and four hours per day. Every week a different topic concerning everyday life activities was dealt with, for example, "going to the supermarket". These everyday activities helped motivating the illiterates in learning to read and write letters and words. For example, they were shown pictures of fruits or vegetables. Sounds like "A" for apple were presented auditorily and the corresponding letter was shown visually. After being presented with

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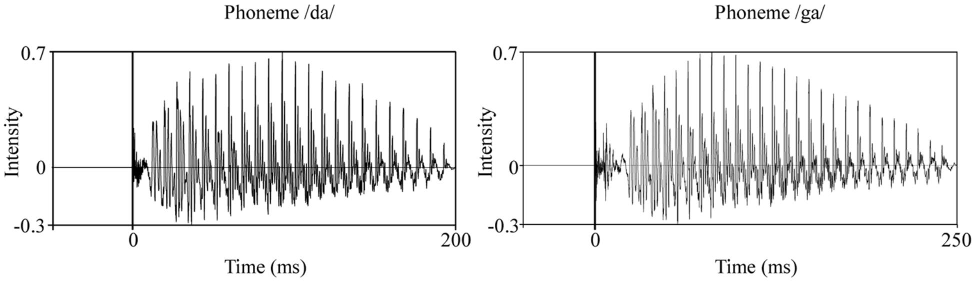
[1] A: elementary language use (A1 & A2); B: autonomous language use (B1 & B2)



Acoustic Parameters	Phoneme /da/	Phoneme /ga/
1st formant (Hz)	615	608
2nd formant (Hz)	1361	1344
3rd formant (Hz)	2479	2456

Figure 1: Illustration of acoustic parameters of the phonemes /ga/ and /da/.Stimuli were recorded and digitized (44.1 kHz, 16 bit sampling rate).The intensity normalized to maximum intensity (0.7 x I/Imax) is displayed.Maximum intensity is equal for both stimuli.A description of the first, second, and third formant of the phonemes is also given. by G. Schaadt, A. Pannekamp, and E. van der Meer, 2013, Developmental Psychology, Advance online publication, p. 5. Copyright 2013 by the American Psychological Association.

all sounds and letters illiterates were asked to write the name of the fruit. To support this, an E-learning program was established where illiterates could learn words and their spelling self-paced. Illiterates did not have to pay for the literacy course. They were, however, excluded if they attended the course less than 70% of the time.

To control for the environment as a confounding factor, the experimental procedure of the EEG-experiment before and after the one-year literacy course was the same and took place in the same laboratory.

Data recording and analysis

The EEG was recorded from Ag AgCl cap-mounted electrodes (F7, F3, Fz, F4, F8, FC5, FCz, FC6, T7, C3, Cz, C4, T8, CP5, CPz, CP6, P7, P3, Pz, P4, P8, PO3, POz, PO4, Oz) with the systems ground at C2. The vertical electrooculogram (VEOG) was recorded from electrodes placed above and below the right eye. The horizontal electrooculogram (HEOG) was recorded from positions at the outer canthus of each eye. Electrode impedances were kept below 5 kΩ. The EEG was acquired with Brain Amp DC amplifier (Brain Products; Gilching, Germany) at a sampling frequency of 250 Hz. Recordings were referenced online to the left mastoid and re referenced offline to the average reference. According to Dien [46], the choice of reference only becomes notable when too many channels are used to include all of them in the analysis. In the present study we only recorded 29 channels and only F3, Fz, F4, FCz, C3, Cz, C4 electrodes were included in the analysis. Therefore, the impact of reference choice in the present study should be marginal [46]. Offline, a band-pass filter from 0.1-24 Hz was applied to each single subject dataset. EEG epochs containing eye artifacts were semi-automatically scanned via the algorithm by Gratton et al. [47]. Detected blinks ≤ +/- 170 µV were accepted as such, and each individual data set was corrected by subtracting the individually identified average blink of each participant. Muscle artifacts and other noise transients were scanned and rejected. Trials with a standard deviation >80 µV within a sliding window of 200 ms were rejected automatically. At least 90 artifact-free deviant trials were required for an individual average to be included in further analyses. The EEG data were averaged per participant and per condition between -100 to 400ms relative to the onset of the stimuli. Baseline correction was applied to a period from -100 to 0 ms relative to the stimulus onset. In a second step, grand averages were computed for each condition across subjects. All EEG analyses were carried out with the BrainVision Analyzer Version 1.05 (Brain Products; Gilching, Germany).

Statistical Analyses

All statistical analyses were conducted by using the Statistical Package for the Social Science (SPSS) Version 20 (IBM; Walldorf, Germany).

In order to define the time window for the MMN potential, the difference curves (deviant-standard) were plotted. The time window for analysis of MMN amplitude ranged, in accordance with Näätänen et al. [12] from 150-250 ms. For the statistical analysis of MMN, we computed the mean amplitude according to the above mentioned time-window separately for the ERP in response to the deviant and standard stimuli. Further, we computed regions of interests (ROIs), one ROI for left frontal (F3; C3), one ROI for right frontal (F4; C4), and one ROI for central (Fz; FCz; Cz) areas, separately for the stimulus /da/ and /ga/. Repeated measures analyses of variance (ANOVAs) were performed to test for significant enhancement of MMN.

A four-factorial analysis of variance (ANOVA) with the factors condition (standard, deviant), region (left frontal, right frontal, central), stimulus (/da/, /ga/), and assessment (before a one-year literacy course, after a one-year literacy course) was performed. If the interactions between the factors condition and assessment and between the factors condition, assessment and region were significant we computed a post-hoc pairwise comparison at the level of assessment to test for the significance of MMN before and after a one-year literacy course. If the interactions between the factors condition and stimulus, between the factors condition, stimulus, and assessment, between the factors condition, stimulus, and region, and between the factors condition, stimulus, assessment and region were significant we computed a post-hoc pairwise comparison at the level of stimulus to test for the significance of MMN in response to the stimuli /da/ and /ga/.

To control for the impact of nonverbal intelligence and years of school attendance on the results of MMN before a one-year literacy course, we further computed an analysis of covariance (ANCOVA) with the factor condition (standard, deviant), stimuli (/da/, /ga/), and the covariates HNTand years of school attendance.

P-values were Bonferoni corrected. Greenhouse-Geisser corrected values are given when there was more than one degree of freedom in the numerator. Effect size ηp^2 is reported.

Results

Figure 2 shows the ERP responses to standard and deviant stimuli for illiterates before and after the one-year literacy course and the difference waves (deviant – standard). There was no significant main effect of condition, *F*\(1, 7)<1. Interactions between the factors condition and stimulus [*F*(1, 7)<1], between the factors condition, stimulus, and assessment [*F*(1,7)=2.89; p=.13; ηp^2=.27], between the factors condition, stimulus and region [*F*(2, 14)<1] and between the factors condition, stimulus, assessment, and region [*F*(2,14)=1.08; p=.36; ηp^2=.13] did not become significant. However, the interaction between condition and assessment was significant, *F*(1,7)=9.93, p<.02, ηp^2=.59.At the level of assessment, a significant main effect of condition, F(1, 7)= 6.07, p <.03, ηp^2=.46, was found before the one-year literacy course. However, the difference between the ERP response to standard stimuli and the ERP response to deviant stimuli (deviant-standard) was positive (*M*=0.151). Further, we found a significant main effect of condition after the one-year literacy course, *F*(1, 7)=3.55, p<.05, ηp^2=.34. Here, the difference between the ERP response to standard stimuli and the ERP response to deviant stimuli was negative (M=-0.193). Additionally, we found a marginally significant interaction between condition, assessment, and region, *F*(2, 14)= 3.39, p<.08, ηp^2=.33. Post hoc pairwise comparisons showed a significant positivity for frontal left (p<.05) and frontal right (p<.02) regions before a one-year literacy course. After a one-year literacy course we found a significant negativity for frontal left (p<.03) and a marginally significant negativity for frontal right (p<.06) and central regions (p<.10). For descriptive statistics of MMN (Table 2). Before the one-year literacy course, there was no significant interaction between the factor condition and the covariates HNT results [*F* (1, 5)<1] and school attendance [F (1, 5)< 1].

Discussion

The study aimed at investigating the development of auditory phoneme discrimination, one of the most important cognitive abilities regarding literal abilities, in response to literacy acquisition. Namely, we analyzed the MMN, the characteristic ERP marker for auditory phoneme discrimination, in illiterates before and after a one-year literacy course. The study yielded the following main findings: First, illiterates did not show a discernible MMN before the one-year literacy course, but a positive mismatch response. The impact of nonverbal intelligence and years of school attendance on the MMN before illiterates took part in a one-year literacy course was not significant in our sample. Second, illiterates showed a significant change of polarity from a positive mismatch response before the one-year literacy course to an MMN after the one-year literacy course. The significant change of polarity of the amplitude of the mismatch response from before to after the one-year literacy course was mainly present at left frontal electrodes (F3, C3). Since MMN serves as an ERP marker for auditory phoneme discrimination [12], the findings support the assumption that auditory phoneme discrimination can be altered by literacy acquisition. We found a significant change of the polarity of the mismatch response in illiterates as a function of a one-year literacy course. The positive mismatch response before the one-year

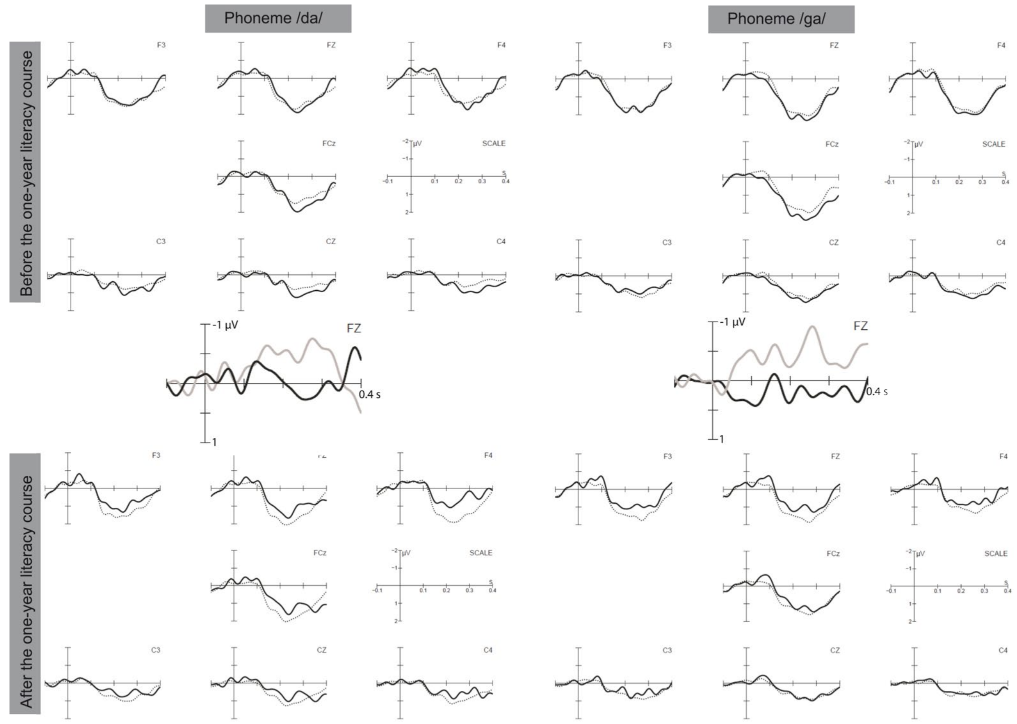


Figure 2: Event-related potentials and difference waves before and after a one-year literacy course. Left panel: Event-related potentials (ERPs) for standard stimuli (dotted line), and ERPs for deviant stimuli (solid line) in response to /da/. Right panel: ERPs for standard stimuli (dotted line), and ERPs for deviant stimuli (solid line) in response to /ga/. Top panel: ERPs before a one-year literacy course. Bottom panel: ERPs after a one-year literacy course.Middle panel shows the difference wave at FZ (deviant – standard) before (black line) and after (grey line) a one-year literacy course.

	MMN left frontal (F3, C3)	MMN central (Fz, FCz, Cz)	MMN right frontal (F4, C4)
Before a one-year literacy course /da/	0.134 (0.333)	-0.102 (0.602)	0.012 (0.301)
After a one year literacy course /da/	-0.219 (0.477)	-0.281 (0.428)	-0.119 (0.370)
Before a one-year literacy course /ga/	0.371 (0.603)	0.182 (0.311)	0.487 (0.517)
After a one year literacy course /ga/	-0.292 (0.266)	-0.250 (0.438)	-0.176 (0.518)

* Note: number in brackets = standard deviations

Table 2: Descriptive information of MMN difference curve given in µV (mean amplitude; deviant–standard) before and after the one-year literacy course (N=8) separately for /da/ and /ga/.

literacy course is surprising as we reported a no discernible mismatch response in illiterates before the one-year literacy course [4]. However, the sample was only partially overlapping. In the literature positive mismatch responses are normally attributed to developmental changes in the brain. For example Wetzel et al. [48] found a positive mismatch response in kindergarteners during a complex discrimination task. However, studies show that a positive mismatch response can mainly be associated to developmental deficits, such as language deficits and the risk for dyslexia in children [49,50]. Further investigations could show similar sources for the positive mismatch response in normally developing kindergarteners and the MMN in adults [51]. Maurer et al. however report an additional midline source in the adult MMN in response to phonemes, which they assumed to be associated to some attentional component. Regarding the generation of the MMN two sources are discussed, namely the IFG and the STG. The STG is associated to the bottom-up processing of auditory deviances and the IFG is associated to top-down processes modulating the deviance detection by attentional switches [25,26]. The involvement of these two sources highly depends on the type of deviance [52] and possibly on the development of auditory processing and experience. Dehaene et al. [36] could show reduced activity of the planum temporale in illiterates. Additionally, they found reduced activity of the IFG in illiterates compared to literate controls. These results and results at hand could lead to the conclusion that the reduced MMN [4] or even the positive mismatch response in illiterates might be associated to the reduced top-down modulation of the IFG, namely the reduction of attentional switches in response to deviant stimuli. A study by Landgraf et al. [53] could show attentional deficits in illiterate adults, which were reduced after literacy acquisition. It is highly unlikely that illiterate adults were not able to actively process and discriminate phonemes. Results of our illiterate sample in the phonological awareness task show that illiterates had similar phonological awareness abilities like preschoolers indicating the ability to process auditory information consciously. However, for these tasks attention is indispensable, because individuals have to respond actively. It is possible that illiterates need to investigate more resources for phonological awareness tasks due to the possibly reduced involvement of the IFG during passive auditory phoneme discrimination contributing to phonological awareness [9]. It has been shown that phonological awareness improves from before to after literacy acquisition [54,55] in first grades [56,57] and in illiterates [58-60], which might be associated to the development of the mismatch response in illiterates. Next to the possible attentional aspect of the top-down part of the generation of the MMN [19], long-term representations of phonemes might contribute to the altered top-down influence on the generation of the MMN in illiterates after the one-year literacy course.

According to the DRC-Model by Coltheart et al. [35] the lack of literacy acquisition affects the phoneme discrimination system and long term representations of phonemes. Hence, the phoneme discrimination system is not stressed frequently enough, resulting in weaker long-term representations of phonemes and consequently in reduced MMN. Therefore, we can conclude that the one-year literacy course seemed to cause neural activity patterns to cohere stronger in illiterates and the phoneme system was addressed more frequently. Hence, stronger cell junctions and therefore stronger long-term representations of phonemes were built. Winkler et al. [61] suggested that MMN responses are memory dependent. Therefore, Näätänen and Winkler [62] and Winkler et al. [15] concluded that the MMN stands for on-line modifications of a perceptual model. This perceptual model needs to be updated when the auditory input does not match the previous prediction. Thus, the negativity is elicited. The formation of the perceptual model is facilitated by long-term memory traces [63]. In our study, after the one-year literacy course the coherence of neural activity patterns in response to phonemes was strong enough and long-term representations of phonemes were built to evoke a MMN, mainly present at left frontal electrodes [64,35]. The study by Dehaene et al. [36] supports this conclusion. They found a significant increase in the activity of the left planum temporale, responsible for phonological coding of speech [37] after literacy acquisition in adults. Further, it has been shown that training of phonological awareness abilities facilitates literacy acquisition. Küspert and Schneider [65] could demonstrate that practicing rhymes, segmenting syllables, and listening can help to improve literacy acquisition in children at risk for dyslexia. This and our results, therefore, indicate the importance of considering discrimination training in literacy courses more thoroughly.

Although we did find a significant change of the polarity of the amplitude of MMN from before to after the one-year literacy course Sheehan et al. [66] argued that training effects can simply be explained by increasing familiarity with the stimulus material, which could also be the case in our sample. In the present study literacy acquisition can be interpreted as training. Phonemes such as /da/ and /ga/ contribute to the difference in meaning of words in German (e.g., /Ga/umen vs./Da/umen) and were therefore inevitably, but not explicitly, present in the one-year literacy course. Further research is needed to disentangle the relationship between and the direction of the impact of literacy acquisition and auditory phoneme discrimination. Nonetheless, this study can be reported as a first step showing that literacy acquisition seems to have an influence on passive auditory phoneme discrimination.

Since the sample size in the present study was limited and only female participants were tested results should be replicated in a larger sample with male and female participants. In addition, several studies demonstrated that memory representations of foreign phonemes have to develop first to be discriminated [67]. In our study not all participants were of German origin and phoneme discrimination abilities could have simply been enhanced by improvement in the German language. However, we excluded participants with only elementary language proficiency (A1; CEFR). Further, Cheour found Finish children to show normal MMN patterns in response to French-specific phonemes after 2 months of visiting a French kindergarten without having given them specific phoneme discrimination training [68]. For our migrant participants, the mean number of years spent in Germany was 14.4 years. This and results by Cheour et al. [68] underpin the conclusion that the results of our study are not simply due to improvement in the German language, but mainly due to literacy acquisition. In addition, it would be interesting to further study whether writing acquisition or reading acquisition is actually leading to the change in the mismatch response in illiterates as we have only acquired measurements for writing abilities. We expect reading acquisition to have a stronger impact on the change of the mismatch response. Coltheart et al. [35] showed that print exposure and hence reading are stressing the phoneme system and long-term representations of phonemes.

Our conclusions would be validated further by testing an illiterate control group not receiving a one-year literacy course or even taking part in a different kind of activity. By comparing these two groups, it could have been shown that the change of the MMN amplitude might be explicitly attributed to literacy acquisition and not only to simple training effects. Additionally, the amount of electrodes should be enhanced to be able to analyze the source of the change regarding the MMN and therefore to be able to test our hypothesis that the change in the MMN amplitude in illiterates can mainly be attributed to top-down influences of the IFG on the generation of MMN. Future studies should address these issues. However, other studies also found that literacy acquisition seems to facilitate speech comprehension and phonemic processing [69-71]. Considering the results at hand and results by Dehaene et al. [36] it has to be questioned whether reduced MMN in children and adults with dyslexia [2,3,29-33] is really a cause for dyslexia or more likely a consequence of abnormal literacy acquisition.

Conclusion

The study demonstrated for the first time that an altered mismatch response in illiterate adults can be modified by literacy acquisition. Thus, literacy acquisition manifests itself on the neurophysiological level and the changed polarity of the mismatch response can be seen as a function of an improvement in reading and writing. This stresses the importance of literacy acquisition for auditory phoneme discrimination, top-down influences on auditory phoneme discrimination (i.e., attentional aspects and long-term representation of phonemes), and its related brain functions, namely MMN.

Furthermore, explicit auditory discrimination training should be considered in literacy training-programs – not only for adults, but also for children. Further research is needed to analyze the relation between literacy acquisition and auditory phoneme discrimination in adults, in normally developing children and in children with dyslexia. The subgroup of illiterates seems to be a suited sample to better understand this relationship. Due to its good re-tests reliability on single subject-level [39,40] independency of attention and objectivity, the MMN is a promising neurophysiological marker for auditory phoneme discrimination of high scientific and diagnostic relevance.

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