Developmental Cognitive Neuroscience 2S (2012) S129–S138

Contents lists available at SciVerse ScienceDirect

Developmental Cognitive Neuroscience

journal homepage: http://www.elsevier.com/locate/dcn

Impact of phonological processing skills on written language acquisition in illiterate adults

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ARTICLE INFO

Article history:
Received 28 April 2011
Received in revised form
16 November 2011
Accepted 18 November 2011

Keywords:
Alphabetization course
Illiteracy
Adults
Phonological processing skills
Written language acquisition

ABSTRACT

Illiteracy remains a world-wide problem not only for children but also for adults. Phonological processing has been defined as a crucial factor for the acquisition of written language, which usually occurs in childhood. However, it is unclear to what extent phonological processing is necessary in order for *adults* to acquire written language skills. We tested 47 illiterate adults before and after a one-year alphabetization course in several cognitive domains relevant to phonological processing and compared their results to 41 matched controls who did not take part in the alphabetization course. Phonological awareness in the narrower sense (e.g., phoneme association) was a stronger predictor of alphabetization outcome than demographic variables such as years of education. In addition, despite improvement of illiterate individuals in phonological awareness, short-term memory, and visual attention from before to after the alphabetization course, they did not reach the phonological processing level of literate controls. Our results confirm that the alphabetization of adults requires and enhances phonological processes similar to those of children. Nevertheless, specific aspects, such as improvements in short-term memory or visual attention, need to be considered in order to improve and optimize alphabetization programs for adults.

1. Introduction

Nowadays, reading and writing skills are indispensable for addressing everyday life challenges. However, about one-tenth of the world's population is illiterate (UNESCO, 2010), involving not only the question of how to educate children. Adults who are unable to read and write require specific educational methods to ensure learning success. Because this topic has been neglected in the current literature, the present study addresses the problem of illiteracy by looking at how specific cognitive abilities—so-called phonological processing skills—contribute to and can improve the acquisition of reading and writing skills in illiterate adults.

Formal education plays a decisive role in alphabetization. On the one hand, being able to understand and produce written language increases individuals' performances on neuropsychological tests such as visual perception, logical reasoning, and memory (Laurendeau-Bendavid, 1977). On the other hand, a higher educational level is associated with superior cognitive abilities, including, but not limited to memory, language, and problem solving (Ardila et al., 1989; Lecours et al., 1987a,b, 1988; Ostrosky et al., 1998; Rosselli et al., 1990). Improvements in

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doi:10.1016/j.dcn.2011.11.006

language-related cognitive tests have been associated with duration of education (Cornelius and Caspi, 1987). In fact, in order to obtain written language skills, young children rely on already acquired phonological processing skills (Jansen et al., 2002).

The most important phonological processing skills for successful alphabetization are *phonological awareness*, *phonetic recoding*, and *visual attention* (Brown, 1981; Mann and Liberman, 1984) (for a discussion on the influence of attention and intelligence on alphabetization, please refer to Landgraf et al., 2011). Here, phonological awareness refers to "... one's awareness of and access to the phonology of one's language ..." (Wagner and Torgesen, 1987, p. 192). Further, articulating written words, that is transforming written language symbols into speech (reading), is based on phonetic recoding in short-term memory and the subsequent initiation of motor programs (speech production).

Several studies have shown that phoneme–grapheme associations are important during the process of written language acquisition. Several temporal lobe regions have been identified to be involved in written language acquisition, especially the visual word form area (VWFA), and the planum temporale. Brem et al. (2010) investigated the development of print sensitivity in young kindergarten children by administering letter trainings to two groups of children, which did not initially differ in letter knowledge. After the training program was administered to one group, however, the authors showed that improvements in printed number knowledge were associated with higher activation in the VWFA in this group. These results suggest that print sensitivity develops during the earliest phase of reading acquisition in childhood and it indicates the importance of mapping print and sound for the development of the later reading network.

The planum temporale is involved in phonological coding of speech and is sensitive to the congruity between speech sounds and a simultaneous visually presented letter—the so-called matching of graphemes and phonemes. Blau et al. (2009) compared the neural activity of dyslexic adults during trials of phonemes with auditorily matching graphemes, and trials of phonemes with non-matching graphemes. Interestingly, dyslexic adults showed similar activation patterns in the planum temporale during both trial types. In normal reading subjects, in contrast, the planum temporale was activated during the presentation of graphemes with auditorily matching phonemes only. This suggests that literate individuals interpret mismatching pairs as non-existing pairs whereas dyslexic patients do not seem to be able to interpret mismatching pairs as non-existent. Thus, dyslexic individuals proceed with undifferentiated neural processing possibly leading to even poorer phoneme–grapheme correspondence.

Regarding neural activity in the superior temporal gyrus, literate and dyslexic children have shown similar bilateral activation patterns during auditory rhyme judgements (Desroches et al., 2010). However, dyslexic children did not show a reliable activation of the fusiform gyrus. Normal reading children seem to activate orthographic representations automatically during phonological processing whereas dyslexic children do not. This deficit is in line with the poor development of phoneme–grapheme correspondence in dyslexic patients (Desroches et al., 2010). Dehaene et al. (2010) investigated brain responses to spoken and written language in illiterates, literates that became literate in adulthood, and literates that became literate in childhood. Most importantly, the authors found enhanced activation in left and right superior temporal regions of the planum temporale with increasing literacy. These results suggest that this region may be a prime candidate for enhanced phonemic processing that accompanies reading acquisition. Further, reduced activation in this region observed in dyslexic patients may be a consequence of abnormal reading acquisition rather than a cause of dyslexia. Dehaene et al. (2010) also found that activation in the left inferior temporal cortex, roughly corresponding to the VWFA, increases as a function of reading performance, suggesting a top-down recruitment of an orthographic script. Overall, these results suggest that similar functional changes in the brain occur during early (childhood) and late (adulthood) language acquisition. Nevertheless, the timing (early vs. late) of language acquisition has important implications for how far reaching these changes are and to what degree written language mastery will be acquired.

Intact visual attention supports reading by focusing gaze on written words (Fawcett, 1995; Mann and Liberman, 1984; Smith-Spark, 2003; Swanson, 2001). Furthermore, writing words require, apart from semantic and phonological access, phonetic information to be retrieved from long-term memory and involve specific hand motor programs (Graham et al., 2000; Tan et al., 2005). Therefore, a strong link has been established between phonological awareness, phonetic recoding, visual attention, and literacy (Content, 1984; Shankweiler and Fowler, 2004; Wagner and Torgesen, 1987).

Yoncheva et al. (2010) investigated how attention to speech sounds (rhyme judgement) and to non-speech sounds (tone-triplet matching) would influence cortical activity. The authors found that paying selective attention to speech sounds increased activity in the VWFA. This result is in line with the well-established connectivity between areas related to auditory and visual word perception in skilled readers and demonstrates the nature of the multiply connected networks for reading and writing competences.

Phonological awareness provides the basis for phoneme–grapheme associations. Aside from the ability to detect/recognize speech units, phonological awareness can be understood in a narrower (phoneme manipulation) and a broader (syllables/words manipulation) sense. While phoneme manipulation ability usually develops with the acquaintance of an alphabetic system (de Gelder et al., 1993; Read et al., 1986), syllable and word manipulation may already be possible before literacy is acquired. For example, rhyme detection is easily performed by preschoolers (Bradley and Bryant, 1983; Lenel and Cantor, 1981), as are syllable or word comparisons (Liberman et al., 1974). Furthermore, six-year olds who are able to read outperform those who are not able to read in their syllabic synthesis performance (Mousinho and Correa, 2009). Even with regards to written language acquisition disabilities, it has been shown that 17-year-old dyslexic teenagers perform worse than eight-year-old, normal-reading children on phonological awareness tasks (Fawcett, 1995).

The neurophysiological underpinnings of phonological awareness have been investigated with the event-related brain potential (ERP) marker called mismatch negativity (MMN). MMN responses are a consequence of the presentation of deviant stimuli in a sequence of standard stimuli. MMN does not depend on attentional processes. It occurs at around 100–200 ms after stimulus onset (Naatanen et al., 1978, 1993). In language acquisition research, MMN provides the possibility to measure individual discrimination abilities for simple (frequency, duration, pitch) as well as complex (phonemes, tone patterns) stimuli (Alho et al., 1990; Naatanen, 1995; Sams et al., 1985). For example, children and adults with dyslexia show reduced MMN during phoneme detection than normally developing children (Schulte-Korne et al., 1998, 2001). Further, dyslexic individuals have difficulties detecting changes in tone frequency (Baldeweg et al., 1999; Kujala et al., 2006; Kujala and Naatanen, 2001), tone duration (Corbera et al., 2006), and complex tone patterns (Kujala et al., 2000). In our own laboratory, collecting EEG data and looking at MMN, we found that auditory discrimination is impaired in illiterate adults (Schaadt et al., submitted for publication). This indicates that due to the lack of formal education, the ability to discriminate phonemes is reduced.

Interestingly, illiterate adults show similar broad and narrow phonological awareness as preschoolers. Illiterate adults are able to rhyme, to manipulate syllables (Bertelson et al., 1989; de Santos Loureiro et al., 2004; Morais et al., 1986), and to phonologically discriminate between similar syllable pairs (Adrian et al., 1995; de Santos Loureiro et al., 2004). However, adult illiterates have problems adding consonants to (Morais et al., 1979) or removing consonants (Bertelson et al., 1989; Lukatela et al., 1995) from word beginnings. While illiterate individuals have no difficulty memorizing semantically related word pairs, they do show deficits in memorizing phonologically related word pairs and in repeating pseudo-words (Reis and Castro-Caldas, 1997). These results indicate that due to their insufficient phonological processing skills, illiterate individuals use semantic verbalization strategies for effective communication.

It is not clear, whether phonological awareness in the narrower sense is a prerequisite or a consequence of successful alphabetization (Tarone and Bigelow, 2005). For example, the ability to remove a phoneme at the beginning of a word correlates significantly with the duration of schooling (de Santos Loureiro et al., 2004). Further, first graders improve significantly in a vowel-replacement task within six months after schooling (Wimmer et al., 1991) and phoneme and syllable segmentation improves during alphabetization (Liberman et al., 1974). In their review, Castles and Coltheart (2004) summarized longitudinal studies investigating the causal relationship between phonological awareness and acquisition of literacy. The authors provide evidence that phoneme detection and manipulation may be more closely related to the acquisition of literacy than syllable segmentation and rhyming. One shortcoming of these studies is that they are only correlational in nature. Another shortcoming is that they have not been tested with regards to their specificity of alphabetization programs for adults.

The main goal of the present study was to identify means that optimize alphabetization success in illiterate adults. Phonological awareness has been identified as one of the most decisive factors that influences alphabetization success. Yet, it is a rather heterogeneous construct. The only consistent finding in the literature is that the ability to manipulate phonemes can discriminate between literate and illiterate individuals (de Santos Loureiro et al., 2004). Hence, with the goal of improving alphabetization programs for adults, it is necessary to investigate (1) whether literacy acquisition in adults follows similar developmental trajectories (from broad to narrow) as in children, and (2) whether phonological awareness in the narrower sense can actually predict alphabetization success. There is no clear evidence as to whether literacy evokes changes in phonological awareness or whether phonological awareness evokes literacy. Yet, from an ecological validity perspective, we wanted to explore what factors would predict literacy acquisition in adults. In other words, in order to improve alphabetization programs, it is of greater importance to look at factors that predict literacy success, rather than looking at what being literate would predict.

To this end, we investigated how an alphabetization course outcome of illiterate adults can be predicted by changes in their phonological awareness. We administered the "Bielefeld Screening for Early Recognition of Dyslexia" (BISC, Bielefelder Screening zur Früherkennung von Lese-Rechtschreibschwierigkeiten, Jansen et al., 2002) to a group of illiterate and a group of literate adults. The illiterate group was tested twice, once before and once after a one-year alphabetization course. The literate group was tested once. As outcome measures of the alphabetization course, we used standardized reading and writing tests for children, which are designed to differentiate lower-range reading and writing skills during literacy acquisition.

We hypothesized that a substantial proportion of improvement in reading and writing skills during an alphabetization course could actually be predicted on the basis of measures of phonological awareness. We expected that individuals who improved in reading and writing would also improve in phonological awareness. Specifically, we predicted improvements in phonological awareness in the narrower sense, that is, phoneme detection and discrimination. Phonetic recoding and visual attention might also improve during the alphabetization course. However, only improvements in (narrow) phonological awareness were expected to directly predict the alphabetization outcome. Finally, we compared the phonological awareness results of the illiterate group to literate individuals.

2. Materials and methods

2.1. Participants

In this study, 47 illiterate individuals and 41 literate controls participated. Groups were matched on gender and age (see Table 1). All participants in the illiterate group and three in the literate group were of non-German origin

Table 1
Demographic information of the two participant groups.[a]

	Illiterate group	Literate group
Number of participants	47	41
Gender (number)	29 F	21 F
Age (mean)	38.3 (8.8)	34.0 (11.3)
Years of education (mean)	4.4 (3.9)	11.2 (1.4)
Handedness (number)	44 R/3 L	39 R/1 L/1 M
Course attendance (days)	132 (34)	–

[a] *Abbreviations*: F, females; years of education, number of years individuals spent in regular school (12 = university entrance certification); R, right-handed; L, left-handed; M, mixed-handed; course attendance, length of time illiterates took part in the alphabetization course; numbers in brackets, standard deviations.

coming from more than 20 different countries, such as Turkey, Pakistan, or Ghana. Illiterate individuals had been living in Germany for an average of 11.5 years (standard deviation, SD = 7.8 years). They were included in the study once they had signed up for the alphabetization course. The study was conducted according to the Declaration of Helsinki from 1964. All participants gave their consent prior to participation, for which they were paid. After the last session, individuals were debriefed.

2.2. Materials and procedure

2.2.1. Procedure

Participants completed a set of cognitive tests at the cognitive science laboratory of Humboldt University Berlin. Only the results of the phonological awareness test are reported here. The illiterate group was tested twice in our laboratory, before and after they accomplished a one-year alphabetization course. Alphabetization success measures were also assessed. The literate control group was tested once. The cognitive testing took place in a quiet and sufficiently illuminated room.

2.2.2. Stimuli

BISC: The "Bielefeld Screening for Early Recognition of Dyslexia" (BISC, Bielefelder Screening zur Früherkennung von Lese-Rechtschreibschwierigkeiten, Jansen et al., 2002) is a standardized test for preschool children administered verbally. Re-test reliability is moderate (up to .79). Overall test performance correlates significantly with reading (.58) and writing skills (.52) in second graders, indicating high predictive validity. The seven subtests, which are described in detail below, assess important aspects of the ability to acquire written language skills (Wagner and Torgesen, 1987) such as phonological awareness, phonetic recoding in short-term memory, visual attention concerning words and phonemes, and long-term memory retrieval. In our test sessions, a trained instructor explained each task and illustrated instructions with two practice items per subtest. All words, syllables, and phonemes were administered auditorily using pre-recorded test material (BISC audio CD). Test completion took about 30 min.

Phonological awareness was assessed using the following subtests. For the "rhyming task" (German: "Reimen"), participants had to indicate whether two words rhyme or not. The number of correct responses (max. 10) was recorded as the task result. The subtest assesses the integration of phoneme comparisons and rhyme detection. For the "syllable segmentation task" ("Silben segmentieren"), participants had to segment spoken words into syllables. The number of correct responses was recorded (max. 10). This subtest evaluates word segmentation performance. For the "phoneme to word comparison task" ("Laut-zu-Wort-Vergleich"), participants were first exposed to a target phoneme. Subsequently, they listened to a one- or two-syllable word and had to decide whether the target phoneme was present in the word or not. An example would be: "Is there an 'I' in the word 'Igel'?"(German for 'hedgehog'). The number of correct answers (max. 10) was assessed as the task result. The test measures the recognition of single phonemes in words. For the "phoneme association task" ("Laute assoziieren"), words were presented with artificial pauses. Participants had to recognize the word as a whole. For example, the German word for pliers ("Zange") would be read as "Z" followed by a pause of about 1 s and then "ange." The number of correct responses (max. 10) was assessed here. The task measures whether participants are able to establish the connection of two sounds in order to form a word.

Phonetic recoding in short-term memory was tested by the "repetition of pseudo-words task" ("Pseudowörter nachsprechen"). Here, participants had to repeat nonwords such as "Risolamu." The number of correct responses (max. 10) was assessed. The test assesses articulation, memory span, and motor control abilities.

Visual attention to words and phonemes was tested using the "word comparison task" ("Wort-Vergleich Aufgabe"). Here, participants were shown a word (target) at the top of a page, e.g., "Floh" (German for flea). At the bottom of the same page, participants were presented with four words, one of which is the target word. Participants were asked to indicate the target word. The reaction time and number of correct answers (max. 12) were assessed. The test measures visual word comparison.

Long-term memory retrieval was tested by the "color naming task" ("Schnelles Benennen Farben"). This test consisted of two subtests. First, participants were shown 24 black and white line drawings of familiar fruits (lemon, plum) and vegetables (tomato, salad). Participants had to name the objects' colors as quickly as possible. Reaction time was the first parameter of the task. The second part was an adjusted stroop paradigm. The same 24 objects were shown. However, this time they were colored in a way that did not correspond to the naturally occurring color. For example, a tomato could be depicted in blue. Again, participants had to name the correct color of the object as quickly as possible. The reaction time difference between the two tasks was the second parameter of the test. The test itself measures (a) retrieval of relevant color features of objects and (b) how incongruent (e.g., blue tomato) visual information impacts this information retrieval and color naming.

Finally, we assessed overall BISC performance by calculating the mean percentile rank of its eight subtests. This average percentile rank provided an overall impression of performance increase regarding the individual skills underlying reading and writing.

Table 2
Demands of the HSP1 (assessed before the alphabetization course) and HSP2 (assessed after the alphabetization course one year later).

HSP 1 (M1)		HSP 2 (E2)	
German	English	German	English
Baum	Tree	Bäckerei	Bakery
Telefon	Telephone	Handtuch	Towel
Hund	Dog	Zähne	Teeth
Mäuse	Mice	Fahrrad	Bicycle
		Schnecke	Snail
		Räuber	Robbers
		Eimer	Bucket
		Mäuse	Mice
		Kerze	Candle
		Sandkiste	Sandbox
		Blätter	Leaves
		Kamm	Comb
		Regenwurm	Earthworm
		Stiefel	Boots
Die Fliege fliegt auf Uwes Nase	The fly flies on Uwe's nose	Anna verkleidet sich vor dem Spiegel	Anna dresses up in front of the mirror
		Hier ist ein Gespenst	Here is a ghost
		Das kann nur Peter sein	This can only be Peter
40 graphemes		148 graphemes	
10 words		30 words	

HSP: The Hamburg writing test (HSP, Hamburger Schreibprobe, May, 2000) was administered as an outcome measure of the alphabetization course for the illiteracy group. Its re-test reliability is very good (.92–.99). Performance on this test correlates with school essay writing (r^2 = .78–.82), indicating high predictive validity. Before the course, the HSP 1+ (designed to be used in the middle of first grade) was administered. After the course, the HSP 2 (end of 2nd grade) was used. Participants had to write words that were read to them aloud (see Table 2). The percentage of graphemes written correctly was assessed. The test result provided information on each individual's ability to write.

ELFE: Another outcome measure of the alphabetization course was the word reading comprehension test (ELFE, Leseverständnistest, Lenhard and Schneider, 2006). The re-test reliability of the ELFE is also very good (.91). The concurrent validity is good, which is indicated by a high concordance between test results and teacher evaluations (r^2 = .71). The ELFE was administered before and after the one-year alphabetization course. Participants were confronted with a picture of an object (e.g., a window), the target word (German "Fenster"), and three words that had similar phonemes and graphemes, as well as an equal number of syllables ("Felsen" (rock), "Fehler" (error), "Fremder" (stranger)). Participants had to match the picture to the target word. The percentage of correct items was assessed. This test assessed the ability to read.

2.3. Data analysis

Predictive Analysis SoftWare (PASW 18, IBM) was used to conduct statistical analyses. Unless otherwise specified, data were normally distributed (Kolgomorov–Smirnov test, test for homogeneity). The significance level for all two-tailed statistical tests was .05.

Raw values of all BISC subtests were transformed into standardized percentile ranks according to the test manual. For example, a percentile rank of 75 means that the individual's score is the same or better than 75% of the normed comparison population. Further, the average of the BISC subtests was computed to estimate overall performance.

The results of the BISC, the HSP, and the ELFE tests were compared within the illiterate group with time of testing (before vs. after the alphabetization course) as a within-subject factor using paired *t*-tests. These indicated whether or not illiterate participants improved in their performance after the alphabetization course compared to before the course.

Furthermore, the results of the BISC were compared between groups (illiterates vs. literates) using independent *t*-tests separately for the first and the second test sessions. The scores from the single test time for the literate group were used for both comparisons. This showed whether there was a difference in the performances of the illiterates and literates and how this difference changed from before to after the alphabetization course.

Finally, two kinds of stepwise multiple regression analyses were conducted. First it was determined whether significant variance on the alphabetization outcome measures (ELFE and HSP) could be accounted for by the BISC subtests or by demographic variables for the illiterate group. Second, inverse regression analyses were conducted determining whether variance in the BISC subtests could be accounted for by the alphabetization outcome measures or demographic variables for the illiterate group. For all analyses, variables were entered simultaneously into the regression model. The data submitted to the regression analyses fulfilled the normality assumptions (normal distribution, homoscedasticity).

2.4. Correlation with demographic data

We calculated Pearson's bivariate correlation coefficients between test performances and demographic

Table 3
Subtest results of the BISC for the illiterate group (two assessments) and the literate group (one assessment).

BISC subtests	Illiterate group		Literate group
	Before the alphabetization	After the alphabetization	
Phonological awareness			
Rhyming	38.83 (35.15)	37.26 (33.85)	94.19 (18.64)
Syllable segmentation	57.15 (31.03)	58.21 (31.32)	92.29 (16.57)
Phoneme to word comparison	70.72 (33.25)	80.18 (32.78)	98.46 (8.73)
Phoneme association	**58.85 (34.51)**	**78.64 (28.98)**	93.31 (18.31)
Phonetic recoding in short-term memory			
Repetition of pseudo-words	**65.05 (28.87)**	**74.70 (28.68)**	93.30 (9.68)
Visual attention to words and phonemes			
Word comparison (errors)	90.76 (22.70)	94.12 (17.53)	100 (.00)
Word comparison (reaction time)	**11.61 (16.67)**[a]	**6.55 (8.43)**[a]	1.7 (.10)[a]
Long-term memory retrieval			
Color naming (black and white, reaction time)	62.31 (40.07)	70.12 (39.40)	99.25 (4.17)
Color naming (difference: stroop—black and white)	77.54 (30.60)	85.49 (25.40)	92.82 (17.47)
Average BISC score	**67.07 (16.51)**	**73.59 (15.16)**	95.76 (5.66)

Notes. All values are given in percentile rank according to the BISC manual. On all tasks and at all times, the illiterate group performed worse than the literate group except for the "color naming task" (difference: stroop—black and white) after the alphabetization course. Numbers in bold for the illiterate group indicate improvements in percentile rank from before to after the alphabetization class.

[a] For the reaction time measures on the word comparison task, a smaller percentile rank implies a better performance. For calculating the average BISC performance, we used inverse values (e.g., on all other tests, the BISC manual assigns the best performance to percentile rank 100 and the worst to percentile rank 0. In order to be coherent, we used inverse values, e.g., 88.39 for the illiteracy group before the alphabetization course rather than 11.61).

variables. The correlation coefficients >.2 were regarded as low, >.5 as moderate, and >.8 as high (Bühl and Zöfel, 2009).

3. Results

3.1. Demographic variables

Groups did not differ in gender ($\chi^2_{(1)} = .98$, $p = .32$), age ($t(86) = 2.03$, $p > .05$), or handedness ($\chi^2_{(2)} = 1.90$, $p = .39$), but did differ in years of education ($t(59) = -11.12$, $p < .01$).

3.2. BISC

The test results of the literate and illiterate groups on the BISC subtests are depicted in Table 3. We first describe how illiterates' performances improved on the BISC subtests from before to after the alphabetization course. Then we compare the results of the illiterate group to the results of the literate group.

3.2.1. Illiterate group improvement

Phonological awareness: Due to technical difficulties, the data for three illiterate individuals could not be included in the comparison. Illiterate individuals improved in the number of correct responses on the "phoneme association task" from before to after the alphabetization course ($t(43) = 3.08$, $p < .01$). On the other three tasks ("rhyming," "syllable segmentation," and "phoneme to word comparison"), participants did not improve.

Phonetic recoding in short-term memory: Illiterate individuals solved more items correctly on the "repetition of pseudo-words" task after compared to before the alphabetization course ($t(46) = 2.34$, $p < .05$).

Visual attention to words and phonemes: For illiterate individuals, reaction time decreased from before compared to after the alphabetization course on the "word comparison task" ($t(46) = -2.93$, $p = .01$). The number of correct responses did not change.

Long-term memory retrieval. Participants showed similar performances before and after the alphabetization course on all measures of the "color naming task."

Overall performance: The illiterate group improved in overall BISC performance from before compared to after the alphabetization course, as indicated by the significant *t*-test result for the overall percentile rank score ($t(46) = 3.30$, $p < .01$). As defined by the BISC manual, four of the illiterate individuals scored within the range indicating risk for developing dyslexia.

3.2.2. Literate vs. illiterate group

Illiterate individuals performed worse than literate individuals on all subtests and on the overall BISC before and after the alphabetization course. The only exception to this was the performance on the "color naming task" after the alphabetization course. For this task, the illiterate and the literate groups did not differ in their reaction time differences between the simple color naming task and the stroop-like color naming task ($t(73) = -1.76$, $p > .05$; see Section 2 for a more detailed description).

3.3. Alphabetization course outcome measures

Only the illiterate group was tested on the writing (HSP) and reading (ELFE) tests. These tests have been developed for children. Therefore, a ceiling effect for the control group would have been non-informative. Only intra-group comparisons could be conducted. There were seven illiterate individuals that could not be included in these analyses because they did not show up for the second testing session.

HSP. Individuals in the illiterate group did not change in their percentage of correctly written graphemes from before (64%) to after (62%) the alphabetization course ($t(35) = .68$, $p > .05$). However, as mentioned in Section 2, the percentages of two different tests were compared. Before the alphabetization course, a test for 1st graders was used. After the alphabetization course, a test for

2nd graders was used. Therefore, one could conclude that illiterate individuals progressed in their ability to write, maintaining their percentage of correctly written graphemes despite an increase in task difficulty.

ELFE. Considering their reading ability, illiterate individuals significantly improved from before to after the alphabetization course ($t(35) = 5.22$, $p < .01$) in the percentage of correctly read items.

3.4. Regression analyses

For the regression analyses in the direction of predicting variance of alphabetization outcome from BISC performance, the following results were found. The regression analysis for predicting HSP performance of illiterate individuals after the alphabetization course was performed on correctly written graphemes. The "phoneme association task" score before the alphabetization course accounted for 34% of the group variance ($\beta = .58$, $p < .01$). In a second step, years of education accounted for 27% of the group variance ($\beta = .52$, $p < .01$). Finally, in a third step, the "syllable segmentation" score before the alphabetization course accounted for 9% of the group variance ($\beta = .31$ $p < .01$).

The regression analysis for predicting ELFE performance of illiterate individuals after the alphabetization course was performed on correctly identified words. The "phoneme association task" score before the alphabetization course accounted for 32% of the group variance ($\beta = .57$, $p < .01$). In a second step, years of education accounted for 27% of the group variance ($\beta = .52$, $p < .01$).

Of note, BISC variables accounting for significant variance of the writing and reading tests in the regression analyses were tests of phonological awareness only.

For the regression analysis in the direction of predicting variance of BISC performance from alphabetization outcome measures, the following results were found. The correctly identified word score of the ELFE before the alphabetization course accounted for 31% of the group variance in the phoneme association task of the BISC after the alphabetization course ($\beta = .55$, $p < .01$). No other results were statistically significant.

3.5. Correlations with demographic data

Correlations between demographic variables and test performances were low to moderate and infrequent. Using the test results obtained after the alphabetization course, years of education correlated negatively with reaction time on the "word comparison search" task ($r = -.38$, $p < .01$), and positively with performances on the HSP ($r = .51$, $p < .01$) and ELFE ($r = .45$, $p < .01$) in the illiterate group. There were, in contrast, no correlations between the number of years living in Germany and any of the BISC scores. In the literate control group, age correlated negatively with the reaction time difference on the "color naming task" ($r = -.45$, $p < .01$).

4. Discussion

In this study, we investigated the impact of phonological processing skills on alphabetization success in illiterate individuals during a one-year alphabetization course. Confirming our hypotheses, improvements in the abilities to read and write were paralleled by improvements in phonological awareness in the narrower sense (phoneme association), phonetic recoding in short-term memory (repetition of pseudo-words), and visual attention (word comparison). More importantly, phoneme association was a stronger predictor of reading and writing skill improvements of illiterate individuals than was years of education. Syllable segmentation, another component of phonological awareness, also predicted writing skill improvement. Reading skills, in turn, also predicted phoneme association. Except for a stroop-like color naming task, illiterate individuals performed worse than literate controls on all measures. These results suggest that especially phonological awareness in the narrower sense, but also short-term memory and visual attention measures to some extent, contribute to written language acquisition above and beyond demographic variables. These results are intended to help optimize alphabetization programs.

The present study confirmed our main hypothesis. The improvement of illiterate adults in reading and writing skills can be predicted on the basis of phonological awareness measures. In our study, the subtest "phoneme association" accounted for 34% and 32% of the variance of writing and reading skill acquisition, respectively. This task requires participants to unite phonemes with words. Syllable segmentation accounted for 9% of the variance of writing skills. This task requires participants to split words into syllables. In addition, illiterate individuals significantly improved from before to after the alphabetization course in phoneme association. The results are in line with former research showing that phoneme manipulation ability improves through formal education (Castles and Coltheart, 2004; de Santos Loureiro et al., 2004; Liberman et al., 1974; Wimmer et al., 1991) and through acquaintance with an alphabetic system (de Gelder et al., 1993; Read et al., 1986). In our study, the tasks that were associated most closely with phoneme analysis were the best predictors of alphabetization success. This finding is in line with the observation that phoneme manipulation ability can discriminate between literate and illiterate individuals (de Santos Loureiro et al., 2004). Because illiterate individuals before the alphabetization course possess phonological awareness abilities similar to preschoolers before entering school (Adrian et al., 1995; Bertelson et al., 1989; de Santos Loureiro et al., 2004; Morais et al., 1986), the adults appear to acquire written language skills in a manner similar to that of the children. Interestingly, this may even be the case for the differentiation between the acquisition of reading and writing skills because reading performance in the ELFE predicted phoneme association (31% of variance accounted for). Hence, the relation between reading and phonological awareness might be closer than that between writing and phonological awareness in both children and adults (Berninger et al., 2002; Graham et al., 2000; Tan et al., 2005). Together with our results, this implies that the development of phonological awareness skills in the narrower sense, that is, phoneme manipulation ability, which is underdeveloped in illiterate adults (Bertelson et al., 1989; Lukatela et al., 1995; Reis and Castro-Caldas, 1997), supports adults' success in written language acquisition courses, specifically in reading but also in writing.

Nevertheless, the number of years of education was the second strongest predictor of alphabetization progress in the present illiterate adult sample. This demographic variable accounted for 27% of the variance in both writing and reading improvements, indicating that variables other than phonological awareness may be involved in written language acquisition. Regarding our BISC results, this notion was confirmed. Illiterate individuals improved from before to after the alphabetization course on “repetition of pseudo-words” and visual “word comparison” subscales. The former subscale assesses phonetic recoding as well as articulation and motor control. The latter subscale assesses visual attention to words and letters. Improvement of illiterate individuals on both tests and in overall BISC performance may have been due to the alphabetization program of the illiterate individuals. This is in line with studies showing that diverse types of cognitive abilities are associated with educational level (Ardila et al., 1989; Cornelius and Caspi, 1987; Lecours et al., 1987a,b, 1988; Ostrosky et al., 1998; Rosselli et al., 1990). In fact, phonological processing skills that have been acquired before beginning primary school may actually permit written language acquisition (Jansen et al., 2002). de Santos Loureiro et al. (2004) argue that phonological memory improves with level of alphabetization. Further, illiterates show a reduced ability to repeat pseudo-words compared to individuals with weak literacy abilities (Kosmidis et al., 2006). Improvements in articulation, phonological memory span, and visual attention could be due to the fact that during the alphabetization program, illiterate individuals were continuously confronted and familiarized with letters, phonemes, and words. Yet, as revealed by our regression analyses and in line with our main hypotheses, these abilities did not directly predict the alphabetization outcome. Overall, these results imply that phonetic recoding in short-term memory and visual attention could, mediated by the level of education, support written language acquisition in illiterate adults.

Strikingly, the literate group outperformed illiterates before and after the alphabetization course on almost all measures in this study. Former results have confirmed profound phonological processing deficits in illiterate individuals. Dellatolas et al. (2003) reported that illiterate individuals showed deficits in repeating pseudo-words, identifying rhymes, and replacing phonemes at the beginnings and ends of the words. In a different study, illiterate individuals showed deficient syllable analysis skills compared to good readers (Adrian et al., 1995). Reis and Castro-Caldas (1997) also reported difficulties in repeating pseudo-words in illiterate individuals. In a PET-study, Castro-Caldas et al. (1998) showed more activation for literate than illiterate individuals in the anterior cingulum, the right frontal insula, the left nucleus lentiformis, and the anterior thalamus during a pseudo-word repetition task. No difference in activation patterns of the two groups was observed when repeating familiar words. The same research group reported in a subsequent study (Petersson et al., 2000) that, based on a simple network model for language processing, this difference between the literate and illiterate individuals affects the interaction between Broca’s and Wernicke’s area as well as the interaction between Broca’s area and the inferior parietal cortex. The authors explain that this may be indicative for abnormal modulation of attention to the language network, verbal working memory, and articulation of verbal output in illiterates. In other words, illiterate individuals may lack an adequate neural network that could generate new phonological output, which is based on the phoneme analysis of pseudo-words.

Consequently, the acquisition of written language abilities may actually lead to further brain development, even in the adult brain. Castro-Caldas et al. (1999) argue that the neural processing of written language involves visuo-auditory-motor associations in the left hemisphere, which then increases intra- and inter-hemispheric neuroconnectivity. The corpus callosum is responsible for some of the connections between as well as within hemispheres. The corpus callosum, being involved in intra- and inter-hemispheric communication, was shown to be smaller in width in illiterate subjects compared to literate late learners. Specifically, number of fibres with smaller caliber was lower in illiterate individuals. The authors argue that regular training in reading and writing stimulates inter-hemispheric neural networks and its absence may result in poor development of the proper transcallosal connections. In a subsequent neurofunctional study, Castro-Caldas et al. (2009) tested literates that learned reading and writing later in life and literates that learned reading and writing at a normal age in a visual recognition task with abstract Portuguese nouns. While both groups did not differ in behavioural parameters, their brain activity patterns differed significantly. The authors found that late learners activated right temporo-parietal areas more than ‘normal’ learners. ‘Normal’ learners, in contrast showed higher activation in the left inferior frontal cortex. These results suggest, on the one hand, strategic differences regarding task solution relevant brain activation. On the other hand, this implies that language acquisition related information processing may alter brain functionality. The difference in hemispheric activity was due to a very late neurofunctional signal during information processing. Therefore, it may be that information related to written language is being processed and conducted to the left hemisphere very early in the process of reading in literate controls. Late literate individuals, on the other hand, may process reading related information less focused involving late right hemispheric mechanisms.

Carreiras et al. (2009) compared structural brain scans between individuals who acquired literacy in adulthood and illiterate individuals. The results showed that late literates had more gray matter compared to illiterates in five posterior brain regions: the dorsal occipital areas associated with higher level visual processing, the left supramarginal and superior temporal areas associated with phonological processing, and the angular gyri and posterior middle temporal regions associated with semantic processing. Further, the authors found a greater amount of white matter in the splenium of the corpus callosum which can be associated with the interhemispheric connection of the left and right angular gyri. Further, the results suggest that the increased functional coupling of visual and phonological processing areas is accomplished either directly or by means of semantics.

Our results suggest that some of this visual and phonological coupling is preserved in illiterate individuals. The single exception to the deficits of illiterate individuals in our study was the color naming task. After the alphabetization course, the reaction time differences between naming an object's color when seeing black and white images vs. naming an object's color when seeing incongruent object images (blue tomato) no longer differed between groups. This measure strongly reflects the influence of executive functions (Davidson et al., 2006; Miyake et al., 2000) such as inhibition, which is closely related to intelligence and the effective allocation of cognitive resources during learning processes (van der Meer et al., 2010). Instead of phonological awareness, this stroop result may reflect learning abilities that support the generation of new knowledge representations. In fact, in another study at our laboratory, we found that crystallized and fluid intelligence contribute above and beyond the influence of attention to successful written language acquisition (Landgraf et al., 2011).

A limitation of the present study is the relatively small sample size. Preferably, the current analyses should be tested on larger samples to investigate the reliability of the results. Further, the literate control groups were predominantly German native speakers whereas the illiterate individuals had a non-German language background. There is evidence that in second language acquisition, the ability to discriminate phonemes develops much slower than in first language acquisition (Iverson et al., 2003; Zhang et al., 2005). Hence, the differences in phonological awareness between controls and illiterates might also partially be explained by the differences in native languages. Although this is a longitudinal study, it comprises only one year of alphabetization. Test results and learning curves may change during the subsequent alphabetization process. For example, other subtests of the BISC may have other learning curves that do not show a change during one year of alphabetization in adults. Hence, it is necessary to conduct studies with illiterate adults that look at how alphabetization can be optimized over a longer period of time. Eventually, alphabetization may turn out to be a life-long learning process if initiated in adulthood.

4.1. Conclusion

This study is one of the first to evaluate how improvements in phonological processing impact the acquisition of written language skills in illiterate adults during an alphabetization course. We showed that phonological awareness factors in the narrower sense (e.g., phoneme association) are stronger predictors of alphabetization outcome than demographic variables such as years of education. Further, illiterate individuals improve in phonological awareness but also in short-term memory and visual attention during the alphabetization course. Despite improvement, they do not reach the level of phonological functioning of literate controls. The results suggest that alphabetization of adults follows a path similar to that of children. However, some specific aspects on narrow and broad phonological awareness skills need to be taken into account in order to improve and optimize alphabetization programs for adults and to ensure an effective integration of alphabetizing individuals into our modern information societies.

Conflict of interest

There are no conflicts of interest.

Acknowledgments

This research was supported by a grant from the German Federal Ministry for Education and Research (01AB091002). Further, we would like to thank Mrs. Prof. Dr. Ada Sasse and Mrs. Dr. Christine Wagner from the Institute of Educational Science of Humboldt-Universität zu Berlin for assessing the HSP and ELFE data. Finally, we would like to thank all participating individuals for their time and efforts!

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