



Biliteracy and acquisition of novel written words: the impact of phonological conflict between L1 and L2 scripts

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Abstract

The acquisition of new orthographic representations is a rapid and accurate process in proficient monolingual readers. The present study used biliterate and bialphabetic population to address the impact of phonological inconsistencies across the native (L1) and second (L2) alphabets. Naming latencies were collected from 50 Russian–English biliterates through a reading-aloud task with familiar and novel word forms repeated across 10 blocks. There were three Script conditions: (1) native Cyrillic, (2) non-native Roman, and (3) Ambiguous (with graphically identical, but phonologically inconsistent graphemes shared by both alphabets). Our analysis revealed the main effect of Script on both reading and orthographic learning: naming latencies during training were longer for the ambiguous stimuli, particularly for the novel ones. Nonetheless, novel word forms in the ambiguous condition approached the latencies for the familiar words along the exposures, although this effect was faster in the phonologically consistent trials. Post-training tests revealed similarly successful performance patterns for previously familiar and newly trained forms, indicating successful rapid acquisition of the latter. Furthermore, we found the highest free recall rates for the ambiguous stimuli. Overall, our results indicate that phonological inconsistency initially interferes with the efficiency of novel word encoding. Nevertheless, it does not prevent efficient attribution of orthographic representations; instead, the knowledge of two distinct alphabets supports a more efficient learning and a better memory for ambiguous stimuli via enhancing their encoding and retrieval.

Introduction

Orthographic learning refers to readers' ability to form novel representations of the word spellings in their mental lexicon (Álvarez-Cañizo et al., 2019; Kwok & Ellis, 2015; Kwok et al., 2017; Maloney et al., 2009; Share, 2008a, 2008b; Share & Stanovich, 1995). This ability develops when the reader is exposed to novel written word forms, first learning how to read and later—during independent reading (Share, 2008a, 2008b; Share & Stanovich, 1995). Thus, throughout

repeated phonological decoding (i.e., print-to-sound) of novel words, new representations are formed for these stimuli enabling their direct visual recognition in subsequent encounters. This mechanism is crucial for the acquisition of novel vocabulary in the visual domain as well as for the development of efficient reading and communication skills.

Numerous studies have systematically investigated the near-immediate acquisition of novel written word forms following very short training protocols of no more than ten exposures (Álvarez-Cañizo et al., 2018, 2019; Bowers et al., 2005; Clay et al., 2007; Cunningham et al., 2002; de Jong & Share, 2007; Kwok & Ellis, 2015; Kwok et al., 2017; Maloney et al., 2009; Martens & de Jong, 2008; Qiao et al., 2009; Qiao & Forster, 2013; Salasoo et al., 1985; Share, 1999; Suárez-Coalla et al., 2016; Tamura et al., 2017; Wang et al., 2012). Some of these studies have reported detectable learning effects already during training—for instance, in the reduction of the lexicality effect, i.e., the difference between naming latencies for novel and familiar words (e.g., Salasoo et al., 1985). Even more commonly, existing studies report the decrease of the length effect (i.e., the reduction

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of differences in naming latencies between short and long novel words) with learning (e.g., Álvarez-Cañizo et al., 2019; Kwok & Ellis, 2015; Kwok et al., 2017; Maloney et al., 2009). These results indicate a change in the reading strategy for the trained words as a consequence of the formation of orthographic representations evolving from sequential letter-by-letter decoding to a whole-word visual recognition strategy.

Other studies provide evidence regarding post-training access to newly acquired orthographic representations, manifested as better recall (through typing) or better recognition (among novel non-trained foils) of the newly trained words (Cunningham et al., 2002; Share, 1999). Similarly, some studies register interference effects caused by the learned stimuli during processing of orthographically related familiar words, which is taken as a sign of lexical competition following the integration of novel items into the mental lexicon (Bowers et al., 2005; Clay et al., 2007; Qiao & Forster, 2013; Qiao et al., 2009). In general, these and similar findings indicate the emergence of very rapid and robust effects of orthographic learning in different languages such as Spanish (Álvarez-Cañizo et al., 2018; Suárez-Coalla et al., 2016), Italian (Paulesu et al., 2000), English (Tamura et al., 2017; Wang et al., 2012), and Dutch (de Jong & Share, 2007; Martens & de Jong, 2008).

Importantly, the majority of studies reporting rapid orthographic learning use monolingual populations, thus exploring the acquisition of novel words in L1 reading. However, due to the global growth of bilingual population, the number of proficient second language (L2) readers (so-called biliterates) who incorporate new vocabulary through L2 reading is constantly growing. Moreover, biliteracy often implies managing a typologically different alphabet or script (in which the same unit of the spoken language, such as the phoneme, is represented by different written characters or graphic signs, as, e.g., in Latin, Greek or Cyrillic scripts) or even a different writing system (in which not only the scripts are different, but also the units of the spoken language that are represented, as in English or Japanese Kana, where written characters represent phonemes or syllables, respectively).

These cases are quite common in the highly multilingual world, and they motivate several specific research questions. First, does orthographic learning of L1 and L2 words differ, especially in situations when the two writing systems and/or scripts are substantially different? Second, what are the factors that influence orthographic learning in such cases? The past few years have seen numerous reports documenting systematic cross-lingual transfer effects between L1 and L2 (see Chung et al., 2019; Lallier & Carreiras, 2018 for recent reviews). For instance, several studies have addressed the impact of mapping the same letters onto different sounds across languages, by studying bilinguals whose two languages share the same alphabet (e.g., Brysbaert et al., 1999;

Jared & Kroll, 2001; Jared & Szucs, 2002; von Studnitz & Green, 2002). Importantly, these studies show that bilinguals activate phonological representations from both of their languages simultaneously. Other reports examining biliterates across different writing systems or scripts, such as Japanese–English (Ando et al., 2014; Nakayama et al., 2012), Korean–English (Kim & Davis, 2003), Chinese–English (Zhou et al., 2010), or Russian–English (Jouravlev et al., 2014), report cross-script phonological priming effects. In particular, phonological representations generated from primes in one script facilitate the recognition of targets in another script, thus suggesting integration of phonological representations across languages. However, although extensive research has studied reading across different languages and scripts, fewer studies have addressed the interplay between two writing systems or scripts during orthographic learning. The present study presents an attempt to fill this gap by studying orthographic learning in a biliterate population fluent in two different languages which employ two different scripts.

Reading is often conceptualized as extracting or decoding phonological information from visual input by translating written messages into spoken ones (Perfetti, 2003; Share & Stanovich, 1997). This is particularly true for unknown or low-frequency words whereby a sublexical translation of print-to-sound must be carried out in the absence of any pre-existing phonological or semantic representations. For high-frequency words, however, the access to whole-word orthographic representations also enables reading via a direct access to the phonological or the semantic levels of word-specific information, thus effectively allowing a double-route access (Grainger & Ziegler, 2011). In general, reading is likely to be rather similar across L1 and L2 orthographies, since the core process is universal across writing systems. However, the existence of a variety of scripts (within and across different writing systems) as well as their variations lead to incongruencies between the native and non-native scripts. This heterogeneity affects both decoding and subsequent word learning in the L2 alphabet. In particular, writing systems and scripts may differ in terms of the visual complexity of the graphemic representations: some contain a small number of strokes and a relatively small set of written characters (e.g., Spanish or Hebrew), while others include a much wider variety of strokes and a larger set of written characters (e.g., Arabic, Indian Kannada, or Chinese) (Abdelhadi et al., 2011; McBride-Chang et al., 2011; Nag, 2007). Alphabets may also differ in their orthographic representation: the grain size, or unit of spoken language that is represented by visual characters, from single phonemes, like in French or Russian, to syllables or morphemes, like in Japanese Kana or Chinese, respectively (Perfetti & Dunlap, 2008; Perfetti et al., 2002). Finally, it is customary to refer to the orthographic depth or the transparency/regularity in the

print-to-sound mappings. Orthographic depth ranges from consistent one-to-one mapping of graphic signs onto sounds in transparent orthographies like Finnish, Greek, or Indian Devanagari to inconsistent one-to-many and many-to-one mappings in opaque orthographic systems like in English or French (Seymour et al., 2003; Ziegler & Goswami, 2005).

Consequently, efficient decoding and orthographic learning in an L2 script depend on several challenging tasks. First, biliterates must learn the orthographic units specific to L2 script as well as their phonological correspondences. Second, they need to manage the eventual inconsistencies between L1 and L2 scripts, meaning that a lower level of incongruency allows for better decoding and orthographic learning outcomes. Thus, orthographic inconsistency between L1 and L2 scripts, in terms of the level of orthographic representation or orthographic regularity, leads to different reading strategies affecting word learning in the non-native script (Hamada & Koda, 2008; Schwartz et al., 2014). For instance, a study investigating novel word learning in Korean–English and Chinese–English biliterates showed that the decoding and recall of novel words in L2 English was better among Korean learners of English. This effect is explained by a higher consistency between Korean and English reading, since both follow phonological decoding of visual patterns (letters) into sounds, whereas in Chinese, graphic signs (logographs) are holistically transformed into a whole morpheme (Hamada & Koda, 2008).

Furthermore, the level of phonological inconsistency across alphabets, in terms of the symbol-to-sound correspondences carried out in L1 and L2 reading, could also play an important role both in the acquisition of decoding and orthographic learning skills in the L2 alphabet or script. However, the effects of phonological inconsistencies across L1 and L2 scripts, led by decoding of the same visual characters into different sounds across scripts, have been poorly understood so far, likely due to the lack of research into cross-linguistic grapheme overlap. Nonetheless, several studies have addressed the effect of orthographic overlap across languages with the same alphabet by means of cognates—words that are translation equivalents and have total or partial orthographic overlap across L1 and L2 (such as “piano” or “tomaat”, examples of identical and non-identical English–Dutch cognates; Bultena et al., 2013; Cop et al., 2017; Peeters et al., 2013). In these studies, the grapheme overlap typically leads to a faster processing of cognates than non-cognate control words, reflecting a cross-lingual facilitatory effect resulting from the co-activation of both words within an integrated lexicon. However, as orthographic cognates usually share aspects of phonological decoding (i.e., the cognate word piano is pronounced similarly in English and Dutch), such effects may also be explained by phonological rather than purely orthographic factors,

and they can be rather different when the overlap involves phonological inconsistencies across languages and scripts. This view is supported by the studies exploring the impact of the phonological incongruency across L1 and L2 scripts using visual word recognition tasks (Havelka & Rastle, 2005; Lukatela, 1999; Lukatela & Turvey, 1990; Rastle et al., 2009). In these studies, mainly conducted in Serbo-Croatian–English biliterates, L2 English words are systematically named slower when they contain ambiguous or inconsistent graphemes that sound differently in L1, than those containing non-ambiguous, L2-specific graphemes. This phonological ambiguity effect is generally attributed to the application of two competing decoding rules to the graphemes with the same visual but different phonological representations in the two languages.

Importantly, Cyrillic and Latin (Roman) alphabets are direct descendants of the ancient Greek alphabet and are characterized by having a considerable degree of graphemic overlap. Cyrillic script is used by a relatively large number of readers in the world across many Slavic (such as Russian, Belarusian, Ukrainian, Serbo-Croatian, Bulgarian, or Macedonian) and non-Slavic languages (such as Tatar, Mongolian, and Ossetic). At the same time, users of Cyrillic are usually extensively exposed to the Roman alphabet through education, literature, TV, cinema, advertising etc. Moreover, this population is also often relatively proficient in English and/or other Western European languages, and thus fluent in reading Roman script. In addition, some cultures, such as Serbian, use Roman and Cyrillic scripts interchangeably in their native language. Although both Roman and Cyrillic alphabets have their script-specific or unique graphemes (i.e., ш, ж, ф, ч only present in Cyrillic; v, q, z, f only present in Roman), several graphemes are used in both scripts. Some of these shared graphemes are mapped onto a comparable phonological representation (i.e., k, t, o, a), whereas others have a different mapping across scripts (i.e., “p”, decoded as /p/ in Roman but as /t/ in Cyrillic, or “h”, decoded as /h/ in Roman but as /n/ in Cyrillic). As a result, words sharing graphemes in both scripts have different phonological mapping and meaning across both languages (i.e., “cop” is read as /cop/ in Roman but as /sor/ in Cyrillic, which means “litter” in Russian). Although such phonological ambiguity effects have been showed to affect the reading latencies in Cyrillic–Roman biliterates, it is unclear how the corresponding processes unfold during novel word learning. Taking into account the key role of phonological assembly in reading, especially in alphabetic languages such as English (Ehri, 1992; Goswami & Bryant, 2016; Share, 2008a, 2008b; Snowling & Göbel, 2011), it is reasonable to expect that inconsistent phonology across alphabets would impact the formation of new L2 orthographic representations through phonological decoding processes, and hence the acquisition of efficient L2 reading skills.

The present study explores the orthographic learning processes in a group of Russian–English biliterates. Here, we disentangled the effect of phonological inconsistency from the effect of novel word learning per se by manipulating consistently the L2 alphabet stimuli. Namely, we used the L2 stimuli consistent or inconsistent with the L1 decoding rules. The novel word forms were repeatedly presented in different script conditions (Cyrillic, Roman, ambiguous) in a reading-aloud task together with familiar words enabling us to test the impact of the training on lexical differences. We formulated two specific research questions. First, we aimed to determine whether L1–L2 phonological inconsistencies influence the formation of new orthographic representations. Second, we investigated whether such inconsistencies are also reflected in the subsequent access to these representations (through active and controlled retrieval and through automatic recognition). To these ends, we measured orthographic learning process online during the training phase (through a reading-aloud task) and offline—at the post-training session—via recall, recognition, and lexical decision tasks. Recall and recognition tasks were used to directly evaluate the access to newly-represented word forms—either via active and controlled retrieval (recall task) or via an automatic and superficial familiarity-based process (recognition task). Lexical decision task was used to evaluate the orthographic representations of novel word forms indirectly—by examining the corresponding interference during a forced stimuli categorization. Following other word learning studies using similar approaches (Leminen et al., 2016; Merkx et al., 2011), we hypothesized that the newly trained novel word forms would be more difficult to reject as non-words than completely unfamiliar pseudowords, which would be reflected in differential response latencies and/or accuracy. Regarding our first research question, we hypothesized that phonological inconsistencies related to the L1–L2 overlap would affect the formation of new orthographic representations since such inconsistencies should lead to an interference in the phonological decoding during orthographic learning. Therefore, we expected that access to the novel L2 words with inconsistent graphemes would be associated with longer naming latencies as well as with a smaller reduction of lexical differences with familiar words, in comparison with novel L2 words with graphemes consistently decoded across L1 and L2 alphabets. As for our second research question, we expected that new orthographic representations acquired under phonological ambiguity would be poorly accessed both in recall and recognition tasks during the post-training assessment. Moreover, we expected a poor access to the novel L2 words with inconsistent graphemes reflected in the lexical decision task performance. Particularly, we expected a more frequent categorization of these stimuli as non-words to cause a weaker interference than the categorization of the words well represented in reader’s lexicon

showing longer latencies and higher number of errors. Finally, a general effect of native alphabet was expected, with better orthographic representation and access for novel words presented in L1 Cyrillic script.

Materials and methods

Participants

Fifty students recruited from the National Research University—Higher School of Economics and Moscow State University of Psychology and Education (23 females, aged between 18 and 30 years old, $M_{\text{age}} = 20.8$, $SD = 2.78$) took part in the experiment. All participants were right-handed native Russian (L1) speakers with normal or corrected-to-normal vision and no history of cognitive, neurological, or psychiatric disorders. All of them had English as their second language (L2), with different speaking and reading proficiency levels and relatively late learning onset (see Table 1 for details). In addition, 34 of them were also speakers of other languages (L3).¹ The study was approved by the Ethics Committee of the Department of Psychology, National Research University Higher School of Economics.

Stimuli

Experimental stimuli consisted of 12 familiar words and 12 pseudowords (namely, orthographically legal but meaningless stimuli, thus acting as novel word forms to be learned). These stimuli were equally divided into unambiguous L1 Cyrillic, unambiguous L2 Roman, and ambiguous script conditions. Therefore, 12 familiar words were presented in (4) Cyrillic (e.g., “*uaz*”), in (4) Roman, (e.g., “*vet*”), or in (4) ambiguous script (e.g., “*cop*”), and the same was done for the 12 novel word forms (4 in Cyrillic, e.g., “*uaz*”; 4 in Roman, e.g., “*vaz*”; and 4 in ambiguous script, e.g., “*pex*”). The full list of experimental stimuli can be found in “[Appendix](#)”. All stimuli were 3 letters in length with a Consonant–Vowel–Consonant (CVC) structure. Novel words were designed maintaining the first letter of a familiar word in the corresponding script condition to ensure maximal similarity. In addition, stimuli presented in L1, L2 and ambiguous conditions were matched across each group of familiar and novel words in log trigram frequency (paired tests carried out using nonparametric Mann–Whitney–Wilcoxon confirmed no differences across conditions, all contrasts

¹ German: $n = 19$; French: $n = 11$; Spanish: $n = 6$; Latin $n = 4$; Italian: $n = 3$; Ukrainian: $n = 3$; Arab: $n = 2$; Armenian: $n = 1$; Chinese: $n = 1$; Swedish: $n = 1$; Indonesian: $n = 1$; Czech: $n = 1$; Belorussian: $n = 1$; Danish: $n = 1$.

Table 1 Participants' second language (English) proficiency evaluation obtained by means of LEAP-Q Questionnaire

	Mean	SD, range
General L2 proficiency (0–100)	66.67	20.14, 83.33
L2 proficiency (0–10)		
Listening	6.92	2.00, 8
Speaking	6.16	2.23, 9
Reading	6.92	2.00, 8
General L2 exposure (0–100)	44.67	15.48, 66.67
L2 exposure (0–10)		
Friends	6.16	2.23, 9
Family	7.42	1.89, 8
Reading	2.96	2.16, 9
Language tapes/self-instruction	0.6	0.98, 3
TV/media	6.36	2.54, 10
Radio/music	3.78	3.07, 9
Factors contributing to L2 learning (0–10)		
Friends	3.78	2.87, 10
Family	1.72	2.43, 8
Reading	6.9	2.50, 10
Language tapes/self-instruction	4.64	3.21, 10
TV/media	4.32	3.12, 10
Radio/music	6.4	2.49, 9
Years immerse in L2 environment		
Country	0.58	1.40, 7
Family	0.09	0.31, 1.83
School/work	0.92	2.62, 12
Age of L2 acquisition	7.82	2.71, 13
Age of L2 fluency onset	14.77	3.15, 15
Age of L2 reading acquisition	11.59	3.64, 15
Age of L2 reading fluency onset	15.09	2.90, 12
Number of non-native languages learnt	3.18	0.99, 3

$p > 0.1$). Trigram frequency values for L1 and L2 stimuli were taken from Russian National corpus (<http://www.ruscorpora.ru/new/search-main.html>) and British National Corpus (<https://www.english-corpora.org/bnc/>) online databases, respectively, and log transformation was applied to normalize both datasets.

Importantly, all unambiguous stimuli in Cyrillic and Roman scripts were designed using graphemes specific to each alphabet (e.g., *j*, *uu*) as well as those common in both languages and mapped onto the same phonemes (*a*, *u*), i.e., phonologically consistent across scripts. However, in the ambiguous condition, stimuli were created by combining common and consistent graphemes with common but inconsistent graphemes, namely those used in both Cyrillic and Roman alphabets but decoded into a different sound depending on the script (i.e., the grapheme “p” is decoded as /p/ in Roman but as /t/ in Cyrillic, and the grapheme “x” is decoded as /ks/ in Roman but as /h/ in Cyrillic). To

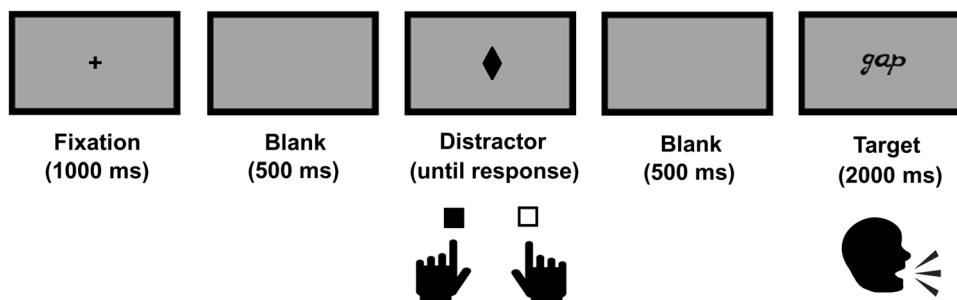
ensure the stimuli ambiguity in the ambiguous condition, handwriting fonts were used in the study since they provide a larger choice of overlapping graphemes (see “Appendix”). For instance, the English word “cop” written this way reads as /sor/ in Russian (meaning “litter”), thus resulting in the decoding ambiguity. The combination of italic “Notperfect regular” and “Swanky and Moo Cyrillic” fonts with small manual edits was used to optimize the letters for these purposes. The same handwriting style font was used for both the training and post-training tasks, including the corresponding experimental instructions. An additional stimuli set was used as foils for the recognition and lexical decision tasks during the post-training phase. Thus, for each task, 48 untrained stimuli were constructed (2 foils per each previously trained stimulus), maintaining the first two letters of the corresponding stimulus in the training task and replacing the third one to make a novel foil item, ensuring sufficient difficulty of the post-training assessment tasks.

Procedure

The duration of the entire experiment was approximately 1 h. Participants underwent (1) a training phase consisting of a reading-aloud task and (2) a post-training test phase comprising recall, recognition, and lexical decision tasks to assess the outcomes of learning. Before the training phase, participants also completed the full version of the Leap Questionnaire (Marian et al., 2007), a tool that collects self-reported, subjective judgements of L2 proficiency and L2 exposure, coded in 0–100 and 0–10 scales, respectively. A minimum level of L2 proficiency (at least 15 points on the general scale for L2 proficiency) was required for participation in the study, ensuring low-to-medium L2 proficiency and capability for L2 reading.

During the training phase, participants were presented with the set of 24 familiar and novel word forms repeatedly across 10 different blocks (see Fig. 1 for experimental sequence). The participants were told they would see a series of both familiar and novel words, presented either in L1 (Russian) or in L2 (English), and they were asked to read them aloud as quickly and accurately as possible. The stimuli were presented in black font against a grey background at the center of a computer screen by means of E-Prime software (Psychology Software Tools, Inc., Schneider et al., 2002). A Microsoft LifeChat LX-3000 headset (with a noise-cancelling microphone) was used to collect participant's vocalisations for each stimulus. Stimulus presentation was pseudorandomized within each block and participant to prevent the presentation of two consecutive stimuli from the same condition. Moreover, given that the previous presentation of an L1 or L2 stimuli could bias the pronunciation of an ambiguous stimulus, each trial included a distractor target stimulus (a white or a black diamond) presented between

Fig. 1 Sequence of stimuli presentation during the reading-aloud task (training phase)



target stimuli (see Fig. 1). Participants had to indicate the color of the diamond by pressing the corresponding keyboard key with their right (L) or their left finger (D). Similar to previous studies addressing cross-language naming (e.g., Reverberi et al., 2018), such an inter-trial non-linguistic distractor task (the categorization of the target color) was introduced to prompt participants to disengage from the reading processes, thus preventing or minimizing the influence of the preceding stimulus script on the language chosen to read the ambiguous stimuli. The keys were labeled with corresponding color stickers. The color of distractor stimuli was randomized across trials and responses were counterbalanced across participants (namely, half of them responded to white color with their right index finger and black with their left index finger, whereas the other half did the opposite). Before starting the training task, participants were presented with 12 practice trials (2 trials per condition) using stimuli which were similar, but not identical to the main task. During the training, participants took two breaks (after 4th and 7th blocks) to avoid fatigue.

Immediately after completing the reading-aloud task, participants underwent the post-training phase starting with a recall task, in which they were asked to write down all stimuli they could remember from the previous training phase. Answers were collected on a paper sheet with 30 spaces to fill, with no time restriction. Immediately after that, participants carried out the recognition and the lexical decision tasks sequentially with the same procedure and stimuli, but with different instructions. In both, the stimuli previously presented during the training phase were presented together with foils. Stimuli were presented in randomized order at the center of a computer screen by means of E-prime software. Participants were asked to press a button on a keyboard (D or L, labeled with a white or a black sticker) to decide whether the stimulus had been previously presented in the training phase or not (in the recognition task) and to categorize the stimulus as a real word or non-word (in the lexical decision task). For half of the participants, D button was labeled with a white sticker and L button with a black sticker, with the opposite for the other half; moreover, half of the participants pressed white for those stimuli previously trained and black for the stimuli not previously trained, whereas the other half

did the opposite. Color coding rather than characters (such as Y/N) were used to avoid any idiosyncratic influence of reading key labels on the main task. Response time was not limited; both latency and accuracy were collected in both tasks.

Data analysis

Training phase

Reading latencies obtained at the reading-aloud task were extracted manually for each trial and participant using Praat software (Boersma and Weenink). Utterances containing errors (incorrect pronunciations, mix of alphabets in ambiguous stimuli, no response or hesitation sounds, in which voice sounds, such as “err...”, “uhm...”, etc., are produced, but the stimulus is not named) were excluded from the analysis (representing 2.33% of all trials). Therefore, responses to ambiguous stimuli were considered equally correct if read in Russian or English, but not if the utterance included a mixture of both alphabets. In addition, responses whose latencies were 2 standard deviations above or below the mean were also rejected (4.16% of data). The ambiguous non-word stimulus “*cuk*” was also excluded from the analyses, because this stimulus was pronounced in Russian in 99.6% of cases, thus being an outlier in the ambiguous subset.

To determine the effect of the presentation script on the reading latencies of both novel and familiar words across the training blocks, an inferential analysis using mixed-effects modelling was carried out. This method allows to simultaneously enter random participant or item effects in addition to the experimental variables thus effectively separating the fixed effects of predictor variables (Baayen et al., 2008; Barr et al., 2013). The analysis was conducted in R software (Team, 2013) using the lmer package (Baayen et al., 2008). Block (from 1 to 10), Lexicality (familiar and novel words), and Script (Cyrillic, Roman and Ambiguous) were entered as predictor variables (fixed effects), participants and items were treated as random effects, and the RTs—as the dependent variable. The final model included fixed effects for lexicality, script and block, random intercepts for participant, and item and by-participant random slopes for lexicality

and script. More complex model with all the within-subject and within-item predictors as random slopes failed to reliably converge (Barr et al., 2013). Variance inflation factor (ranged from 1.01 to 1.32) reported no collinearity issue in the model. R-default treatment contrasts were altered to sum-to-zero contrasts before running the model, so that all fixed effect were contrast-coded (Schad et al., 2020). We used lmerTest packages (Kuznetsova et al., 2017) to calculate *p* values and Type III *F* statistics for main effects and interactions using Satterthwaite approximations to determine degrees of freedom. Post hoc analysis was achieved using the framework provided by the emmeans package (Lenth, 2018). We first determined the estimated marginal means (EMMs) and their standard errors, and then pair-wise comparisons. In addition, we used asymptotic *dfs* (i.e., *z* values and tests) to prevent emmeans from calculating the *df* for the EMMs.

We further conducted a Bayes Factor analysis to adjust *p* values ($BF_{01} < 0.0001$), to quantify the statistical evidence supporting the interaction between the three factors. The Bayes factor analysis was calculated using the Bayesian Information Criterion (BIC) approximation of the Bayes Factor (Wagenmakers, 2007). The Bayes Factor BF_{01} was calculated using the BIC values for the model without the interaction (the null hypothesis H_0) and for the model with the interaction (the alternative hypothesis H_1), using the formula $BF_{01} = \exp((BIC(H_1) - BIC(H_0))/2)$ (Wagenmakers, 2007, p. 796). A BF_{01} less than 1 would suggest evidence in support of H_1 (i.e., the alternative hypothesis), whereas BF_{01} greater than 1 would suggest evidence in support of H_0 (i.e., the null hypothesis) and $BF_{01} = 1$ would suggest equivalent evidence for the two hypotheses.

Complementary analyses were carried out to determine the language in which stimuli presented in the ambiguous script were read across the training blocks (see supplementary material section A). In addition, linear regression analyses were also implemented to study the effects of (1) L2 proficiency level, (2) L2 age of acquisition, and (3) exposure to L2 on the training effectiveness reflected in the naming latencies obtained at the end of the exposures (see supplementary material section B).

Post-training phase

For the recall task, the number of correct recalled stimuli across each condition and participant was calculated and converted into to a percentage scale. A two-way rmANOVA (using R function aov) was performed taking the percentage of correct responses as a dependent variable, as well as lexicality and script as independent variables. All *p* values were adjusted using the FDR correction method for multiple comparisons. For recognition and lexical decision tasks, only correct responses were entered in the analysis

Table 2 Mean and standard error of naming latencies (RTs) for familiar and novel word forms in different scripts at the first and the last block of the training task

	Block 1		Block 10	
	Familiar	Novel	Familiar	Novel
L1	632 (26.3)	761 (26.4)	552 (26.4)	575 (26.3)
L2	809 (26.4)	936 (26.4)	628 (26.3)	651 (26.4)
Ambiguous	789 (26.3)	1068 (29.7)	666 (26.3)	735 (29.6)

(discarding 8.36% of trials in recognition and 13.07% in the lexical decision task). All responses below 500 ms and above 2500 ms were excluded from the analysis (excluding 5.64% and 15.93% of responses in recognition and in lexical decision task, respectively). Then, the remaining RTs below or above 2 standard deviations were excluded from data analysis. Accuracy data and RTs of correct responses were analyzed using generalized and linear mixed-effect models, respectively. All models were conducted with familiarity (trained, non-trained foil), script (Russian, English, Ambiguous), and lexicality (familiar, novel) as fixed effects and item and participant as random effects. The final models of both recognition and lexical decision task included by-participant random slopes for lexicality and by-item random slopes for lexicality. More complex model with all relevant random structures failed to reliably converge. Car package with the Type III Wald χ^2 -statistics (function Anova) (Fox et al., 2016) was used to test for significance for accuracy data and to calculate *p* values.

Results

Training phase

Table 2 shows the mean latencies obtained in the reading-aloud task, separated by block (first vs. last), lexicality (familiar vs. novel), and script type (L1, L2, ambiguous). The final model revealed statistically reliable main effects of block, as naming latencies significantly decrease across the training (block 1: $M = 832$; block 10: $M = 634$), lexicality, given novel words showed longer naming latencies ($M = 738$) than familiar words ($M = 663$) and script, with naming latencies differing depending on the alphabet of presentation (L1: $M = 606$; L2: $M = 711$; ambiguous: $M = 784$). We also found reliable interactions between block \times script, block \times lexicality, and marginally lexicality \times script; importantly, the three-way interaction block \times script \times lexicality was also found reliable. See Table 3 for detailed statistical results. A Bayes Factor analysis was conducted to evaluate the statistical evidence for the three-way interaction. The Bayes Factor BF_{01} was calculated using the BIC

Table 3 Statistical results obtained for response latencies collected during the training (reading-aloud task)

Global analysis (latency in reading-aloud task)												
Block	$F(9, 10,947.5) = 141.47, p < 0.001$											
Lexicality	$F(1, 22.2) = 18.32, p < 0.001$											
Script	$F(2,25.1) = 29.20, p < 0.001$											
Script \times lexicality	$F(2,17) = 3.30, p = 0.061$											
Block \times lexicality	$F(9, 10,947.5) = 18.80, p < 0.001$											
Block \times script	$F(18, 10,947.4) = 5.49, p < 0.001$											
Block \times lexicality \times script	$F(18, 10,947.3) = 1.89, p = 0.012$											
Random effects												
Groups name	Variance			Std. dev			Corr					
Participant (intercept)	9577.2			97.86								
Lexicality	500.9			22.38			0.58					
Script 1 (English)	2618.4			51.17			0.48 0.39					
Script 2 (Russian)	876.0			29.60			0.09 0.14 – 0.57					
Item (intercept)	1473.1			38.38								
Residual	26,892.3			163.99								
Number of obs.: 11,219; groups: participant, 50; items, 23												
Follow-up comparisons												
Script \times lexicality across blocks												
	Block 1				Block 10							
	Estimate	SE	<i>z</i>	<i>p</i>	Estimate	SE	<i>z</i>	<i>p</i>				
L2 vs. L1 in familiar	177.2	32.6	5.436	<0.0001	75.7	32.6	2.320	0.0407				
Ambiguous vs. L1 in familiar	156.9	34.1	4.597	<0.0001	115.2	34.2	3.370	0.0023				
Ambiguous vs. L2 in familiar	– 20.3	33.4	0.608	0.5434	39.5	33.4	1.182	0.2370				
L2 vs. L1 in novel	176.1	32.7	5.393	<0.0001	75.8	32.6	2.326	0.0200				
Ambiguous vs. L1 in novel	307.1	36.8	8.345	<0.0001	159.8	36.7	4.350	<0.0001				
Ambiguous vs. L2 in novel	131.0	36.1	3.631	0.0003	83.9	36.0	2.331	0.0200				
Novel vs familiar in L1	129.3	32.4	3.993	0.0001	23.5	32.4	0.724	0.4688				
Novel vs. familiar in L2	128.2	32.5	3.949	0.0001	23.6	32.4	0.728	0.4666				
Novel vs. familiar in ambiguous	279.5	35.1	7.953	<0.0001	68.1	35.1	1.940	0.0524				
Lexicality \times block across scripts												
	L1				L2				Ambiguous			
	Estimate	SE	<i>z</i>	<i>p</i>	Estimate	SE	<i>z</i>	<i>p</i>	Estimate	SE	<i>z</i>	<i>p</i>
Block 1 vs. block 10 in familiar	80.45	16.5	4.881	<0.0001	181.96	16.6	10.969	<0.0001	122.21	16.5	7.415	<0.0001
Block 1 vs. block 10 in novel	186.26	16.5	11.272	<0.0001	286.53	16.6	17.248	<0.0001	333.62	19.9	16.794	<0.0001
Novel vs. familiar in block 1	129.3	32.4	3.993	0.0001	128.2	32.5	3.949	0.0001	279.5	35.1	7.953	<0.0001
Novel vs. familiar in block 10	23.5	32.4	0.724	0.4688	23.6	32.4	0.728	0.4666	68.1	35.1	1.940	0.0524
Block \times scripts across lexicality												
	Familiar				Novel							
	Estimate	SE	<i>z</i>	<i>p</i>	Estimate	SE	<i>z</i>	<i>p</i>				
Block 1 vs. block 10 in L1	80.45	16.5	4.881	<0.0001	186.26	16.5	11.272	<0.0001				
Block 1 vs. block 10 in L2	181.96	16.6	10.969	<0.0001	286.53	16.6	17.248	<0.0001				
Block 1 vs. block 10 in ambiguous	122.21	16.5	7.415	<0.0001	333.62	19.9	16.794	<0.0001				
L2 vs. L1 in block 1	177.2	32.6	5.436	<.0001	176.1	32.7	5.393	<0.0001				
Ambiguous vs. L1 in block 1	156.9	34.1	4.597	<0.0001	307.1	36.8	8.345	<0.0001				

Table 3 (continued)

	Block × scripts across lexicality							
	Familiar				Novel			
	Estimate	SE	<i>z</i>	<i>p</i>	Estimate	SE	<i>z</i>	<i>p</i>
Ambiguous vs. L2 in block 1	− 20.3	33.4	− 0.608	0.5434	131.0	36.1	3.631	0.0003
L2 vs. L1 in block 10	75.7	32.6	2.320	0.0407	75.8	32.6	2.326	0.0200
Ambiguous vs. L1 in block 10	115.2	34.2	3.370	0.0023	159.8	36.7	4.350	<0.0001
Ambiguous vs. L2 in block 10	39.5	33.4	1.182	0.2370	83.9	36.0	2.331	0.0200

values for the model with no interaction (the null hypothesis H0) and for the model with an interaction of block by lexicality by script (the alternative hypothesis H1). The Bayes Factor, $BF_{01} < 0.001$, indicates “strong” evidence for the alternative hypothesis (i.e., an interaction between three predictors) according to Jeffreys’s (1961) classification scheme.

Moreover, a power analysis was conducted using simulate () function in the lmer4 package (Bates et al., 2015) within the R statistical computing environment. This study includes a relatively small number of items per condition, which was necessary to fulfil the strict requirements controlling various orthographic and psycholinguistic variables across conditions. To ensure no lack of power in our results, and based on the mixed-effect model that included the same effect structure (fixed effects for script, block and lexicality, random intercepts for participant and item and by-participant random slopes for script and lexicality), 1000 simulations of the model were conducted separately for each condition as well as two-way and three-way interactions. It produced an estimate of statistical power of 0.965 with our sample of 50 participants (i.e., in 965 out of 1000 simulation runs, the model detected a significant three-way interaction of block by script by lexicality), thus largely ruling out the possibility that the present results may lack statistical power.

The three-way block × lexicality × script interaction confirmed that repeated exposures across the ten training blocks led to a decrease in the differences between familiar and novel words, although differently depending on the script of presentation. To disentangle the three-way interaction, the interaction between lexicality × script across the training blocks was explored (see Table 3). Post hoc analyses (pair-wise comparisons) revealed that in the first training block, familiar and novel words were differently influenced by the script effect, with novel words showing longer naming latencies when read in L2 script, and, particularly, in the ambiguous script, in comparison to those read in L1. However, familiar words showed similar effect of non-native alphabet when presented in L2 or in ambiguous script in comparison to L1. Nonetheless, in the last training block, novel and familiar stimuli did not any more differ in their naming latencies depending on the script of presentation. Hence, this pattern of results indicates a different impact of

the script effect for novel and familiar words which changed across the training. Figure 2 shows the reading latencies pattern across the training blocks for all familiar and novel words.

Second, the lexicality × block interaction was explored across the levels of script factor. These results confirmed that differences between novel and familiar words were differently reduced along the exposure as a function of the script, due to different effects of training on each of the scripts (see Table 3). In particular, post hoc comparisons for the effect of block revealed that, for familiar words, the highest latency decrease across the ten exposures was found in L2 followed by ambiguous and by L1 scripts. However, for novel word forms, the highest reduction in naming latencies was registered for the stimuli presented in ambiguous and L2 scripts followed by those presented in L1 script. Such different pattern in the naming latency drop for novel and familiar words led to a different attenuation of the lexicality effect across scripts (see Table 4 for detailed statistical results across all blocks). Although, in general, initial differences for familiar and novel stimuli in the beginning of the training were found reduced at the end of the task, this reduction was faster in non-ambiguous L1 and L2 conditions than in the ambiguous script condition. Thus, the initially reliable differences between familiar and novel words presented in both L1 and L2 scripts were eliminated already by the third and second presentation, respectively. However, reliable differences between familiar and novel words presented in ambiguous script disappeared only at the last presentation.

Post-training phase

Recall task

The rmANOVA revealed a statistically reliable effect of script [$F(2,98) = 22.464$, $p < 0.001$]. Pair-wise comparisons, using paired *t* test, revealed differences across the three alphabets, with better recall rates for stimuli presented in the ambiguous script (59.4%) than those presented in L2 (47.7%, $p < 0.0001$) or L1 alphabets (36.5%, $p < 0.0001$); moreover, recall scores also differed between L1 and L2 scripts, with

Fig. 2 Mean naming latencies (RTs) obtained across training blocks for each experimental condition (familiar and novel words in L1, L2 and ambiguous scripts)

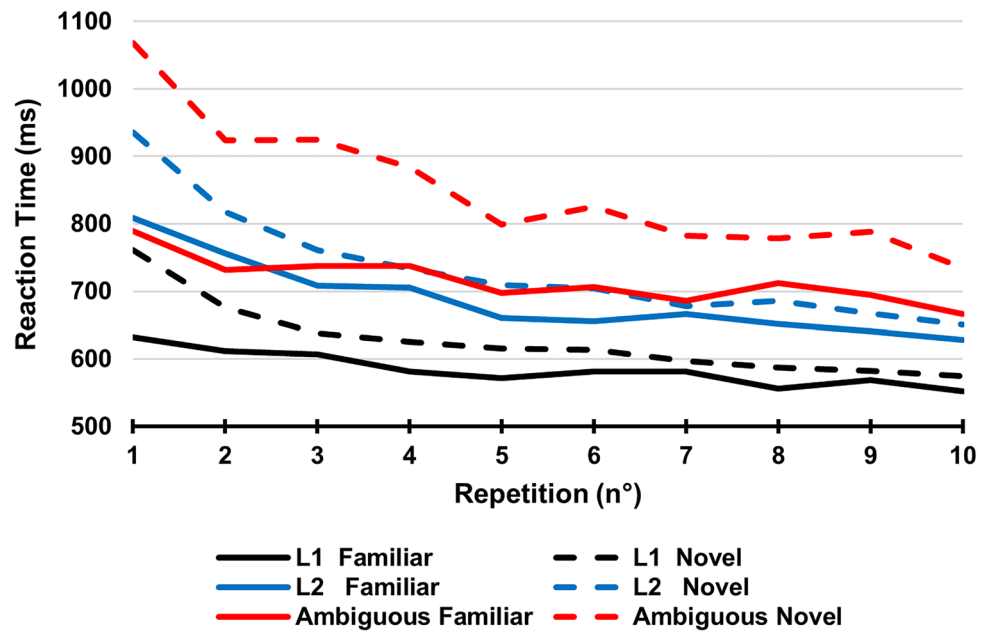


Table 4 Lexicality effect obtained for each script condition and block across the training task

	L1		L2		Ambiguous	
	Estimate	<i>p</i> value	Estimate	<i>p</i> value	Estimate	<i>p</i> value
Block 1	129.3	0.0001	128.2	0.0001	279.50	<0.0001***
Block 2	63.9	0.0485*	63.0	0.051	192.7	<0.0001***
Block 3	31.2	0.335	54.8	0.091	187.4	<0.0001***
Block 4	42.8	0.186	29.3	0.36	152.0	<0.0001**
Block 5	43.9	0.175	48.3	0.13	105.5	0.0027**
Block 6	31.1	0.337	48.8	0.13	121.8	0.0005**
Block 7	14.3	0.657	12.70	0.70	96.5	0.006**
Block 8	31.3	0.333	34.7	0.28	68.9	0.0496*
Block 9	13.9	0.668	25.5	0.43	91.7	0.0087**
Block 10	23.5	0.468	23.63	0.46	68.1	0.052

***<0.0001
 **<0.01
 *<0.05

the lowest percentage of correctly recalled stimuli found in the native alphabet ($p < 0.0001$).

Recognition task

The final model revealed reliable effects of familiarity, showing lower recognition latencies (i.e., faster recognition) for trained ($M = 923$ ms) than for untrained stimuli ($M = 1008$ ms) and lexicality, with lower recognition latencies for familiar ($M = 919$ ms) than for novel words ($M = 1012$ ms), regardless of the script of presentation (see Table 5). The interaction familiarity \times lexicality was marginally significant, suggesting that while familiar words showed similar recognition latencies independently of previous training,

novel trained word forms were recognized significantly faster than untrained ones. Thus, novel words exhibited similar recognition times to familiar words when both had been trained, whereas untrained stimuli showed reliable lexical differences. Moreover, the interaction script \times familiarity was also found statistically significant, indicating that stimuli presented in L1 or in ambiguous script showed similar recognition latencies independently of a previous training, whereas those presented in L2 exhibited significantly faster recognition latencies when trained than when presented for the first time in the recognition task. Previously trained stimuli showed similar recognition times regardless of the script of presentation whereas for untrained stimuli, those presented in L1 were discarded slightly faster than

Table 5 Statistical results obtained for response latencies collected in the recognition task

Global analysis (latency in recognition task)											
Lexicality	$F(1, 44.241) = 12.44, p < 0.001$										
Script	$F(2, 43.653) = 0.0432, p > 0.05$										
Familiarity	$F(1, 43.667) = 11.62, p < 0.001$										
Lexicality × script	$F(2, 43.652) = 0.68, p > 0.05$										
Lexicality × familiarity	$F(1, 43.639) = 3.51, p = 0.067$										
Script × familiarity	$F(2, 43.657) = 3.66, p < 0.05$										
Lexicality × script × familiarity	$F(2, 43.657) = 0.52, p > 0.05$										
Random effects											
Groups name	Variance				Std. dev				Corr		
Participant (intercept)	7006.6				83.71						
Lexicality	188.3				13.72				- 0.03		
Item (intercept)	4285.7				65.47						
Lexicality	5175.4				71.94				0.39		
Residual	75,389.8				274.57						
Number of obs.: 2864; groups: participant, 50; items, 69											
Follow-up comparisons											
	Lexicality × familiarity				Script × familiarity						
	Estimate	SE	<i>z</i>	<i>p</i>	Estimate	SE	<i>z</i>	<i>p</i>			
Foils vs. trained in familiar	42.3	30.8	1.370	0.1706	Foils vs. trained in L1	15.3	46.3	0.331	0.7405		
Foils vs. trained in novel	145.6	45.7	3.189	0.0014	Foils vs. trained in L2	189.7	46.0	4.128	< 0.0001		
Novel vs. familiar in foils	149.8	32.2	4.646	< 0.0001	Foils vs. trained in Amb	76.8	50.8	1.513	0.1304		
Novel vs. familiar in trained	46.5	45.0	1.032	0.3021	L2 vs. L1 in foils	86.9	38.0	2.289	0.0574		
					Ambiguous vs. L1 in foils	39.4	39.9	0.989	0.5836		
					Ambiguous vs. L2 in foils	- 47.4	39.8	- 1.193	0.4572		
					L2 vs. L1 in trained	- 87.5	53.0	- 1.649	0.2250		
					Ambiguous vs. L1 in trained	- 22.0	56.0	- 0.393	0.9182		
					Ambiguous vs. L2 in trained	65.5	55.7	1.174	0.4685		

L2, although no differences were observed between L1 and ambiguous or ambiguous and L2 foils. See Fig. 3b. As recognition accuracy was close to 100% across all stimuli, no further analyses were carried out on this data.

Lexical decision task

The analysis carried out on response latencies revealed main effects of *script*, indicating longer reaction times for stimuli presented in ambiguous ($M = 1114$ ms) and L2 ($M = 1138$ ms) than in L1 alphabet ($M = 963$ ms) and lexicality, revealing generally longer response latencies for novel ($M = 1227$ ms) than for familiar words ($M = 929$ ms). We also found reliable interactions of script × lexicality and familiarity × lexicality. No other reliable effects or interactions were registered. Post hoc analyses were carried out in order to explore these interactions in detail (see Table 6). Regarding script × lexicality interaction, we found that novel words showed longer response times when presented in L2 and,

particularly, when presented in ambiguous script, in comparison to those presented in L1 alphabet; in contrast, the categorization of familiar words was particularly delayed when presented in L2 than in ambiguous or in L1 script. The highest RT differences for the lexical categorization of novel and familiar words were found in the ambiguous condition, although also significant in L1 and L2. Regarding the interaction familiarity × lexicality, it revealed that familiar words showed faster reactions for previously trained than for untrained foils, whereas novel words exhibited the contrary pattern, with significantly longer RTs for trained than for foils, thus reflecting an interference effect when categorizing these stimuli as non-lexical items. As a result, differences between novel and familiar words were larger when these stimuli were previously trained than when stimuli received no previous training (see Fig. 3c).

The relatively high error rate in this task (13.07% of the total amount of responses) also allowed for LME analyses to be conducted on accuracy data. The final model revealed

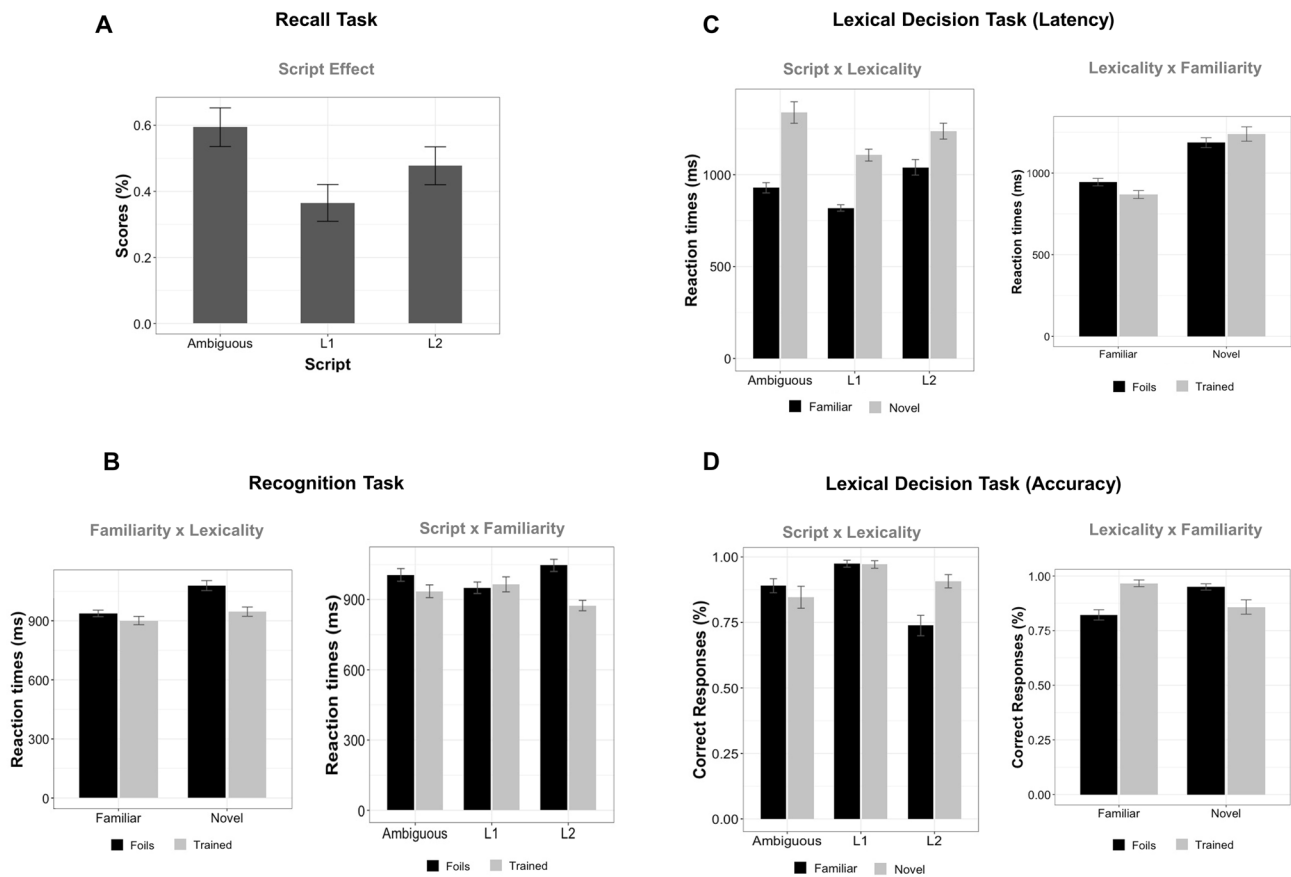


Fig. 3 Results across the three post-training assessment tasks: free recall accuracy (a), recognition RT (b), and lexical decision task RT (c) and accuracy (d)

a main effect of script, with higher percentage of correct categorization of stimuli in L1 ($M = 97.25\%$) than in L2 ($M = 82.25\%$) or in ambiguous script ($M = 86.8\%$). In addition, reliable interactions were found between familiarity \times lexicality and script \times lexicality (see Table 7 for detailed statistical results).

Post hoc analyses were carried out to further investigate the interactions. Regarding lexicality \times script interaction, these revealed significantly better categorization of familiar than novel words when presented in ambiguous script, whereas no differences were observed between these stimuli when presented in L1 or L2 (see Fig. 3d). Thus, familiar words in ambiguous and L1 scripts showed more correct responses than those presented in L2, whereas no differences were observed between ambiguous and L1 script. However, novel word forms showed a different pattern in accuracy, as the greatest percentage of correct responses (i.e., rejections) was observed for those presented in L1 in comparison to those in L2 or in ambiguous script. No accuracy differences were observed between the categorization of novel words in L2 and ambiguous script. Regarding the analysis of the lexicality \times familiarity interaction, it was found that familiar

words used in the training block exhibited significantly better categorization than those untrained; the opposite pattern was obtained for novel word forms, with worse categorization performance observed for the trained items than for foils, reflecting an interference during the categorization of trained novel words as non-lexical stimuli. Therefore, novel words exhibited significantly lower percentage of correct categorization responses than familiar words when these stimuli were previously trained but better categorization than familiar words when presented as foils (see Fig. 3d).

Discussion

The present study investigated orthographic learning of novel words during the use of native and non-native alphabets. In particular, we aimed to determine the impact of phonological inconsistencies established as graphemic overlap between L1 and L2 scripts. To this end, we administered training and post-training tasks to evaluate the processes of orthographic representation building and subsequent access to novel written word forms in a group of Russian–English

Table 6 Statistical results obtained for response latencies collected in the lexical decision task

Global analysis (latency in lexical decision task)										
Lexicality	$F(1, 70.592) = 110.50, p < 0.001$									
Script	$F(2, 49.779) = 28.89, p < 0.001$									
Familiarity	$F(1, 49.950) = 0.09, p > 0.05$									
Lexicality × script	$F(2, 49.782) = 6.15, p < 0.01$									
Lexicality × familiarity	$F(1, 49.961) = 12.97, p < 0.001$									
Script × familiarity	$F(2, 49.627) = 1.47, p > 0.05$									
Lexicality × script × familiarity	$F(2, 49.632) = 2.59, p = 0.08$									
Random effects										
Groups name	Variance				Std. dev				Corr	
Participant (intercept)	13,202				114.90					
Lexicality	5013				70.80				0.70	
Item (intercept)	1250				35.36					
Lexicality	5211				72.19				0.36	
Residual	113,405				336.76					
Number of obs.: 2573; groups: participant, 50; items, 69										
Follow-up comparisons										
Lexicality × familiarity					Lexicality × script					
	Estimate	SE	z	p		Estimate	SE	z	p	
Foils vs. trained in familiar	100.1	31.0	3.230	0.0032	Novel vs. familiar in L1	305	45.9	6.632	<0.0001	
Foils vs. trained in novel	- 84.1	40.7	2.066	0.0479	Novel vs. familiar in L2	251	48.0	5.237	<0.0001	
Novel vs. familiar in foils	250	36.0	6.943	<0.0001	Novel vs. familiar in Amb	471	52.0	9.058	<0.0001	
Novel vs. familiar in trained	435	46.2	9.407	<0.0001	L2 vs. L1 in familiar	222	38.3	5.800	<0.0001	
					Ambiguous vs. L1 in familiar	120	37.1	3.240	0.0088	
					Ambiguous vs. L2 in familiar	- 102	38.6	- 2.645	0.0339	
					L2 vs. L1 in novel	169	46.2	3.653	0.0032	
					Ambiguous vs. L1 in novel	287	51.3	5.586	<.0001	
					Ambiguous vs. L2 in novel	118	52.0	2.265	0.0761	

biliterates, who were exposed to familiar and novel words in a short training session containing visually presented words in L1 Cyrillic, L2 Roman, or ambiguous scripts. Overall, our results demonstrate that phonological inconsistency interfered with the reading automatization of novel word forms. This interference slowed down, but did not prevent the formation of orthographic representations, since similar levels of post-training recall and recognition were observed for the trained and for the familiar words even in the conditions of phonological inconsistency. We discuss these results in more detail below.

The short ten-exposure training protocol used in this study led to a rapid automatization in the decoding of novel word forms presented in either L1 or L2 alphabets. This result corroborates previous findings using similar training protocols and online measures (Álvarez-Cañizo et al., 2019; Kwok & Ellis, 2015; Kwok et al., 2017; Maloney et al., 2009; Salasoo et al., 1985). Specifically, naming latencies progressively decreased to the extent that they matched

those exhibited by familiar words at the end of the training. Nonetheless, the improvement in the naming latencies and acquisition of orthographic representation depended on the phonological ambiguity of the stimuli’s grapheme-to-phoneme correspondence. Thus, the reading of novel words with ambiguous graphemes was slower than reading of the words containing unambiguous graphemes. However, this ambiguity effect was mainly present at the beginning of the training when these stimuli were still unfamiliar, but it was significantly reduced at the end of the training. This pattern suggests that the orthographic familiarity established through repeated exposure mitigated the impact of phonological inconsistency. Similarly, the impact of the phonological ambiguity was stronger for novel words (cf. Havelka & Rastle, 2005; Lukatela, 1999), but, importantly, this effect was registered at the beginning of the training only, indicating that the decoding of novel stimuli at the early training stages is carried out in a serial manner via grapheme-to-phoneme correspondence, and is therefore particularly

Table 7 Statistical results obtained for correct responses collected in the lexical decision task

Global analysis (accuracy in lexical decision task)									
Lexicality	$\chi^2(1)=0.70, p>0.05$								
Script	$\chi^2(2)=20.55, p<0.001$								
Familiarity	$\chi^2(1)=1.76, p>0.05$								
Lexicality \times script	$\chi^2(2)=7.74, p<0.05$								
Lexicality \times familiarity	$\chi^2(1)=21.48, p<0.001$								
Script \times familiarity	$\chi^2(2)=1.68, p>0.05$								
Lexicality \times script \times familiarity	$\chi^2(2)=3.11, p>0.05$								
Random effects									
Groups name	Variance		Std. dev		Corr				
Participant (intercept)	0.5718		0.7562						
Lexicality	0.6300		0.7937		0.25				
Item (intercept)	0.6996		0.8364						
Lexicality	0.6350		0.7969		- 0.46				
Number of obs.: 2879; groups: participant, 50; items, 69									
Follow-up comparisons									
	Lexicality \times familiarity				Lexicality \times script				
	Estimate	SE	<i>z</i>	<i>p</i>	Estimate	SE	<i>z</i>	<i>p</i>	
Foils vs. trained in Familiar	- 2.35	0.663	- 3.540	0.0004	Novel vs. familiar in L1	- 0.528	0.810	- 0.651	0.5147
foils vs. trained in novel	1.30	0.425	3.068	0.0022	Novel vs. familiar in L2	0.895	0.650	1.378	0.1683
Novel vs. familiar in foils	1.41	0.522	2.698	0.0070	Novel vs. familiar in Amb	- 1.620	0.761	- 2.130	0.0332
Novel vs. familiar in trained	- 2.24	0.728	- 3.081	0.0021	L1 vs. L2 in familiar	2.833	0.792	3.578	0.0010
					Ambiguous vs. L1 in familiar	- 0.998	0.861	- 1.159	0.4777
					Ambiguous vs. L2 in familiar	1.835	0.772	2.378	0.0458
					L1 vs. L2 in novel	1.410	0.514	2.742	0.0168
					Ambiguous vs. L1 in novel	- 2.090	0.539	- 3.880	0.0003
					Ambiguous vs. L2 in novel	- 0.680	0.491	- 1.384	0.3491

affected by the ambiguity. However, as new stimuli gained orthographic familiarity across the training and led to the incorporation of new representations in the reader's lexicon, the impact of phonological ambiguity decreased. Indeed, the reading of both novel and familiar ambiguous words was similarly affected by phonological inconsistencies at the end of the training, indicating that by that point, the novel words followed a reading strategy less dependent on phonological decoding and more on the direct access to their newly acquired memory traces.

Importantly, acquisition of orthographic representations for novel words with ambiguous graphemics was registered both in online and offline measures. First, it was observed as the elimination of the lexicality effect in the ambiguous condition at the end of the training, an effect that typically reflects differences between familiar lexicalized words and new unfamiliar entries (e.g., Forster & Chambers, 1973). This finding likely indicates the incorporation of the newly trained ambiguous L2 word forms into the orthographic lexicon regardless of the inconsistencies in their decoding and

the lack of meaning and enabling parallel whole-form processing. Interestingly, utterances registered for novel ambiguous words indicate that these stimuli were likely represented as non-native words. Indeed, ambiguous novel words were mainly read in English rather than in Russian language, a reading choice that did not change as a consequence of the training. Such preference for reading ambiguous novel words using L2 decoding rules could be tentatively explained by the learning context of the task, in which novel stimuli may tend to be considered as unknown L2 words rather than as unknown L1 (since the participant may assume familiarity with more words in L1 than in L2). Familiar words presented in the ambiguous script condition showed, in contrast, a different pattern of reading, since these stimuli were more often read as Russian words. This could be related to a more robust representation of these stimuli in readers' L1 lexicon, likely due to more exposure to them within native Russian rather than within English reading contexts. Nonetheless, familiar ambiguous words still exhibited a much less marked preference than novel ones for reading in

one over another language. Indeed, analysis of the switching pattern between languages showed that familiar words exhibited a dynamic pattern of reading whereby words were interchangeably read either in Russian or English language across the exposures, suggesting strong orthographic decoding skills in both languages. Novel ambiguous word forms, however, showed a more static reading pattern with a smaller number of switches from one language to another, mainly read—and hence represented—in L2 orthographic lexicon. Likely, training these stimuli in more ecological reading contexts (e.g., with novel ambiguous words embedded in L1 and L2 texts) would facilitate their progressive representation in both languages, resulting in their efficient and dynamic recognition across both L1 and L2, as observed for familiar ambiguous words.

Second, our post-training data also confirm efficient access, and thus acquisition of orthographic representations, for novel ambiguous words, as these stimuli showed similar performance for familiar words both in recall and recognition tasks, despite the associated grapheme-to-phoneme ambiguity. Moreover, ambiguous novel words were recognized faster than untrained ambiguous novel word forms presented as foils. This finding indicates the presence of a successful orthographic learning, similarly to previous studies using orthographic choice tasks in unambiguous L1 scripts (Cunningham et al., 2002; Share, 1999). Furthermore, our lexical decision task data also suggest the formation of stable orthographic representations of the newly trained novel words regardless of phonological inconsistencies. The responses to these words took longer and were more error-prone than the rejection of novel but untrained words. This pattern, in agreement with that found in previous studies (Leminen et al., 2016; Merckx et al., 2011), indicates an interference during the categorization of previously trained words as non-lexical items, thus suggesting some level of memory representation for these stimuli, not evident for untrained foils that lack representations in the readers' mental lexicon.

Overall, results from both training and post-training tasks demonstrate that, although phonological ambiguity interferes with the efficient decoding of novel words, such effect does not prevent the successful development of orthographic representation in reader's lexicon. These findings contradict one of our initial hypotheses predicting poorer achievement of orthographic learning for novel words with ambiguous L2/L1 graphemes. Nonetheless, the build-up of orthographic representations for ambiguous words must be examined carefully not only at the end, but also along the training. This online analysis showed that the process of building an orthographic representation was actually delayed for those words with inconsistent grapheme-to-phoneme decoding: whereas novel words presented in consistent L1 and L2 scripts matched the naming latencies for familiar words as early as at their second exposure (in case of those in L2)

or third exposure (for those in L1), the naming of novel ambiguous words became fully comparable to the familiar words only at the tenth presentation. Such effect of phonological inconsistency in the orthographic learning of novel words may not be surprising considering the critical role of phonological decoding in the acquisition of reading and in novel word learning, as particularly evident when this skill is limited or impaired (Kyte & Johnson, 2006; Perfetti, 2003; Share & Stanovich, 1997). In essence, our prediction of poorer performance was not entirely incorrect, but could now be specified based on the result as a poorer acquisition speed, yet leading to the same ultimate performance. Importantly, these findings show, for the first time, the impact of phonological inconsistencies across L1 and L2 alphabets on the acquisition of new vocabulary during reading.

The successful achievement of orthographic learning of novel words under conditions of phonological inconsistency could be tentatively explained by the availability of two different reading strategies, each corresponding to the decoding principles of L1 and L2 alphabets. Encountering an orthographic ambiguity activates corresponding grapheme-to-phoneme decoding rules in both languages and then forces the reader to choose a decoding strategy (which, for novel items, resulted more often in the selection of L2 decoding rules); as a consequence, the processing of these stimuli becomes more effortful, increasing the attentional resources allocated to reading them, which is especially true in a single-word presentation paradigm, where there are no rules or prompts that could facilitate the election of a reading strategy. Although this leads to the naming latencies' inflation, it may also lead to a deeper memory encoding. Indeed, the script effect obtained in the recall task corroborates this interpretation, showing better retrieval for stimuli with ambiguous grapheme-to-phoneme decoding (both familiar and novel), in comparison to those presented in consistent L1 Cyrillic or L2 Roman graphemes, and thus suggesting the presence of stronger orthographic representations for the words whose reading is possible following not one, but two different decoding strategies. Therefore, although the knowledge of two alphabets may interfere with the phonological decoding of words with ambiguous phonemic correspondences across alphabets, it ultimately seems to contribute to their better memory and learning, particularly to the retention and access of their memory traces. Such effect, previously described as a desirable difficulty effect (Bjork, 1994), has been consistently found across different contexts including reading (Diemand-Yauman et al., 2011) and lexical acquisition (Eskenazi & Nix, 2020), showing better memory retention of stimuli as a consequence of their effortful encoding, by means of their presentation in hard-to-read fonts or, in this case, in phonologically ambiguous graphemes across L1–L2. Therefore, although the processing of words that can be read across different languages is effortful

at encoding, such effort turns into beneficial or desirable, as it leads to advantageous retention enhancements. This view agrees with previous studies showing the role of biliteracy in reading and novel word learning, the so-called biliteracy advantage. In these studies, biliterates show better orthographic learning than bilingual monoliterate learners, likely as a consequence of a higher flexibility of their orthographic systems (Kahn-Horwitz et al., 2014; Modirkhamene, 2006; Schwartz et al., 2007, 2014). Notably, in these studies, the facilitation was based on the transfer of orthographic characteristics across languages using non-overlapping writing systems in the absence of any decoding conflict. In contrast, in the present research, the biliteracy advantage appears to be driven by inconsistencies across orthographic scripts, leading to higher control and monitoring of decoding processes and, consequently, stronger retention of novel words. This suggestion that inconsistencies across overlapping alphabets could lead to advantages in orthographic learning should still be further explored in future research, for instance by a direct comparison of mono vs. biliterate populations and of overlapping vs. non-overlapping L1/L2 combinations in the same individuals.

Regarding the process of orthographic learning under conditions of phonological consistency, results found in this study confirmed the effective acquisition of orthographic representations for novel words with non-ambiguous graphemes, both in the native and non-native alphabets. Indeed, naming latencies for novel words both in L1 Cyrillic and L2 Roman scripts decreased significantly across their training and matched those obtained for familiar words very quickly, already after two or three exposures, indicating similar reading automatization in native and non-native scripts. Moreover, in both alphabets, the performance for novel words in recall and recognition tasks did not differ from the one exhibited by familiar words, indicating efficient access to newly formed memory traces after training. These results confirm previous findings in biliterate population, reflecting the rapid acquisition of new vocabulary through L2 reading (Chung et al., 2019; Schwartz et al., 2014; van Daal & Wass, 2017). Importantly, the present study extends these findings by addressing this topic in bialphabetic population and comparing orthographic learning under native and non-native scripts, highlighting the role of phonological inconsistencies in this process. Nonetheless, more research is needed to further understand reading and orthographic learning processes in biliterate population, particularly in regards to the underlying brain mechanisms that support the successful representation of novel words even in conditions of phonological inconsistency. To this end, future studies could conduct a similar experimental design to the one carried out here and complement it with online recordings of brain activity during the training using, e.g., EEG or MEG paradigms that are known to be sensitive to orthographic memory trace

activations (Bakker et al., 2015; McLaughlin et al., 2004; Mestres-Missé et al., 2007; Partanen et al., 2018). Moreover, future investigation might consider manipulating the context of training, by repeatedly presenting novel words either in isolation or in association with a semantic reference (for instance, by associating them with pictures or photographs of novel object, or embedding them in sentences). Importantly, such manipulation would go beyond the study of purely orthographic learning addressed in the present work, and could investigate the acquisition of fully fledged lexical representations through the integration of word's features at orthographic, phonological, and semantic levels of information. Likely, meaningful training conditions would facilitate novel word learning, as has been suggested in previous studies (Angwin et al., 2014; Bermúdez-Margaretto et al., 2020; Havas et al., 2018; Takashima et al., 2014), and would potentially reduce the impact of phonological inconsistencies led by graphemic overlap across L1–L2. Importantly, the number of novel words used in such studies should be kept to a minimum (as in the present experiment), thus ensuring both limited variability and a strict control across conditions as well as preventing memory overload in learners. While providing obvious methodological advantages (which is particularly important for new designs not used previously, such as the one here), this practice, may be associated with a diminished statistical power, which is usually mitigated by conducting a priori power analysis. In the present study, we used observed power instead to ensure that our data had sufficient statistical power. At the same time, we are conscious of the fact that the observed power often overestimates the true power of a study (Hoenig & Heisey, 2001; Vasisht & Nicenboim, 2016, pp. 359); hence, it must be considered as a limitation in the present study, which should be overcome in future research by conducting a priori power analysis.

The level of L2 proficiency was assessed in the present study by means of the LEAP-Q questionnaire, which is based on participant's self-ratings. This has been repeatedly demonstrated to be a sensitive tool for the assessment of L2 proficiency and experience across different languages. Importantly, the criterion-based validity of LEAP-Q was successfully established by confirming a relationship between self-reported data on this questionnaire and participants' performance on objective, behavioural measures (such as reading fluency, vocabulary, or grammaticality judgment tasks)—both in L1 and L2 (Marian et al., 2007). Nevertheless, some previous findings suggest that self-ratings might be less reliable than objective L2 proficiency measures (e.g., Khare et al., 2013; Lemhöfer & Broersma, 2012; Wen & van Heuven, 2017). Indeed, many existing studies (e.g., FitzPatrick & Indefrey, 2010; Lemhöfer & Broersma, 2012; van der Meij et al., 2011) have used more objective L2 proficiency measures in addition to participants' self-ratings,

which is especially important if these metrics are used to predict experimental data. Therefore, the sole use of LEAP-Q in our work may still be considered as a limitation. Future studies on word learning (as well as on language processing in general) which involve biliterate or bilingual populations should combine validated and standardized self-assessment questionnaires with objective measures aiming to better predict the impact of L2 proficiency on experimental data (e.g., Lemhöfer & Broersma, 2012).

Regarding the stimuli trained in the native alphabet, these exhibited generally better reading performance than those presented in the non-native script. That is, novel words in L2 alphabet showed slower naming latencies than those in L1 script despite the training. This second alphabet effect is not surprising considering that our sample consisted of unbalanced Russian–English biliterates who learnt English and the corresponding Roman alphabet during their late childhood, as reflected by the high age of acquisition. Consequently, language proficiency and exposure to scripts were also unbalanced, giving us an additional leverage in comparing L1 and L2 orthographic learning performance. A different pattern of results could be expected in a better-balanced group of early biliterates where it would be reasonable to expect not only a smaller L2 alphabet effect but also a reduced phonological inconsistency leading to a more efficient L2 word learning. Indeed, results of regression analyses partially support this view (see supplementary material section) as L2 proficiency and exposure predicted faster decoding after training—both under consistent and inconsistent script conditions. Future research will need to compare orthographic learning skills across early and late bialphabetic learners to corroborate this preliminary finding.

Finally, it is worthwhile to highlight that the present research provides empirical evidence about reading and orthographic learning skills in Russian (as particularly exhibited by stimuli presented in non-ambiguous, L1 Cyrillic script). Since this language is highly similar to many other alphabetic languages in terms of orthographic representation and depth, and is closely related to many Indo-European languages, results reported here may contribute not only to the investigation of Russian language, but, importantly, could be generalizable to other languages as well. Indeed, the majority of studies addressing orthographic learning and related topics are conducted in handful of Western European languages, predominantly English, despite the fact that this language has several characteristics that make it an outlier in comparison to many other languages across the world (most importantly, its extreme orthographic depth with poor transparency between written and spoken forms) which question the conventional generalization of English-based results to other languages (Seymour et al., 2003; Share, 2008a, 2008b; Ziegler & Goswami, 2005). Thus, the present study extends this research, providing evidence for decoding and novel word learning

process in a rather transparent orthography, comparable to many other languages and scripts within the world's family of alphabetic systems.

Appendix: Stimuli used in the study. Note that the same handwritten font was used across all tasks

L1 Script		L2 Script		Ambiguous Script	
Familiar Words	Novel Words	Familiar Words	Novel Words	Familiar Words	Novel Words
<i>шаз</i>	<i>шаз</i>	<i>kid</i>	<i>kof</i>	<i>gap</i>	<i>gex</i>
<i>шок</i>	<i>шоу</i>	<i>law</i>	<i>leg</i>	<i>pot</i>	<i>per</i>
<i>шак</i>	<i>шеу</i>	<i>vet</i>	<i>vaz</i>	<i>cop</i>	<i>cuk</i>
<i>жан</i>	<i>жеж</i>	<i>jam</i>	<i>jod</i>	<i>nap</i>	<i>nem</i>

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Code availability The code used in this study is available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare no conflict of interest.

Ethics approval The manuscript does not contain clinical studies or patient data. The study was approved by the Ethics Committee of the Department of Psychology, National Research University Higher School of Economics.

Consent to participate All participants gave their written consent to take part in the study.

Consent for publication All authors have approved the manuscript and agree with its publication.

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