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Individual differences in pseudohomophony effect relates to auditory categorical perception skills

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ABSTRACT

The study examined whether individual differences in the quality of phonological representations, measured by a categorical perception task (CP), are related with the use of phonological information in a lexical decision pseudohomophone task. In addition, the lexical frequency of the stimuli was manipulated. The sample consisted of Spanish-speaking normal reading adults. When high frequency stimuli were used, CP explained a significant proportion of the variance observed in the pseudohomophone effect. This result supports the idea that, even in normal reading adults, the use of phonological information during lexical access depends on the quality of their phonological representation.

1. Introduction

This study experimentally investigated the relationship between quantitative differences in phoneme categorical perception (CP) skills and the magnitude of the pseudohomophone effect in adult normal readers. Influential computational models emphasize the relation between the quality of the phonological codes and how effective the phonological lexical access is. For instance, Harm and Seidenberg (1999) provides a computationally explicit account of how phonological representations affect literacy. In this model, lexical access processes are characterized by the formation of componential representations in the mapping from orthography to phonology (see also Harm, McCandliss, & Seidenberg, 2003). While there are numerous empirical studies investigating this hypothesized relation in children (e.g., Godfrey, Syrdal-Lasky, Millay, & Knox, 1981), however, the studies with adults are sparse and focused on the comparison between participants with very different reading skills (for instance, Serniclaes, Ventura, Morais & Kolinsky, 2005, comparing illiterate with literates adults). Thus, our aim was to evaluate whether quality of phonological codes (measured by a CP task) mediates the use of phonological information in lexical access (measured by the pseudohomophone effect) even in normal reading adults.

A pseudohomophone is a pseudoword that sounds like a real word (e.g., in English, BRANE). Pseudohomophone reaction times (RTs) are longer than for pseudowords (e.g., BRANE vs. BRAIS) in lexical decision tasks. A pseudohomophone activates its own phonological form and a real word, and therefore longer RTs are needed to reject them than for pseudowords, which do not sound like real words. Importantly, the more active the real word phonological form, the more the expected interference, and hence a longer RT.

The pseudohomophone effect shows cross-linguistic and individual differences. In English, the pseudohomophone effect is larger in low-frequency pseudohomophones than high-frequency ones. The most common explanation of the interaction between lexical frequency and the pseudohomophone effect is based on which participants can reject high frequency pseudowords (including pseudohomophones) as real words using the information of the visual form of the stimuli. On the other hand, participants could have not a strong representation of the visual form of the low frequency words which are used in the formation of low frequency pseudowords and, hence, it is more probable the use of phonological information to reject these stimuli as real words (Pexman, Lupker, & Jared, 2001). Interestingly, Cuetos and Domínguez (2002) observed a very strong effect of pseudohomophones both in high-frequency conditions and low-frequency ones using a Spanish speaking sample. Complementary, Goswami, Ziegler, Dalton and Schneider (2001) found that German children had greater error rates than English children in a lexical decision pseudohomophone task. Thus, it seems that transparent orthography languages show greater interference effects in

Abbreviations: CP, Categorical perception.

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high frequency stimuli, what could be interpreted as evidence of the relevancy of the phonological information in these languages (see also Goswami, 2000).

The role of the phonological component can also be modulated by individual differences. Holyk and Pexman (2004) selected a non-word naming task as a phonological skill measure. As they predicted, participants with better phonological skills presented a greater pseudohomophone effect, thus indicating there are individual differences in word access as a function of differences in phonological skills.

However, non-word naming and lexical decision pseudohomophone tasks are both reading tasks, loading over the phonological route. Thus, a non-word naming task does not independently assess a general phonological component. To achieve this aim, phonological participation in reading (e.g., through a pseudohomophony task) has to be associated with a non-reading phonological task.

A little studied source of variation in normal readers is the auditory end of grapheme–phoneme correspondences. Au and Lovegrove (2001) found that differences in an auditory temporal-order judgment task (ATOJ) were related to a high-level reading task. However, the ATOJ task involved a pair of sine wave tones, so there was no direct relation between the core mechanism of phonological route, grapheme–phoneme correspondences, and these non-speech stimuli.

The basic phenomenon in phoneme perception is categorical perception (CP). Discrimination between two sounds of the same category is worse than between two sounds of different categories (Liberman, Harris, Hoffman, & Griffith, 1957). Although there is no reason to expect qualitative differences in CP between adult normal readers, some quantitative parameters could exert a subtle influence during lexical access. It has been found that CP in normal readers is weaker in children than in adults (Hazan & Barrett, 2000) and this becomes stronger with increasing age (Serniclaes et al., 2005). Thus, normal readers differ in CP during the learning reading process, at least quantitatively. Moreover, Serniclaes et al. (2005) found that although there were no discrepancies in the classic CP measure between illiterate and literate adult subjects, there were significant differences in an identification task, specifically in the degree of the slope. As Sprenger-Charolles, Colé, and Serniclaes (2006) state, slope is an index of categorical accuracy or quality. Thus, the more pronounced the slope, the more accurate the identification of a sound as belonging to a category. Therefore, an identification task could provide an accurate measure of phonological representations suited to adult normal readers.

In the present study, we investigated individual differences in a general phonological component involved in reading and CP skills. First, we used a pseudohomophone effect task due to its unequivocal phonological character. Furthermore, our study was conducted in Spanish, a transparent orthography language in which phonological information in reading is more relevant than in English. Second, to assess phonological skills, we focused on a quantitative measure of differences in the categorization of speech sounds, instead of the reading phonological skill task used by Holyk and Pexman (2004) or the non-speech stimuli used by Au and Lovegrove (2001). The identification task provides a direct measure of phoneme representations, one of the ends in the mapping involved in the phonological route. Third, we manipulated the lexical frequency of pseudohomophones to assess whether differences in CP have the same impact regarding high-frequency words versus low-frequency ones.

2. Material and method

2.1. Participants and apparatus

The participants were 121 undergraduate psychology students from the University of Málaga. They were Spanish language native speakers with no reading or hearing impairments. The tasks were performed on IBM-PC computers in semi-isolated individual cubicles. The task order was randomized. Lexical decision and phoneme identification tasks were developed using E-Prime 1.02 and Superlab Pro software, respectively. Headphones were used in the phoneme identification task.

2.2. Procedure

We used a lexical decision task in order to measure the pseudohomophone effect. The subjects saw strings of letters on the screen and had to decide, as quickly and accurately as possible, whether each string was a real word or not. All stimuli were randomly presented.

Each trial began with a fixation point in the centre of the screen that lasted 1000 ms, and which was replaced by the test item. The subjects were instructed to press the "z" key if the item was a word, or the "m" key if the item was a pseudoword. The item remained on screen until the subject responded or 2000 ms had passed. The next trial started automatically after a 1000-ms timeout.

The set of stimuli included two lists of 40 words (A and B) of the same lexical length (4 or 5 letters and two syllables) and lexical frequency (an average of 16 per million in list A and 15 per million in list B). Half of the words in each list were high-frequency words (A: 31 per million, B: 29 per million) and the remaining half were low-frequency words (A & B: 1 per million). From each word in the B list we created two types of stimuli by changing one letter: pseudohomophones and pseudowords. Thus, from the word 'CERA' (wax, in Spanish) 'ZERA' (pseudohomophone) and 'KERA' (pseudoword) were created. We used the same letters to form the pseudohomophones as well as the pseudowords. We thus manipulated the phonological similarity to real words, maintaining visual similarity and letter frequency (see Appendix A). Also, another list of 40 words of medium frequency (8 per million) was used as fillers. In brief, we formed six experimental word conditions: high-frequency words, low-frequency words, high-frequency pseudowords, low-frequency pseudowords, high-frequency pseudohomophones and low-frequency pseudohomophones.

In the auditory identification task, the stimuli were isolated syllables randomly presented. The participants were instructed to listen to the sound and decide whether it was /ba/ or /pa/, and to press the corresponding key. Eleven sounds were presented 6 times, totalling 66 sounds during the experiment. The subjects were trained with 12 practice trials before performing the experimental task.

The /ba/–/pa/ stimuli used were taken from a continuum constructed from the syllables which manipulate Voice Onset Time (VOT) using the F1 cutback technique (Liberman, Delattre, & Cooper, 1958). The stimuli ranged from −60 ms to +60 ms VOT. The VOT is defined as the length of time that passes between when an occlusive consonant is released and when the vocal cord begin to vibrate. As the VOT increases, perception rapidly changes from a voiced to an unvoiced stop consonant and vice versa. This abrupt change in consonant identification is an example of categorical speech perception and is a central feature of auditory discrimination. The auditory processing task provided three measures. The *slope* is the main measure of the limits of categorical perception in the continuum. The *error* value indicates to what extent the scores are consistent with the group. The *boundary* indicates the location of the slope in the continuum. We combined these three factors in order to improve the sensibility of the measure, following a similar strategy that, for instance, Ramus et al. (2003). These three factors compose a measure of CP that allows the subjects to be classified according to their auditory processing skills, using the formula

$$Zerror + ABS(ZBound * (0.20)) + (ZPend * (-1)).$$

3. Results

The mean RTs of correct responses and error rates are shown in Table 1. We first assessed the effect of pseudohomophony using an ANOVA 2 (Lexical Frequency: High vs. Low) × 2 (Homophony: Pseudohomophones vs. Pseudowords). This ANOVA showed a significant main effect of Homophony, F1 (1, 111) = 156.89, $p<0.001$, $\eta^2=0.58$; F2 (1, 75) = 16.29, $p<0.001$, $\eta^2=0.18$; a Lexical Frequency × Homophony interaction was significant only in the participants analysis (F1), F1 (1, 111) = 5.43, $p=0.022$, $\eta^2=0.47$; F2 (1, 75) < 1. No other effects were significant (Fs < 1). Thus, we obtained a significant main effect of Homophony and an interaction between Homophony and Lexical Frequency in the F1 analysis.

We then analyzed individual differences in the pseudohomophony effect due to differences in the CP variable. To achieve this, we performed two linear regression analyses with the CP score as a predictor of the magnitude of the pseudohomophony effect (i.e., pseudohomophones RTs minus pseudowords RTs). Due to the interaction between Homophony and Lexical Frequency in the analysis by subjects, we performed the regression analysis in each level of the variable Lexical Frequency separately. These analyses yielded a significant result for high frequency, F (1, 110) = 10.89, $p=0.001$, $R^2=0.09$. For low frequency, CP was not a good predictor of the magnitude of the pseudohomophony effect, F (1, 110) < 1, $R^2=0.005$ (see Fig. 1). Thus, it seems that there was an influence of the CP variable on reading, but it was only found with stimuli formed from high-frequency words.

To further evaluate the effect of CP on reading, we compared the groups of participants with extreme scores in this variable. Thus, we formed two between-subjects groups, one including the participants with better scores on the syllabic discrimination task, (named CP1; N = 37, the best third of participants in CP) and the other including the participants with lower scores in CP (named CP3; N = 37, the worst third of participants in CP).

We repeated the previous analysis of the homophony effect, but with a new variable named 'CP Group' with two levels: CP1 and CP3. Thus, we performed an ANOVA 2 (Lexical Frequency: High vs. Low) × 2 (Homophony: Pseudohomophones vs. Pseudowords) × 2 (CP Group: CP1 vs. CP3). This analysis again showed a main effect of Homophony, F1 (1, 72) = 108.01, $p<0.001$, $\eta^2=0.6$; F2 (1, 75) = 16.29, $p<0.001$, $\eta^2=0.18$; and a marginal effect of the CP Group on the participants effect, F1 (1, 72) = 3.02, $p=0.086$, $\eta^2=0.04$ that reached significance in the analysis by items, F2 (1, 75) = 45.79, $p<0.001$, $\eta^2=0.38$. As shown in Fig. 2, this effect would be due to CP1 having a slower RT than CP3. We highlight the fact that the interaction Lexical Frequency × Homophony × CP Group was significant, F1 (1, 72) = 5.77, $p=0.019$, $\eta^2=0.074$; F2 (1, 75) = 4.35, $p=0.04$, $\eta^2=0.055$. A visual inspection of the means (see Fig. 2) shows that this interaction is due to the stronger effect of pseudohomophones in CP1 than CP3, but only in the condition of high lexical frequency. No other effects were significant. This impression was confirmed when we analyzed the Homophony × CP Group interaction in each level of the Lexical Frequency variable:

1) High Lexical Frequency: The results showed a main effect of Homophony, F1 (1, 72) = 89.49, $p<0.001$, $\eta^2=0.55$; F2 (1, 37) = 9.25, $p=0.004$, $\eta^2=0.2$ as well as a main effect of CP Group, marginal in the F1 and significant in F2, F1 (1, 72) = 3.31, $p=0.073$, $\eta^2=0.044$; F2 (1, 37) = 28.12, $p<0.001$, $\eta^2=0.43$. Importantly, the interaction Homophony × CP Group was significant, F1 (1, 72) = 6.87, $p=0.011$, $\eta^2=0.087$; F2 (1, 37) = 5.05, $p=0.031$, $\eta^2=0.12$.
2) Low Lexical Frequency: The results showed a main effect of Homophony, F1 (1, 72) = 41.18, $p<0.001$, $\eta^2=0.36$; F2 (1, 38) = 7.26, $p=0.01$, $\eta^2=0.16$, as well as the trend to a main effect of CP Group, F1 (1, 72) = 2.48, $p=0.12$, $\eta^2=0.033$; F2 (1, 38) = 17.95, $p<0.001$, $\eta^2=0.32$, but, the interaction Homophony × CP Group was not significant F1 (1, 72) < 1; F2 (1, 38) < 1.

In brief, the homophone effect tended to be larger with high-frequency stimuli. When we included the CP Group variable in the analysis, it was found that the CP Group had a significant influence on the pseudohomophone effect.

Table 1
Results.

Condition	Reaction time	Errors %
High-frequency words	681 (82)	1% (2)
High-frequency pseudohomophones	879 (127)	14% (10)
High-frequency pseudowords	806 (101)	2% (3)
Low-frequency words	816 (100)	23% (10)
Low-frequency pseudohomophones	870 (122)	18% (11)
Low-frequency pseudowords	818 (112)	2% (3)

Note. Reaction times and error percentages for each condition (standard deviations in parentheses).

4. Discussion and conclusions

We investigated whether there are individual differences in general phonological processing that affect lexical access in a sample of normal adult readers. To achieve this aim, we studied the relationship between a perceptual variable, CP, and the use of phonological information during lexical access measured using a pseudohomophone task. Thus, we complemented previous work that associated a pseudohomophone effect with a non-word naming task as a measure of subject phonological skills (Holyk & Pexman, 2004). In contrast to previous work, given that our experiment associates a perceptual variable with a reading variable, the results obtained might be reflecting a more general phonological processing underlying at least the process of reading and CP. Moreover, consistent with the study by Cuetos and Domínguez (2002), we manipulated the lexical frequency of the words, pseudowords and pseudohomophones used in the lexical decision task.

We found that CP had a clear influence on phonological information processing in reading, especially in the case of high-frequency pseudohomophones. Thus, even in good adult readers, the use of phonological information during reading is subject to variations regarding individual differences in CP.

It is important to explain how CP exerts its influence on the lexical access process. In adults, actual performance in reading is the result of a learning process that begins very early in childhood. Once reading skills become consolidated, there is a wide agreement in the literature that representational systems of graphemes and phonemes are closely related (Harm et al., 2003). It seems reasonable that the formation of grapheme-phoneme representations were deeply influenced by CP level. Thus, if we consider general phonology processing as a quantitative dimension, then, without reach the serious consequences that underlie dyslexia, small differences in the quality of phonological representations could affect the componential nature of the letter-sound mappings. Thus, people with better phonological efficiency could build up componential representations richer in the use of phonological information than less efficient people, and this might explain the differences detected in the present experiment.

Another interesting question is why CP had a greater impact on high-frequency stimuli. A frequent word is more strongly activated, or more difficult to inhibit, than a less frequent word. Thus, it seems possible that the individual differences in the pseudohomophone effect were only detected with the high-frequency stimulus simply because with this set of stimuli the pseudohomophone effect tends to be larger (in fact, we obtain a trend to the interaction between Lexical

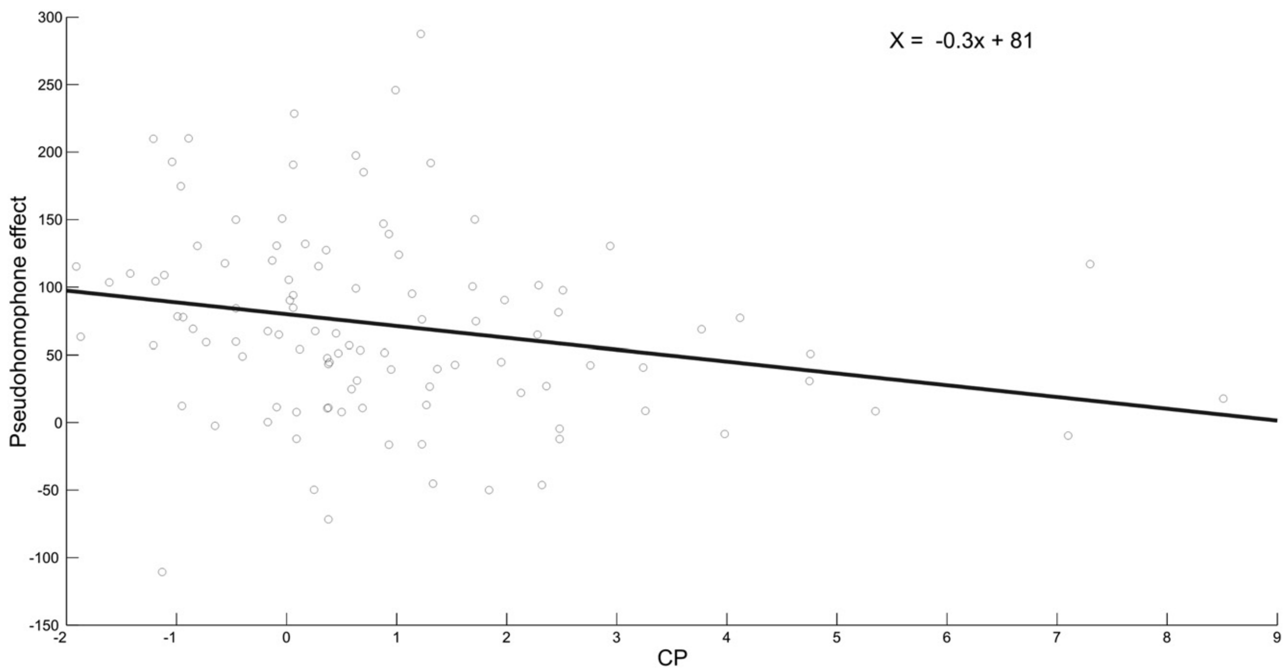

Fig. 1. Linear regression of the pseudohomophone effect's magnitude on the categorical perception (CP) variable.

Frequency and Homophony variables. This interaction reaches significant levels in the F1 analysis, that is favourable to the idea that pseudohomophone effect is larger in high frequency than low-frequency stimulus). Thus, the pseudohomophone effect may require a minimum threshold for the differences due to CP to become detectable, and this threshold is reached only in high-frequency conditions.

In conclusion, we show that perceptual variables such as CP can affect the use of phonological codes in reading even in normal adult readers. More research is needed on the possible consequences of this interaction and to explore the relationship between these results, which were obtained in normal adult readers, and reading disorders such as dyslexia.

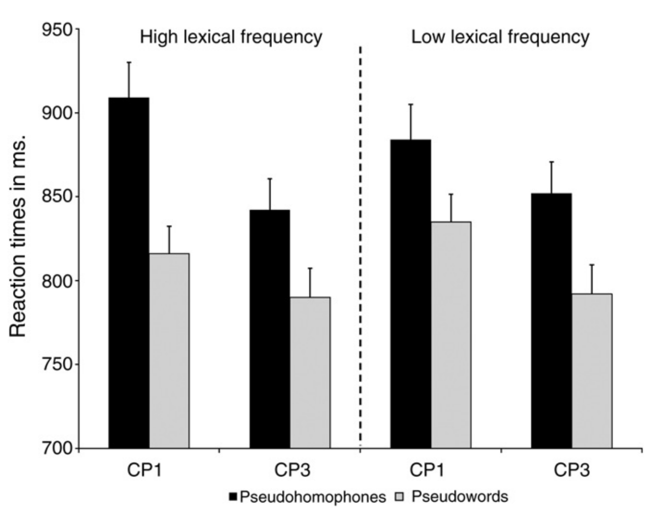

Fig. 2. Mean reaction time of each condition in the CP1 and CP3 groups.

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Appendix A

High Lexical Frequency stimuli (italic letters are the letters that become real words in pseudowords and pseudohomophones).

Words	Pseudowords	Pseudohomophones
Fino	*k*era	*z*era
Gota	*b*ifra	*z*ifra
Humo	su*y*ia	su*z*ia
Lujo	vo*v*es	vo*z*es
Meta	*ll*ita	*z*ita
Moda	na*k*e	na*b*e
Nota	nu*k*e	nu*v*e
Paro	*z*aso	*b*aso
Piso	*k*ela	*b*ela
Pozo	su*y*e	su*v*e
Puro	*y*ola	*k*ola
Raro	*b*opa	*k*opa
Ruta	*z*uba	*k*uba
Sopa	*y*ura	*k*ura
Taza	lo*z*o	lo*k*o
Tela	fa*b*o	fa*y*o
Tenis	*v*ave	*y*ave
Techo	si*k*a	si*y*a
Subir	vi*z*a	vi*y*a
Sodio	ra*z*o	ra*ll*o

Low Lexical Frequency stimuli (italic letters are the letters that become real words in pseudowords and pseudohomophones).

Words	Pseudowords	Pseudohomophones
Sepia	*z*ate	*v*ate
Setas	*k*olo	*v*olo
Sifón	*ll*ado	*b*ado
Sigla	*k*iga	*b*iga
Sosas	*ll*ilo	*b*ilo
Gafe	*z*ava	*k*ava
Higo	*b*opo	*k*opo
Maga	cu*z*o	cu*k*o
Mota	*b*uña	*k*uña
Mulo	ja*ll*a	ja*k*a
Peto	*k*eba	*z*eba
Pijo	*v*epa	*z*epa
Pomo	*b*etro	*z*etro
Rizo	*ll*irio	*z*irio
Romo	go*ll*es	go*z*es
Ruge	*z*ugo	*ll*ugo
Seso	ho*v*a	ho*ll*a
Tejo	*k*ogur	*ll*ogur
Tila	*k*acer	*ll*acer
Tina	sa*z*o	sa*ll*o

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