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How do Scrabble players encode letter position during reading?

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Abstract

Background: A number of experiments with skilled adult readers have shown that a transposed-letter pseudoword (e.g., CHOLOCATE) is considerably more word-like than a control replacement-letter pseudoword (e.g., CHOTONATE). For instance, in lexical decision, response times are longer and less accurate for CHOLOCATE than for CHOTONATE (i.e., a transposed-letter effect). **Method:** Here, we examined how letter position coding is attained in individuals who excel in orthographic-lexical processing: competitive Scrabble players. To this end, we conducted a lexical decision experiment with two types of pseudowords (transposed-letter vs. replacement-letter pseudowords). **Results:** Data showed that while the transposed-letter effect does occur in expert Scrabble players, the magnitude of the effect is dramatically smaller than in a control group of university students—in particular, for the accuracy data. **Conclusions:** The parameters responsible for the flexibility of letter position coding in models of visual word recognition must be modulated by the degree of expertise in orthographic-lexical processing.

Keywords: Visual-word recognition, letter-position coding, reading, expertise, individual differences.

Resumen

¿Cómo codifican los jugadores de Scrabble la posición de las letras durante la lectura? **Antecedentes:** en experimentos con lectores adultos, las pseudopalabras creadas por transposición de letras (v.g., CHOLOCATE) se confunden frecuentemente con su palabra base. Por ejemplo, en tareas de decisión léxica ("¿es el estímulo una palabra?"), los tiempos de respuesta son mayores y con mayor porcentaje de errores para CHOLOCATE que para su control ortográfico CHOTONATE (es decir, un efecto de transposición de letras). **Método:** en el presente experimento examinamos los procesos de codificación de la posición de las letras en individuos particularmente expertos en el procesamiento ortográfico-léxico: jugadores de Scrabble de competición. Para ello, se realizó un experimento de decisión léxica con dos tipos de pseudopalabras (vía transposición de letras [CHOLOCATE] vs. vía sustitución de letras [CHOTONATE]). **Resultados:** si bien los jugadores expertos de Scrabble muestran un efecto de transposición de letras, la magnitud del efecto es mucho menor que en estudiantes universitarios no entrenados a Scrabble, en particular para los datos de precisión. **Conclusiones:** en los modelos de reconocimiento visual de palabras, la flexibilidad en la codificación de la posición de las letras en palabras debe ser modulada por la destreza en el procesamiento ortográfico-léxico.

Palabras clave: reconocimiento de palabras, codificación de letras, lectura, expertos, diferencias individuales.

A central issue in cognitive psychology and cognitive neuroscience is how expertise modulates the manner in which we process information (e.g., see Bilalić, Langner, Erb, & Grodd, 2010; Dehaene & Cohen, 2007). Here, we focus on how expertise in Scrabble, a popular word game, modulates the processes underlying visual word recognition. In each turn of a Scrabble game, players have to combine up to seven single-letter tiles—each letter has a point value that is higher for less common letters— to form a word within a 15x15 crossword grid square according to a number of rules. The player's score for each turn is the sum of the values of the letters that compose the word. Some of these squares are "premium" (i.e., some multiply the value of the letter, and some of the word, by two or three). Undoubtedly, playing Scrabble at a competitive level involves a series of complex cognitive skills: visuospatial processing, orthographic-lexical processing, numerical processing, and strategic thinking (e.g., see Halpern & Wai, 2007).

Research on how competitive Scrabble players identify written words is very scarce. Hargreaves, Pexman, Zdrazilova, and Sargious (2012) found that a semantic effect, namely, the concreteness effect (i.e., responses are faster for concrete than for abstract words) is smaller in competitive Scrabble players than in a control group composed of university students (or age-matched controls). Because Scrabble requires deciding on the legality of the letter string (word/nonword) rather than on meaning, expert Scrabble players seem to rely more on orthographic than on semantic information. Indeed, it is not uncommon to find Scrabble players who win tournaments in languages in which they are not fully fluent. In a recent fMRI study using a lexical decision task, Protzner et al. (2015) found that, when compared to a control group, Scrabble players showed more activation of brain areas associated with working memory and visual perception. In addition, Scrabble players also showed more activation in a brain area that has frequently been associated with the processing of letters—the

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fusiform gyrus (see Carreiras, Armstrong, Perea, & Frost, 2014, for a review of neural models of visual word recognition).

One of the most salient abilities of expert Scrabble players is their exceptional ability to combine letters in different orderings to form words (i.e., their abilities to solve anagrams). This suggests that competitive Scrabble players might encode the positions of letters in strings differently from the rest of us. In the present experiment, we examined how competitive Scrabble players encode letter position in the most popular visual word recognition task: lexical decision ("is the stimulus a word or not?"). The issue of how letter position is encoded during visual word recognition and reading in skilled and developing readers has received a great deal of attention in recent years (see Frost, 2012, for review). A number of experiments have shown that a jumbled-letter nonword such as CHOLOCATE can be easily confused with its base word: CHOCOLATE. Indeed, a well-replicated finding across various tasks (e.g., lexical decision, naming, semantic categorization, sentence reading) is that a transposed-letter pseudoword such as CHOLOCATE produces longer response times and more errors than a replacement-letter pseudoword such as CHOTONATE (e.g., lexical decision: Perea & Lupker, 2004; naming: Perea & Estévez, 2008; sentence reading: Rayner, White, Johnson, & Liversedge 2005; semantic categorization: Taft & van Graan, 1998). The transposed-letter effect (i.e., the difference in performance between a transposed-letter pseudoword and a replacement-letter pseudoword) occurs in the Roman script (e.g., Spanish: Perea & Lupker, 2004; English: Lupker, Perea, & Davis, 2008; French: Schoonbaert & Grainger, 2004; Basque: Perea & Carreiras, 2006), and it also occurs in other scripts (e.g., Arabic: Perea, Carreiras, & Abu Mallouh, 2010; Japanese Kana: Perea & Pérez, 2009; Thai: Perea, Winskel, & Ratitamkul, 2012; Chinese: Gu & Liu, 2015; Hebrew: Velan & Frost, 2011).

The robustness and generality of the transposed-letter effect rules out the slot-coding orthographic coding schemes that assume that each letter is associated with just one position early in processing (e.g., interactive activation model, McClelland & Rumelhart, 1981; multiple read-out model, Grainger & Jacobs, 1996; dual-route cascaded model, Coltheart, Rastle, Perry, Langdon, & Ziegler 2001). Therefore, the majority of the models of visual word recognition that have been proposed in the past two decades employ more flexible orthographic coding schemes. These coding schemes fall into two basic categories: (a) those models that assume that there is perceptual uncertainty at assigning letters to positions (e.g., the letter L in CHOLOCATE would activate not only the fourth letter position but also, to a lesser degree, other neighboring positions; overlap model, Gómez, Perea, & Ratcliff, 2008; LTRS model, Adelman, 2011; spatial coding model, Davis, 2009; noisy Bayesian reader model, Norris, Kinoshita, & van Casteren, 2011); and (b) those models that assume that letter order is encoded via "open bigrams", which is a level of representation that lies between the letter level and the word level (e.g., CHOLOCATE and CHOCOLATE would share nearly all the "open bigrams" generated by the two stimuli, CH, CO; CL, etc.; open-bigram model, Grainger & van Heuven 2003; SERIOL model, Whitney, 2001).

In the present lexical decision experiment, competitive Scrabble players were presented not only with words, but also with two types of pseudowords: transposed-letter pseudowords (e.g., CHOLOCATE) and replacement-letter pseudowords (e.g., CHOTONATE). In this task, the more word-like the pseudoword is, the longer the correct response times and the higher the error rates (see Perea & Lupker, 2004, for discussion). We also manipulated a second factor, the consonant/vowel status of the transposed/replaced letters. Previous research has found that the size of the transposed-letter effect is greater for consonant transpositions than for vowel transpositions, in particular for the accuracy data (Carreiras, Perea, & Vergara, 2007; Lupker, Perea, & Davis, 2008; Perea & Lupker, 2004). In the current experiment, we employed exactly the same design, stimuli, and procedure as in the "transposed-letter" experiment conducted by Carreiras et al. (2007). This allowed us not only to conduct statistical analyses on the data from competitive Scrabble players, but also to conduct a combined analysis with Group (competitive Scrabble players, non-experts) as a between-subjects factor (i.e., we had a baseline criterion: the non-experts). Unlike the Hargreaves et al. (2012) and Protzner et al. (2015) studies, in which the mean age of the Scrabble players was around 60 years, none of the participants in the current experiment was more than 46 years old. This makes our scenario more comparable to the individuals who participated in the Carreiras et al. (2007) experiment (24 university students with no reported practice of Scrabble; M_{age} = 23.5 years). One might argue that the best strategy when designing a control group is to find perfectly age-matched control individuals who only differ in some abilities related to anagramming. However, we must keep in mind that—leaving aside IQ—many competitive Scrabble players excel in other cognitive abilities, so that the recruitment of perfectly age-matched control participants may be a Herculean task that is not exempt from potential criticisms (see Erickson, 2014, for discussion of the issues related to expert vs. normal performance). Furthermore, we should stress that the aim of our baseline group is more modest: we want to have an estimation of the magnitude of the transposed-letter effect in adult skilled readers obtained in a study that used the same design, stimuli, and procedure as the current experiment.

In sum, the present experiment examined whether the substantial expertise at disentangling letter identity and letter position that is required in competitive Scrabble produces a more accurate encoding of letter position during lexical access (i.e., a "lexical tuning" in the orthographic-lexical network; see Castles, Davis, Cavalot, & Forster, 2007; Castles, Davis, & Forster, 2003). In particular, in a developmental study, Castles et al. (2003) found that the magnitude of transposed-letter effects was greater for third graders than for fifth graders or adult readers (see also Acha & Perea, 2008; Perea & Estévez, 2009, for converging evidence in Spanish). Castles et al. (2007) concluded that their data were consistent with "a conceptualization of orthographic development as proceeding from a broadly tuned mechanism to a very precisely tuned mechanism" (pp. 180-181) that would depend on age and reading expertise. If this were so, one would expect that the transposed-letter effect would be greatly diminished in competitive Scrabble players when compared with non-experts. In addition, the use of consonant versus vowel transposition allows us to examine whether letter position coding in individuals with excellent skills in orthographic-lexical processing is modulated by a phonological factor: the consonant/vowel status of the letters.

Method

Participants

Twelve competitive Scrabble players (5 female) were recruited at a national Scrabble tournament in Spain. They took part in the experiment voluntarily. All of them reported playing Scrabble regularly for more than 8 years, and all of them were ELO-rated competitors who frequently participated in local and in national Scrabble tournaments. They were native speakers of Spanish and had normal or corrected-to-normal vision. None of the participants was older than 46 years. For comparison purposes, we also included the data from a non-expert group composed of 24 university students (M_{age} = 23.5 years) with no reported practice of Scrabble—these non-expert data were taken from the lexical decision experiment conducted by Carreiras et al. (2007).

Instruments

To present the stimuli and record the latency/accuracy responses, we employed DMDX software (Forster & Forster, 2003) in a Windows-OS computer. We employed the same set of stimuli as the Carreiras et al. (2007) experiment (240 words and 240 pseudowords). The base words for the pseudowords were 240 Spanish words between 7 and 11 letters (average 8.9 letters; see Carreiras et al., 2007, for further details). For each base word (e.g., CHOCOLATE), there were four pseudowords as a function of type of pseudoword (transposed-letter vs. replaced-letter) and type of transposition/replacement (consonants vs. vowels): 1) a pseudoword created by transposing two internal nonadjacent consonants (CHOLOCATE); 2) a pseudoword created by transposing two internal nonadjacent vowels (CHOCALOTE); 3) a pseudoword created by replacing two internal nonadjacent consonants (CHOTONATE); and 4) a pseudoword created by replacing two internal nonadjacent vowels (CHOCULITE). We created four counterbalanced lists in a Latin square manner, so that if CHOLOCATE were in list 1, CHOCALOTE would be in list 2, CHOTONATE in list 3, and CHOCULITE in list 4. Each list contained 60 pseudowords in each of the four conditions. For the purposes of the lexical decision task, we also selected a set of 240 words of similar length and word-frequency to the ones that were used to create pseudowords (see Carreiras et al., 2007).

Procedure

The experiment was conducted individually in a room adjacent to the game room of a national Scrabble tournament. In each trial, there was a fixation point (+) for 500 ms. This was immediately replaced by an uppercase target item, which remained on the computer screen for 400 ms (i.e., as in the Carreiras et al., 2007, experiment). Participants were instructed to decide, as rapidly and as accurately as possible, whether the target item formed a word in Spanish or not. There was a practice phase with 16 trials (8 words and 8 pseudowords) of the same characteristics as the experimental trials. The entire session lasted between 15 to 20 minutes.

Data analysis

To examine how letter position is encoded in expert Scrabble players, we conducted Analyses of Variance (ANOVAs) based both on participant ($F1$) and item ($F2$) mean lexical decision times and error rates to pseudowords using a 2 (Type of pseudoword: transposition-letter pseudoword, replacement-letter pseudoword) × 2 (Type of transposition/replacement: consonants, vowels) repeated measures design. List (list 1, list 2, list 3, list 4) was also included in the ANOVAs as a dummy factor to remove the error variance due to the counterbalanced lists. We also conducted additional analyses to compare the group of Scrabble players versus the control group. This involved adding Group as a factor in the ANOVAs (i.e., a between-subject factor in the by-subjects ANOVAs and a repeated measures factor in the by-items ANOVAs).

Results

Error responses (3.0% for pseudowords) and lexical decision times beyond the 300-1500 ms cutoffs (4.9% for pseudowords) were excluded from the response time data. These were the same criteria as in the Carreiras et al. (2007) experiment—the cutoffs in the Carreiras et al. experiment removed 3.9% of the correct lexical decision data for pseudowords. The mean lexical decision times for correct responses and percent error of pseudowords in the current experiment as well as the data from the control group (i.e., the data from the Carreiras et al., 2007, experiment) are shown in Table 1.

Competitive Scrabble players

The ANOVAs on the latency data showed that the mean lexical decision times were longer for transposed-letter pseudowords than for replacement-letter pseudowords, $F1(1, 8) = 58.74$, $p<.001$; $F2(1, 231) = 45.61$, $p<.001$. (Five of the cells had missing response time [RT] data, and this is why the degrees of freedom in the denominator of the $F2$ analyses were 231 and not 236.) The main effect of consonant/vowel status was not significant, both Fs < 1. The interaction between the two factors was not significant, $F1(1, 8) = 2.51$, $p = .150$; $F2(1, 231) = 3.57$, $p = .060$—note that the mean RTs for consonant transposed-letter pseudowords and vowel transposed-letter pseudowords were very similar (908 vs. 902 ms, respectively).

The ANOVAs on the error data showed that participants committed more errors to transposed-letter pseudowords than to replacement-letter pseudowords, $F1(1, 8) = 40.01$, $p<.001$; $F2(1, 136) = 31.97$, $p<.001$, and that participants made more errors to the pseudowords created by transposing/replacing two consonants than to the pseudowords created by transposing/replaced two

Table 1
Mean lexical decision times (in ms) and percentage of errors (in parentheses) for pseudowords and words in the experiment

	Type of pseudoword		
	Replacement-Letter	**Transposed-letter**	**Transposed-letter effect**
Scrabble players			
Consonant Transp./Repl.	819 (0.8)	908 (7.8)	89 (7.0)
Vowel Transp./Repl.	836 (1.1)	902 (2.4)	62 (1.3)
Control group			
Consonant Transp./Repl.	917 (6.7)	1041 (30.4)	124 (23.7)
Vowel Transp./Repl.	911 (6.0)	1022 (18.7)	111 (12.7)

Note: For the Scrabble group, the average correct lexical decision time on words was 817 ms and the percentage of errors was 1.0%. For the control group, the average correct lexical decision time on words was 834 ms and the percentage of errors was 4.2%. The data from the control group were taken from Carreiras et al. (2007)

vowels, $F1(1, 8) = 11.90$, $p<.001$; $F2(1, 236)= 14.72$, $p<.001$. More importantly, the interaction between the two factors was significant, $F1(1, 8) = 20.75$, $p<.001$; $F2(1, 236) = 19.19$, $p<.001$. This reflected that the transposed-letter effect was greater for consonant transpositions (7.8%; $F1(1, 8) = 32.05$, $p<.001$; $F2(1, 236) = 36.05$, $p<.001$) than for vowel transpositions (2.4%; $F1(1, 8) = 13.50$, $p = .006$; $F2(1, 236) = 2.80$, $p = .095$).

Combined analyses (Scrabble players vs. non-experts)

The ANOVA on the latency data revealed that, on average, competitive Scrabble players were, on average, 106 ms faster in responding than the non-experts, although the difference only reached statistical significance in the by-items analyses, $F1(1, 28) = 3.50$, $p = .072$; $F2(1, 226) = 294.32$, $p<.001$. (Ten of the cells had missing latency data, and that is why the degrees of freedom in the denominator are 226 instead of 236 in the RT analyses.) In addition, responses to transposed-letter pseudowords were longer than the responses to replacement-letter pseudowords, $F1(1, 28) = 233.01$, $p<.001$; $F2(1, 226) = 269.56$, $p<.001$. More important, the magnitude of the transposed-letter effect was greater in the control group than in the Scrabble group, as deduced from the Group × Type of pseudoword interaction, $F1(1, 28) = 10.44$, $p = .001$; $F2(1, 226) = 7.98$, $p = .005$. None of the other effects was significant.

The ANOVA on the error data showed that Scrabble players committed fewer errors than the individuals in the control group, $F1(1, 28) = 25.56$, $p<.001$; $F2(1, 236) = 302.87$, $p<.001$. In addition, participants made more errors to pseudoword created by consonant transpositions/replacements than to pseudowords created by vowel transpositions/replacements, $F1(1, 28) = 29.62$, $p<.001$; $F2(1, 236) = 45.57$, $p<.001$, and participants made more errors to transposed-letter pseudowords than to replacement-letter pseudowords, $F1(1, 28) = 56.66$, $p < .001$; $F2(1, 236) = 251.76$, $p<.001$. These two main effects need to be explained in light of the Type of pseudoword × Consonant/vowel status interaction, $F1(1, 28) = 35.01$, $p<.001$; $F2(1, 236) = 54.49$, $p<.001$: participants committed substantially more errors to transposed-letter pseudowords created by consonant transpositions than to the transposed-letter pseudowords created by vowel transpositions. We also found a Type of pseudoword × Group interaction, $F1(1, 28) = 23.83$, $p<.001$; $F2(1, 236) = 99.89$, $p<.001$: this reflected that the transposed-letter effect was greater for the individuals in the control group than for the competitive Scrabble players (118 vs. 75 ms, respectively). Finally, the three-way interaction between Group, Type of pseudoword and Consonant/vowel status was significant in the analysis by items, and approached significance in the analyses by participants, $F1(1, 28) = 2.91$, $p = .09$; $F2(1, 236) = 4.51$, $p<.001$: this interaction reflected a floor effect in the error rates for Scrabble players.

Discussion

The goal of the present lexical decision experiment was to examine how competitive Scrabble players encode letter position during reading. Although the sample size was relatively small due to restriction of recruiting highly competitive Scrabble players ($N = 12$), the number of items per condition was elevated (120 transposed-letter pseudowords [e.g., CHOLOCATE]; 120 replacement-letter pseudowords [e.g., CHOTONATE]), thus producing stable patterns in the behavioral data. Results showed that whereas the transposed-letter effect does occur in competitive Scrabble players (e.g., CHOLOCATE produced longer response times and more errors than CHOTONATE), its magnitude was dramatically smaller than in a control group of university students—in particular for the error data. Notably, competitive Scrabble players were able to keep a low error rate even when responding to word-like transposed-letter pseudowords (consonant transpositions: 7.8% of errors; vowel transpositions: 2.4% of errors). In contrast, the control group had a much higher error rate (30.4% vs. 18.8%, for consonant and vowel transpositions, respectively); similarly, in the Perea and Lupker (2004) experiment, also with college student participants, the error rates were 43.5% vs. 24.4% for consonant and vowel transpositions, respectively. Taken together, the present set of data is fully consistent with a "lexical tuning" account (see Castles et al., 2003, 2007) in which greater expertise in the orthographic-lexical components of visual-word recognition is associated with more precisely tuned mechanisms of letter identity/position. What we should stress here is that the higher accuracy level by Scrabble players was not accompanied by slower responses. Instead, correct lexical decision times on pseudowords were faster in competitive Scrabble players than in non-experts (the mean RTs were 834 vs. 873 ms, respectively). Therefore, it is not that Scrabble players are more cautious in their responses; instead, they are more efficient at processing orthographic-lexical information in a lexical decision task. Consistent with this interpretation, responses to words were also less error-prone (and slightly faster) in Scrabble players than in the non-experts (error rates: 1.0% vs. 4.2% of errors, respectively; mean RTs: 817 vs. 834 ms, respectively). These findings suggest that the "quality of information" entering the decision process in the lexical decision task is higher for Scrabble players than for non-experts (see Ratcliff, Gómez, & McKoon, 2004, for modeling and empirical evidence of the diffusion model in the lexical decision task).

A second aim of the experiment was to examine the differences in letter position coding between consonants and vowels in Scrabble players. In the error rates, consonant transpositions produced a larger transposed-letter effect than vowel transpositions (7.0% vs. 1.3%, respectively). Although the magnitude of the effect in the error rates is smaller than in previous research with non-Scrabble players, the pattern is quantitative but not qualitatively different (i.e., pseudowords created by transposing two consonants are more word-like than the pseudowords created by transposing two vowels). With respect to the mean RTs, the transposed-letter effect was numerically larger for consonant than for vowel transpositions (89 vs. 62 ms, respectively). However, as occurred in the Perea and Lupker (2004) experiment or in the Carreiras et al. (2007) experiment, the critical interaction in the latency data was not significant. Taken together, we failed to obtain any signs of a qualitative difference between competitive Scrabble players and non-experts when encoding letter position of vowels and consonants. One could speculate that this might be related to the fact that vowel/consonant status is a phonological factor that plays no role in the game of Scrabble.

While the current experiment was not designed to test "perceptual uncertainty" versus "open bigram" accounts of letter position coding, our findings have relevant implications for models of visual word recognition. To account for the present data, "perceptual uncertainty" models such as the overlap model (Gómez et al., 2008) would use its assumption that the degree of positional noise associated with each position (*s* parameter in the model) is not fixed; in this case, it seems to be modulated by factors related to lexical quality (see Andrews & Lo, 2012; see also Castles et al., 2007). That is, more skilled readers have "developed more precisely specified orthographic representations" than less skilled readers (Andrews & Lo, 2012, p. 152; see also Castles et al., 2007). We acknowledge that it would have been desirable to obtain some additional measures of written language proficiency to examine this issue at greater depth. For the overlap model to accommodate the present data, the value of the *s* parameter in competitive Scrabble players would need to be smaller than in control individuals. As a result, the letter "D" in the transposed-letter pseudoword JUGDE would only activate the neighboring positions only to a small degree—to a lower level than control individuals—and they would produce less activation in the word unit corresponding to JUDGE in the mental lexicon, and consequently fewer chances of a "word" response. Indeed, a similar reasoning was employed by Gómez et al. (2008) to explain why the magnitude of the transposed-letter effect varies with age in developing readers (e.g., see Acha & Perea, 2008; Castles et al., 2003, 2007; Perea & Estévez, 2008). An important issue for future research is to examine in detail how reading skills modulate the processes underlying letter identity and letter position by using a larger (and more constraining) number of conditions, similarly to the Gomez et al. (2008) experiments. Analogously, the family of "open bigram" models could use its current assumptions to account for the present data. A possible mechanism comes to mind: given that Scrabble players use the individual letters in the game, perhaps they rely less on "open bigrams" (and even less on the bigrams of distant letters like [HE] in CHOCOLATE) and hence, the weights between the bigram units and the lexical entry might change.

In summary, the present experiment demonstrated that, consistent with a "lexical tuning" account, substantial expertise in a crossword game that focuses on orthographic-lexical processing (i.e., competitive Scrabble players) leads to a noticeably smaller transposed-letter effect when compared to non-experts. This implies that the parameters responsible for the flexibility in the orthographic coding schemes (e.g., s parameter in the overlap model; σ parameter in the spatial coding model) are not fixed, but modulated by expertise. More research is necessary to examine in greater detail how the participants' abilities, on the basis of standardized reading tests, modulate the process of letter identity/position coding during visual word recognition in developing and adult readers. In particular, from a developmental perspective, it may be important to directly compare the process of letter position coding (e.g., via transposed-letter effects) in a group of children who are trained in Scrabble versus a control group of children who are not trained in Scrabble—note that a "lexical tuning" account would predict smaller transposed-letter effects for the children who were trained in Scrabble.

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