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Is VIRTU4L Larger Than VIR7UAL? Automatic Processing of Number Quantity and Lexical Representations in Leet Words

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Recent research has shown that leet words (i.e., words in which some of the letters are replaced by visually similar digits; e.g., VIRTU4L) can be processed as their base words without much cost. However, it remains unclear whether the digits inserted in leet words are simply processed as letters or whether they are simultaneously processed as numbers (i.e., in terms of access to their quantity representation). To address this question, we conducted 2 experiments that examined the size congruity effect (i.e., when comparisons of the physical size of numbers are affected by their numerical magnitudes) in a physical-size judgment task. Participants were presented with pairs of leet words that were nominally identical except for the embedded digit (e.g., VIR7UAL-VIRTU4L) and were asked to decide as quickly and accurately as possible which word in the pair appeared in a bigger font. In Experiment 1, we examined the congruity effect (congruent: VIRTU4L-VIR7UAL vs. incongruent: VIR7UAL-VIRTU4L vs. neutral: VIR7UAL-VIR7UAL) and the numerical distance effect (distance 1: PAN3L-P4NEL vs. distance 3: VIRTU4L-VIR7UAL). To examine whether the meaning of these words was accessed, we also manipulated word frequency (i.e., a marker of lexical access) in Experiment 2. Results revealed effects of congruity, distance, and word frequency, thus suggesting automatic access to both number quantity and word representations for leet words. These findings favor multidimensional accounts of number/word recognition.

Keywords: leet words, automatic processing, quantity representations, lexical representations, numerical Stroop task

A number of experiments have shown that words in which one or more of their letters are replaced by visually similar digits (e.g., 3 = E, as in the leet word NUMB3R) are processed as their base words without much difficulty. In the initial demonstration of the effect, Perea, Duñabeitia, and Carreiras (2008) found that a brief and masked presentation of a leet word (e.g., M4T3RI4L) was as nearly as effective as the identity prime (MATERIAL), and substantially more effective than a control prime (e.g., M6T2R76L or MOTURUOL; see also Duñabeitia, Perea, & Carreiras, 2009; Kinoshita & Lagoutaris, 2010; Kinoshita, Robidoux, Mills, & Norris, 2014; Lien, Allen, & Martin, 2014; Molinaro, Duñabeitia, Marín-Gutiérrez, & Carreiras, 2010; Perea, Duñabeitia, Pollatsek, & Carreiras, 2009, for converging behavioral/ERP evidence). The usual interpretation of this phenomenon is that the cognitive system tolerates some degree of "noise" in the initial formation of the orthographic code, possibly via top-down feedback from higher levels of processing (see Carreiras, Armstrong, Perea, & Frost, 2014, for a recent discussion of neurally inspired models of visual-word recognition; see also Kinoshita et al., 2014, for a Bayesian account that does not require top-down feedback). That is, there would be some digit-to-letter regularization processes in the early stages of word processing so that the leet words have automatic access to the lexical and semantic representations of their base words (Carreiras, Duñabeitia, & Perea, 2007; Kinoshita et al., 2014; Lien et al., 2014; Perea et al., 2008).

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An important and unanswered question is whether the digits inserted in leet words are simply normalized and then processed as letters, or alternatively, these digits also have the ability to be processed as numbers (i.e., whether their quantity representation is actually accessed). Indeed, Perea et al. (2008) suggested that "it may be the case that the numeric value of the leet digits was never accessed and that this particular item property was irrelevant" (p. 240), but this was not actually tested in their experiments. The present study was aimed to answer this question. In particular, the main aim of the current experiments was to examine whether there is an automatic activation of digits embedded in leet words. What we should note here is that we consider that a process is automatic when it is carried out to completion without monitoring (see Tzelgov, 1997, also Tzelgov & Ganor-Stern, 2005). Under this view, the Stroop effect is considered a paradigmatic marker of automaticity because the meaning of color words is accessed despite the fact that reading is not a task requirement—indeed, it causes a decrease in performance relative to noncolor words. Thus, to explore whether digits inserted in leet words are automatically processed, we employed a variant of the numerical Stroop task. Participants were presented simultaneously with pairs of leet words extracted from the same base word and were asked to decide, as quickly and accurately as possible, which pair member was presented in a larger font size. Words in larger font size could be presented in a congruent or in an incongruent manner with respect to the digit embedded in the leet words (e.g., VIRTU4L-VIR7UAL vs. VIR7UAL-VIRTU4L, respectively). A congruity effect (i.e., faster response times, RTs, to VIRTU4L-VIR7UAL than to VIR7UAL-VIRTU4L) would constitute strong evidence of automatic processing of leet digits embedded in words because it would not only show that digits are processed as numerical quantities, but also the incapacity of the cognitive system to ignore attributes of the stimuli that are not relevant for the task at hand (i.e., the quantities represented by the digits in leet words). But before describing the current experiments in detail, we now briefly review the literature on automaticity in number processing.

The literature on numerical cognition does suggest that the mere presentation of a number seems to be enough to activate its corresponding semantic representation both in numerical and non-numerical tasks (e.g., see Dehaene & Akhavein, 1995; Duncan & McFarland, 1980; Henik & Tzelgov, 1982; Schwarz & Ischebeck, 2003; Tzelgov, Meyer, & Henik, 1992; for a review, see Tzelgov & Ganor-Stern, 2005). The strongest support for automaticity in accessing number magnitude comes from paradigms in which, despite the use of numbers, access to the quantity they represent is not required for the task (Tzelgov & Ganor-Stern, 2005). An example is the physical same-different task. In this task, participants are presented with pairs of single-digit numbers (e.g., 7 9) and have to decide whether the digits presented are perceptually the same or not (e.g., see Dehaene & Akhavein, 1995). The usual finding in these experiments is that responses are slower for close numbers (e.g., 7 9) than for far numbers (e.g., 1 9) (i.e., a numerical distance effect; see Moyer & Landauer, 1967). The numerical distance effect is considered a marker of number processing because the semantic representations of close numbers, such as 7 and 9, overlap more than those of more distant numbers, such as 1 and 9 (Dehaene & Changeux, 1993; Gallistel & Gelman, 1992).

Another excellent paradigm frequently employed to explore the automaticity of number processing is the numerical Stroop task (Besner & Coltheart, 1979; Henik & Tzelgov, 1982). In the variant of the task that is most relevant for our study, participants are presented with two digits, one of which is in a larger font size than the other (e.g., 2 8 or 2 8 or 2 2). Participants are requested to perform a physical size judgment (decide which of the two digits is presented in the larger font size). Despite the fact that the quantities represented by the digits are irrelevant to make the decision, physical judgments are slower and/or more error-prone when the information conveyed by the numbers is incongruent with the information provided by the font sizes (e.g., 2 8) than when it is congruent with the physical information (e.g., 2 8) or even neutral (e.g., 2 2; Choplin & Logan, 2005; Girelli, Lucangeli, & Butterworth, 2000; Henik & Tzelgov, 1982; Pansky & Algom, 1999; Schwarz & Ischebeck, 2003). Furthermore, this (size) congruity effect is typically modulated by the distance between the numeric quantities represented by the digits (e.g., larger congruity effects for 2 8 than for 2 4). While the effect of congruity could be caused by the automatic activation of a quantity representation that would categorize the digits as "small" or "large," the existence of an interaction between congruity and distance provides evidence of access to a more refined numerical representation (e.g., the numbers would be placed on a mental number line; see Tzelgov et al., 1992; see also, Girelli et al., 2000; Szűcs & Soltész, 2007; Tang, Critchley, Glaser, Dolan, & Butterworth, 2006; White, Szűcs, & Soltész, 2011).[1]

It may be important to note here that a recent experiment by Ganushchak, Krott, and Meyer (2010) examined whether number representations were activated when they were embedded in lexicalized shortcuts that were quite familiar to the participants (e.g., 2day, gr8, 4ever, etc.). They employed a parity task with dots (i.e., participants had to decide whether the number of dots presented was even or odd). In their experiment, either the lexicalized shortcut plus the dots were presented simultaneously, or the lexicalized shortcut was presented 250 ms before the dots (i.e., stimulus-onset asynchrony, SOA, of 0 or −250 ms). In the parity task, the digit information from the shortcut could be congruent (e.g., 2day ●●) or incongruent (e.g., 2day ●●●) with the number of dots. As a control, Ganushchak et al. (2010) also included pseudoshortcuts (i.e., shortcuts that do not have a lexical entry, such as 2doy). Their results revealed an interaction between congruency (congruent, incongruent) and type of shortcut (lexicalized shortcut vs. pseudoshortcut). The congruency effect occurred for pseudoshortcuts (2doy ●● around 30 ms faster than 2doy ●●●), but not for lexicalized shortcuts (2day ●● vs. 2day ●●●; a nonsignificant 9 ms difference, p values $>$ .26). The authors concluded that their results "suggest that embedded digits do not add much to the processing effort of shortcuts" (p. 104). However, the story is more complex because a closer look at their data revealed some advantage of the congruent over the incongruent condition when the lexicalized shortcut and the dots were presented simultaneously

[1] What we should note here is that several recent studies, while not denying the automatic access to number representations, have shown that the effects of congruity and numerical distance can be modulated by other factors, such as the characteristics of the task, the amount of practice, or the participants' motivation (e.g., see Cohen, 2009; Defever, Sasanguie, Vandewaetere, & Reynvoet, 2012; Ganushchak et al., 2010; García-Orza, Perea, Mallouh, & Carreiras, 2012; Pansky & Algom, 2002; Wong & Szücs, 2013).

(14 ms, note that since the critical interaction Congruency × Type of shortcut × SOA was not significant, the corresponding *p* value for this comparison was not provided). Thus, the Ganushchak et al. (2010) experiment does not offer unambiguous evidence of whether or not the digits embedded in lexicalized shortcuts can activate number representations.

Therefore, the main goal of the current set of experiments is to examine whether digits embedded in leet words (e.g., VIRTU4L) can be simultaneously processed as numbers and as letters. Importantly, the present data will help refine attentional models that explore the limits of our ability to process multiple representations at once (see Cohen, Konkle, Rhee, Nakayama, & Alvarez, 2014). There are two basic scenarios. On the one hand, as indicated earlier, digits in leet words could be normalized as letters during the early stages of word processing. That is, the digit 4 in VIRTU4L would be processed as the letter A and its numerical quantity would never be accessed (e.g., see Perea et al., 2008). This could be done on the basis of weak inhibitory connections between letters and digits (e.g., spatial coding model, Davis, 2010; see also Kinoshita et al., 2014)—note however that current computational models of visual word recognition do not make any specific claims on how digits are processed. On the other hand, *all* dimensions of the stimuli could be processed at once, and hence the digits embedded in leet words would be processed not only as letters but also as numerical quantities—note that this would strongly suggest that, upon presentation of visual stimuli, there is activation from multiple codes (quantities, lexical representations) in the cognitive system (see Cohen et al., 2014). Clearly, the processing of digits both as part of a leet word and as numbers would pose some problems for those perceptual models that assume that the neuronal representation of one of two possible perceptual interpretations is preferred and the other discarded (e.g., see Klink, van Wezel, & van Ee, 2012).

To tease apart these two explanations, we employed physical-size judgment tasks with leet words. In Experiment 1, participants were presented with pairs of leet words that differed in physical size. We examined the congruity effect (e.g., congruent: VIRTU4L-VIR7UAL vs. incongruent: VIR7UAL-VIRTU4L vs. neutral: VIRTU4L-VIRTU4L) and the numerical distance effect (distance 1: P4NEL-PAN3L; distance 3–4: VIR7UAL-VIRTU4L). To anticipate the findings, we found both a congruity effect and an interaction between congruity and distance with leet words. A potential limitation of Experiment 1 is that it did not include a marker of lexical access (i.e., one might argue that, perhaps, leet words were never processed as lexical units). However, this was alleviated by the presence of a negative relationship between the mean item RT and word frequency (i.e., the strongest predictor of lexical access in all models of visual word recognition; see Carreiras et al., 2014; Norris, 2013, for recent reviews), which suggested that participants were processing the leet words as words. To obtain a firmer conclusion, we designed Experiment 2. Experiment 2 was parallel to Experiment 1 except that we directly manipulated word frequency. That is, the base word of each leet word was a high-frequency word or a low-frequency word. In sum, the conjoint examination of a lexical effect (word frequency) and two numerical effects (congruity and numerical distance) in a physical-size judgment task represents a powerful test not only of the automaticity of number processing and word processing in leet words, but also of the multidimensionality of the access codes of numbers and words upon presentation of a visual stimulus.

Experiment 1: Congruity and Distance

Method

Participants. Thirty-eight undergraduate students participated voluntarily in the experiment. Three participants were discarded for having more than 25% of errors in the task, thus the final sample was composed of 35 individuals (aged between 19 and 55 years; $M_{\text{age}} = 23.50$, $SD = 6.21$; 32 women). All had normal or corrected-to-normal vision, and were naive regarding the purpose of the experiment. None of them reported having problems with numeracy or reading.

Materials. A set of 50 Spanish words of five to nine letters ($M = 6.86$; $SD = 1.08$) was taken from the subtitled-based EsPal database (Duchon, Perea, Sebastián-Gallés, Martí, & Carreiras, 2013) to act as base words in the experiment. The log frequency values ranged between 0.30 and 2.17 per million ($M = 1.06$; $SD = 0.45$). Most words were nouns (84%). All these base words had different letters perceptually similar to leet digits (E = 3, A = 4, S = 5, T = 7). Each base word was converted into two leet words by changing one of the letters (e.g., VIR7UAL and VIRTU4L). In each trial, the word pair was always the same except for the font size (Arial 20-pt and Arial 21-pt) and by the digits included in the leet word (e.g., VIRTU4L-VIR7UAL). The crossing of font size and the difference in numerical value between the numbers included in the leet words created three conditions in the congruity factor: (1) congruent (e.g., VIRTU4L-VIR7UAL); (2) incongruent (e.g., VIRTU4L-VIR7UAL); (3) neutral (e.g., VIRTU4L-VIRTU4L). Furthermore, for the congruent/incongruent pairs, the distance between the digits in the pairs of leet words was also manipulated. Half of the pairs included a distance of 1 (e.g., PAN3L-P4NEL) and the other half included distances of 3 or 4 (e.g., VIRTU4L-VIR7UAL and V3STIDO-VES7IDO, respectively; *vestido* is the Spanish word for dress). The base words employed in the distance-1 and distance 3–4 conditions did not differ in terms of log frequency (distance 1: $M = 1.15$, $SD = 0.54$; distance 3–4: $M = 0.97$, $SD = 0.32$); number of letters (distance 1: $M = 7.08$, $SD = 1.22$; distance 3–4: $M = 6.64$, $SD = 0.91$); number of orthographic neighbors (distance 1: $M = 3.80$, $SD = 3.64$; distance 3–4: $M = 2.69$, $SD = 0.91$); and number of phonological neighbors (distance 1: $M = 6.88$, $SD = 6.29$; distance 3–4: $M = 7.28$, $SD = 5.42$; all p values $> .15$). The stimuli are presented in Appendix A.

Procedure. Participants were tested in a quiet room in small groups of up to 10. They sat in front of a computer monitor located at an approximate distance of 60 cm. Stimuli were presented on a 54.5-cm color monitor running at 60 Hz. Presentation of the stimuli and recording of RTs were controlled by a windows-based computer using E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). Stimuli presentation followed the parameters employed in previous experiments using the numerical Stroop task (e.g., see Kallai & Tzelgov, 2012, for a similar procedure in an experiment using multidigits). Each trial began with a fixation point centered in the computer screen for a random time between 250 and 500 ms to avoid a rhythmic response pattern. Then a pair of leet words was presented in uppercase (in white color on a black background) horizontally aligned, one next to the other (3 cm apart). The smaller word was presented in Arial font 20-pt and the larger word was presented in Arial font 21-pt. We chose a small difference in font so that physical distance would not be too salient. Stimuli stayed on the screen until the participant responded or until 1,500 ms had passed. RTs were measured from target onset until the participant's response. The interval between each trial was 800 ms. In half of the trials, the leet word in larger font appeared on the right side of the screen, and in the other half, it was on the left. Participants were requested to press a right button or a left button, which was the button corresponding to the side of the string in larger font. Instructions emphasized that responses should be made as rapidly and as accurately as possible, and there was no mention of the presence of numerals within the words.

Each of the 50 pairs of leet words was presented 6 times: 3 Congruity conditions (congruent; incongruent; neutral) × 2 Orders (large-small; small-large). Hence, participants were presented with a total of 300 trials. The order of the trials was randomized for each participant. The whole experimental session lasted approximately 25 min.

Design and analyses. Analyses of variance (ANOVAs) were conducted for participants (F_1) and items (F_2) for both the correct response times and error data. We conducted two sets of analyses, one to test the congruity effect and the other to test the interaction between congruity and distance. In the first set of analyses, Congruity (incongruent, congruent, and neutral) was a repeated measures factor in the F_1 and F_2 analyses.[2] In the second set of analyses, the factors were distance between the digits in the pairs (distance 1 vs. distance 3–4) and congruity (congruent vs. incongruent)—note that the neutral condition was not included in the analysis because there is no distance manipulation in this condition (see Kallai & Tzelgov, 2012, for a similar analysis). Congruity was a within-subjects factor in the F_1 and F_2 analyses, whereas distance was a within-subjects factor in the F_1 analysis and a between-items factor in the F_2 analysis. The rationale for this second analysis is that the presence of an interaction between congruity and distance can be considered a stronger evidence of automatic access, as it depends on a more refined number representation (e.g., see Tzelgov et al., 1992). When planned comparisons were conducted, α values were corrected using the Bonferroni adjustment. Partial eta-square values (η^2_p) were reported as measure of effect size. In all the analyses, when the condition of sphericity was not met, the Greenhouse-Geisser correction was applied to correct the degrees of freedom.

Results

RTs smaller than 300 ms or greater than 1,250 ms were discarded from the latency analyses (2.5% of the data). The mean correct RTs and mean proportion of error for each condition from the participant analysis are presented in Table 1.

Effect of congruity. The ANOVAs on mean correct RTs reflected an effect of congruity, $F_1(2, 68) = 10.94$; $p_1 < .001$; $\eta^2_{p1} = .24$; $F_2(2, 98) = 13.55$; $p_2 < .001$; $\eta_{p2} = .22$. Pairwise comparisons (Bonferroni-corrected) revealed faster RTs in the congruent condition (687 ms) than in the incongruent (709 ms; $p_1 < .01$; $p_2 < .001$) and neutral conditions (706 ms; both p values $< .001$). There were no trends of a difference between the incongruent and neutral conditions (both p values $> .99$; see Table 1).

Table 1
Mean RTs and Mean Proportion of Error Responses Considering Both Congruity and Distance in Experiment 1

	Neutral	Congruent	Incongruent
Distance 1			
RT	—	693	708
Errors	—	.08	.13
Distance 3–4			
RT	—	679	710
Errors	—	.07	.17
Total			
RT	706	687	709
Errors	.10	.07	.15

Note. The distance manipulation cannot be applied to the neutral condition.

The analyses on the error rates also revealed a congruity effect, $F_1(2, 68) = 38.98$, $p_1 < .001$, $\eta^2_{p1} = .53$; F_2 (1.57, 76,9) = 37.77, $p_2 < .001$, $\eta^2_{p2} = .43$. Participants committed fewer errors in the congruent condition (7.4%) than in the neutral condition (10%; $p_1 < .05$, $p_2 < .001$), and fewer errors in the neutral condition than in the incongruent condition (14.9%; both p values $< .001$).

Effects of distance and congruity. The ANOVA on the latency data with congruity (congruent vs. incongruent) and distance (distance 1 vs. distance 3–4) showed a main effect of congruity, F_1 (1, 34) = 14.14, $p_1 < .01$, $\eta^2_{p1} = .29$; F_2 (1, 48) = 21.32, $p_2 < .001$, $\eta^2_{p2} = .31$. The main effect of distance was not significant, $F_1(1, 34) = 1.72$, $p_1 = .19$, $\eta^2_{p1} = .05$; $F_2(1, 48) = 1.24$, $p_2 = .27$, $\eta^2_{p2} = .02$. More important, the interaction between these two factors was significant in the analyses by participants, $F_1(1, 34) = 5.52$; $p_1 = .024$; $\eta^2_{p1} = .14$; F_2 (1, 34) = 2.19; $p_2 = .14$; $\eta^2_{p2} = .04$. This interaction reflected that the effect of congruity was greater in the distance 3–4 (30 ms; congruent = 679 ms vs. incongruent = 710 ms) than in the distance 1 (15 ms; congruent = 693 ms vs. incongruent = 708 ms)—note that the congruity effect was significant in both cases (p_1 and $p_2 < .001$; $p_1 = .036$, $p_2 = .032$, respectively).

The analyses on the error response rates revealed a main effect of congruity, $F_1(1, 34) = 77.95$, $p_1 < .001$, $\eta^2_{p1} = .69$; $F_2(1, 48) = 58.28$, $p_1 < .001$, $\eta^2_{p1} = .55$, whereas the effect of distance was not significant, F1(1, 34) = 2.47, $p_1 = .12$, $\eta^2_{p1} = .07$; F2(1, 48) = 2.07, $p_2 = .15$, $\eta^2_{p2} = .41$. Importantly, there was a significant interaction between congruity and distance, $F_1(1, 34) = 13.1$, $p_1 < .01$, $\eta^2_{p1} = .28$; $F_2(1, 48) = 7.65$, $p_2 < .01$, $\eta^2_{p2} = .14$. This interaction revealed that the congruity effect was greater in distance 3–4 (.10; congruent = .07 vs. incongruent = .17) than in distance 1 (.05; congruent = .08 vs. incongruent = .13). Again, the congruity effect was present in both distances: distance 1 ($p_1 < .001$, $p_2 < .01$) and distance 3–4 (p_1 and $p_2 < .001$).

[2] We acknowledge that characterizing an effect as inhibitory or facilitative relative to a neutral condition is not free from shortcomings (e.g., the comparisons are not statistically independent). Nonetheless, these comparisons are common in the literature on Stroop (numerical Stroop) effects, as they serve as a stringent test of automaticity (e.g., see MacLeod, 1991; Tzelgov et al., 1992).

Discussion

The results of the present experiment suggest that the digits embedded in leet words are processed as numerical quantities, as deduced from: (1) an effect of congruity (e.g., VIRTU4L-VIR7UAL faster and more accurately than VIR7UAL-VIRTU4L); and (2) an interaction between congruity and numerical distance. The effect of congruity was greater when the numerical distance between the leet digits was large than when it was small (e.g., the congruity effect was greater with VIRTU4L-VIR7UAL than with PAN3L-P4NEL).

Therefore, these data are consistent with the view that there is an automatic processing of numerical value of digits embedded in words, as we found both a congruity effect and an interaction between congruity and numerical distance in a physical-size judgment task in which number processing is irrelevant. However, one could argue that the leet words were not processed as lexical units in this task. To examine whether leet words in a physical-size judgment task are actually processed as words, it is critical to have a marker of lexical access. Because the words spanned quite a large range of frequencies in the present experiment, we conducted a post hoc analysis to examine the relationship between mean item RT and log of word frequency (i.e., the stronger predictor of lexical access in models of visual word recognition) while the influence of number of letters was partialed out. Results showed an inverse relationship between the mean item RT and the log of word frequency, $r = -.32$ $p = .025$. Even though post hoc analyses must be taken with some caution, these data suggest that participants were accessing the lexical representations of the leet words. However, a much stronger test would be to test the effect of word frequency in a physical-judgment task using a classic experimental design. To that end, Experiment 2 was parallel to Experiment 1 except that, in addition to the manipulation of congruity and numerical distance, we added a third factor: word frequency (i.e., the most studied lexical factor). Thus, half of the words were of high frequency, whereas the other half were of low frequency. The predictions are clear. If leet words were encoded in a multidimensional manner, then the digits in leet words would produce not only a congruity effect and an interaction between congruity and numerical distance in a number-like Stroop task, but also a word-frequency effect (i.e., faster RTs for high-frequency than for low-frequency words). Alternatively, if leet words were *not* encoded in a multidimensional manner, one would expect a congruity effect and a Congruity × Distance interaction in a number-like Stroop task, but not a word-frequency effect (i.e., the leet words would not be processed as words). This latter scenario would pose some limits on how different codes (numerical, lexical) are activated upon presentation of a visual input.

Experiment 2: Word Frequency, Number Congruity, and Distance

Method

Participants. Twenty-five undergraduate students aged between 20 and 29 years ($M_{age} = 21.83$, $SD = 5.25$; 20 women) participated voluntarily in this experiment. All had normal or corrected-to-normal vision, and were naive regarding the purpose of the study. None of them reported having problems with numeracy or reading.

Materials. One hundred Spanish words of five to nine letters (94% nouns) were selected from the subtitled-based EsPal database (Duchon et al., 2013). Half of the words were of low frequency (log frequency range: 0.01 to 1.43; $M = 0.69$; $SD = 0.44$), whereas the other half were of high frequency (log frequency range: 1.60 to 2.83; $M = 1.96$; $SD = 0.28$). These sets of words differed significantly in log frequency per million ($p < .001$) but not in number of letters (low frequency: $M = 7.14$, $SD = 1.24$; high frequency: $M = 7.14$, $SD = 1.16$), number of orthographic neighbors (low frequency: $M = 3.74$, $SD = 3.60$; high frequency: $M = 3.74$, $SD = 3.72$) and number of phonological neighbors (low frequency: $M = 6.94$, $SD = 6.32$; high frequency: $M = 7.24$, $SD = 5.84$; all p values $> .40$). As in Experiment 1, the distance between the digits in the leet words of low and high frequencies was manipulated in the congruent and incongruent conditions. Half of the pairs included a distance of 1 (e.g., GEN3RAL-GENER4L) and the other half included distances of 3 or 4 (e.g., RESP3TO-RESPE7O, the Spanish for respect). The low frequency words employed in the distance-1 and distance 3–4 conditions did not differ in terms of log frequency (distance 1: $M = 0.62$, $SD = 0.46$; distance 3–4: $M = 0.77$, $SD = 0.40$); number of letters (distance 1: $M = 7.04$, $SD = 1.24$; distance 3–4: $M = 7.24$, $SD = 1.26$); number of orthographic neighbors (distance 1: $M = 4.44$, $SD = 3.96$; distance 3–4: $M = 3.04$, $SD = 3.39$); and number of phonological neighbors (distance 1: $M = 8.36$, $SD = 7.54$; distance 3–4: $M = 5.52$, $SD = 4.52$; all p values $> .11$). Likewise, the high frequency words employed in the distance 1 and distance 3–4 conditions did not differ in log frequency (distance 1: $M = 1.93$, $SD = 0.29$; distance 3–4: $M = 2.00$, $SD = 0.27$); number of letters (distance 1: $M = 6.96$, $SD = 1.27$; distance 3–4: $M = 7.32$, $SD = 1.02$); number of orthographic neighbors (distance 1: $M = 4.16$, $SD = 4.17$; distance 3–4: $M = 3.32$, $SD = 2.95$); and number of phonological neighbors (distance 1: $M = 7.80$, $SD = 7.18$; distance 3–4: $M = 6.68$, $SD = 4.19$; all p values $> .27$). The stimuli are presented in Appendix B.

Procedure. Participants were tested following an identical procedure to that in Experiment 1. There was only a difference related with the number of stimuli. In this case, there were 100 pairs of leet words instead of 50. As in Experiment 1, each pair was presented 6 times: 3 Congruity conditions (congruent; incongruent; neutral) × 2 Orders (large-small; small-large). Hence, participants performed a total of 600 trials that were presented randomly. In half of the trials, the leet word in larger font appeared on the right side of the screen, and in the other half, it was on the left. There was a short break every 100 trials. The whole experimental session lasted approximately 40 min.

Design and analyses. The design and analyses were parallel to those of Experiment 1 except for the addition of word frequency as a factor. In the first set of analyses, the factors were congruity (incongruent, congruent, and neutral) and word frequency (high vs. low). Congruity was a within-subjects factor in the F_1 and F_2 analyses, whereas word frequency was a within-subjects factor in the F_1 analysis and a between-items factor in the F_2 analysis. In the second set of analyses, the factors were the distance between the digits in the pairs (distance 1 vs. distance 3–4), congruity (congruent vs. incongruent), and word frequency (high vs. low). Congruity was a within-subjects factor in the F_1 and F_2 analyses, whereas distance and word frequency were within-subjects factors in the F_1 analysis and between-items factors in the F_2 analysis.

Results

RTs smaller than 300 ms or greater than 1,250 ms were removed from the latency analysis (1.2% of the data). The correct mean RT and proportion of errors for each condition of the participant analysis are presented in Table 2.

Effects of congruity and word frequency. The ANOVAs on the latency data with congruity (congruent vs. incongruent vs. neutral) and word frequency (high vs. low) as factors reflected a main effect of congruity, $F_1(2, 48) = 8.97$; $p_1 < .001$; $\eta^2_{p1} = .27$; $F_2(2, 594) = 4.79$; $p_2 < .01$; $\eta_{p2} = .016$. Similarly to Experiment 1, pairwise comparisons (Bonferroni-corrected) showed faster responses in the congruent condition (602 ms) than in the incongruent condition (616 ms; $p_1 < .001$; $p_2 < .01$). The neutral condition (610 ms) was in between these conditions, and it did not differ from either (all p values $> .09$). The main effect of word frequency was also significant, $F_1(1, 24) = 4.3$; $p_1 < .05$; $\eta^2_{p1} = .15$; $F_2(1, 594) = 6.51$; $p_2 < .05$; $\eta_{p2} = .011$. Trials with low-frequency words were responded 7 ms slower than those with high-frequency words (613 and 606 ms, respectively). Finally, the interaction between congruity and frequency was not significant, $F_1(2, 48) = 1.4$; $p_1 = .27$; $\eta^2_{p1} = .06$; $F_2(2, 594) = 1.46$; $p_2 = .23$; $\eta_{p2} = .005$.

The ANOVAs on the proportion of errors, with congruity and word frequency as factors, revealed a main effect of congruity, $F_1(2, 48) = 28.69$, $p_1 < .001$, $\eta^2_{p1} = .55$; $F_2(1, 392) = 33.95$, $p_2 < .01$, $\eta^2_p = .10$. The proportion of errors in the incongruent condition (.11) was greater than in the congruent condition (.06) and the neutral condition (0.7; all p values $< .001$), thus revealing an interference effect. Although the performance in the congruent condition was better than in the neutral condition, this difference did not reach the classical criterion for significance ($p_1 = .07$, $p_2 = .08$). The main effect of word frequency was not significant, $F_1(1, 24) = 1.93$, $p_1 = .18$, $\eta^2_{p1} = .07$; $F_2(1, 594) = 1.36$, $p_2 = .24$, $\eta_{p2} = .002$. The interaction between word frequency and congruity did not approach significance (both F values < 1).

Table 2
Mean RTs and Mean Proportion of Error Responses for Low- and High-Frequency Words, Considering Both Congruity and Distance Conditions in Experiment 2

	Neutral	Congruent	Incongruent
Low-frequency words			
Distance 1			
RT	—	605	621
Errors	—	.069	.11
Distance 3–4			
RT	—	611	617
Errors	—	.055	.117
Total			
RT	611	608	619
Errors	.078	.062	.113
High-frequency words			
Distance 1			
RT	—	596	611
Errors	—	.062	.089
Distance 3–4			
RT	—	598	613
Errors	—	.058	.127
Total			
RT	610	597	612
Errors	.066	.060	.108

Effects of distance, congruity, and word frequency. The analyses considering distance (distance 1 vs. distance 3–4), congruity (congruent vs. incongruent), and word frequency (high vs. low) revealed a main effect of congruity, F_1 (1, 24) = 19.39, $p_1 < .001$, $\eta^2_{p1} = .45$; F_2 (1, 392) = 8.99, $p_2 < .01$, $\eta^2_{p2} = .022$, and also a main effect of word frequency, $F_1(1, 24) = 6.85$, $p_1 < .05$, $\eta^2_{p1} = .22$; $F_2(1, 392) = 8.87$, $p < .01$, $\eta^2_p = .022$. Neither the effect of distance nor any of the interactions between these factors approached significance (all F values < 1.3).

The statistical analyses on the proportion of errors revealed a main effect of congruity, $F_1(1, 24) = 31.82$, $p_1 < .001$, $\eta^2_{p1} = .57$; $F_2(1, 392) = 58.05$, $p_2 < .001$, $\eta_{p2} = .13$, whereas the main effects of distance or word frequency were not statistically significant (all F values < 1.2). As in Experiment 1, the interaction between congruity and distance was significant, $F_1(1, 24) = 5.06$, $p_1 < .05$, $\eta^2_{p1} = .17$; $F_2(1,3\ 92) = 5.93$, $p_2 < .05$, $\eta_{p2} = .015$. This interaction showed that the magnitude of the congruity effect was greater in the distance 3–4 (congruent = .057; incongruent = 0.122, p_1 and $p_2 < .001$) than in distance 1 (congruent = .066; incongruent = .099, p_1 and $p_2 < .01$). None of the other interactions were statistically significant (all p values $>.09$).

Discussion

As in Experiment 1, the results revealed an effect of congruity (i.e., GEN3RAL-GENER4L faster and more accurately than GEN3RAL-GENER4L). Furthermore, we found an interaction between congruity and numerical distance in error rates (e.g., the congruity effect in word pairs from GEN3RAL-GENER4L was smaller than in word pairs like RESP3TO-RESPE7O)—see Kallai and Tzelgov (2012, Experiment 2) for a similar interaction in the error rates. Therefore, by using a new set of stimuli and a new sample of participants, the present experiment offers additional evidence of the existence of an automatic access to the quantities of digits embedded in leet words. But the key finding of the present experiment is that these numerical effects were accompanied by a lexical effect (word frequency). We found faster physical-size decisions for pairs of high-frequency words (RESP3TO-RESPE7O) than for pairs of low-frequency words (EV3NTO-EVEN7O). Therefore, participants can make use of the information stored in the mental lexicon to help them to speed-up their responses, even in a task in which lexical content is not relevant. This is a clear marker of the automaticity of lexical activation. Finally, the absence of an interaction between the numerical factors (distance and congruity) and lexical factors (word frequency) suggests that numerical and lexical information are accessed/processed independently, presumably because there are different cortical mechanisms for digits and letters embedded in digit and letters strings (see Polk et al., 2002).

General Discussion

The main goal of the present experiments was to examine whether digits embedded in leet words (e.g., P4NEL) are automatically processed as quantities as well as letters. While previous research revealed that, due to their perceptual similarity, these digits could be processed as letters (e.g., Kinoshita & Lagoutaris, 2010; Lien et al., 2014; Molinaro et al., 2010; Perea et al., 2008), it was unclear whether their actual numerical values were also accessed or simply normalized into letter forms. To examine this question, we employed a numerical Stroop task that only requires a physical-size judgment. Results showed that the digits embedded in leet words were encoded not only in a letter-like manner, as deduced from a significant word-frequency effect, but also as quantities, as deduced by a size congruity effect (longer responses and more errors for VIR7UAL-VIRTU4L than for VIRTU4L-VIR7UAL). The simultaneous, automatic, and independent processing of the numerical and lexical properties of leet words constitutes the main contribution of the present research.

The automaticity of digit processing can be readily inferred from the congruity effect. In both experiments, numerical quantity of the digits embedded in leet words affected the physical-size decision. The congruent condition produced faster (and/or less error-prone) responses than the neutral and incongruent conditions. Furthermore, the presence of a significant difference between the neutral condition and the incongruent condition (i.e., an interference effect) is a strong marker of automaticity, as it reveals that participants cannot avoid processing numerosity even when it is detrimental for the task (e.g., Tzelgov & Ganor-Stern, 2005). Another marker of quantity processing in the numerical Stroop task is the finding of and interaction between congruity and distance (see Tzelgov et al., 1992). This was observed in Experiments 1 and 2, and it provides converging support in favor of automatic access to quantity representations—note that a rather precise numerical representation is required for this operation. Therefore, our data showed an automatic access to numbers' quantity in a task that does not demand number knowledge (e.g., see Dehaene & Akhavein, 1995; Henik & Tzelgov, 1982; Schwarz & Ischebeck, 2003; Tzelgov, Meyer, & Henik, 1992; for a review, see Tzelgov & Ganor-Stern, 2005). Furthermore, this occurs in a scenario in which digits are not presented in isolation, but inserted in leet words.

The automatic processing of leet words as lexical units was tested in Experiment 2. Even though lexical access was not required by the physical-size judgment task, we found a word-frequency effect (i.e., faster responses to high-frequency leet words than to low-frequency leet words), thus providing evidence of automatic word recognition—note that this is consistent with the correlational data from Experiment 1. It is important to keep in mind that previous studies using leet words employed tasks that explicitly demand lexical access: lexical decision (e.g., Duñabeitia et al., 2009; Kinoshita & Lagoutaris, 2010; Perea et al., 2008, 2009) or semantic categorization tasks (e.g., Lien et al., 2014). Importantly, both numerical and lexical automatisms seem to work independently, as deduced from the lack of interaction between numerical/lexical factors (i.e., these factors have presumably different loci; see Sternberg, 1969, 2011). While the numerical code affected the size-judgment task by its relationship with the physical magnitude (Kadosh & Walsh, 2009; Tzelgov & Ganor-Stern, 2005; Walsh, 2003), word frequency modulated the speed of lexical access. Taken together, the present data showed that number quantity processing and word identification can be carried out to completion without monitoring (see Tzelgov, 1997). Likewise, these findings reveal the incapacity of the cognitive system to ignore attributes of the stimuli (e.g., the quantities represented by the digits embedded in leet words and the lexical representation activated by the perceptual similarity of those numbers with letters) that are not relevant in a low-level (perceptual judgment) task.

The automatic activation of quantity and lexical representation when readers are presented with leet words strongly suggests that the digits can be perceived both as letters and numbers. From a perceptual perspective, this is based on the perceptual similarity of some letters with some numbers, thus creating some perceptual ambiguity. Klink et al. (2012) suggested that in cases of perceptual ambiguity, the representation of one interpretation is preferred and the other discarded. Although not directly designed to test this hypothesis, our data do not support this interpretation. The use of different categories (numbers vs. letters) that are processed in different regions of the brain may be responsible for the simultaneous activation of both representations. Importantly, there are proposals that relate the ability of our cognitive system to process multiple representations of a given stimulus at once with the neural overlap between the categories of the items presented. In an experiment using functional neuroimaging, Cohen et al. (2014) found that the ability to process stimuli from different categories (e.g., faces vs. scenes) was predicted by the amount of separation between neural response patterns, particularly within the occipitotemporal cortex (i.e., nonoverlapping neural representations would imply separate representational resources). In the present experiments, one can speculatively formulate a parallel explanation. When presented with leet words, letters may be normalized in the "visual word-form" area (Cohen, Manion, & Morrison, 2000; Polk et al., 2002), whereas digits may be (independently) recognized in the inferior temporal gyrus (the "visual number-form" area; see Shum et al., 2013). If so, a leet word like VIR7UAL would partially activate these two brain areas. Further research using the methods of cognitive neuroscience would be necessary to assess this hypothesis.

To sum up, the present experiments demonstrated that leet words (e.g., VIRTU4L) produce automatic activation not only of the quantity representation of the numbers (as reflected by the effect of congruity and the interaction of congruity and distance), but also of lexical representations (as reflected by the effect of word frequency) in a physical-size judgment task that does not require access to number/lexical representations. Hence, the present data favor multidimensional accounts of number/word recognition: When reading a leet word (e.g., VIRTU4L), its constituent digit can be simultaneously treated as a letter (A = 4) and as a quantity (●●●●).

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(*Appendices follow*)

Appendix A

Stimuli in Experiment 1

	Distance1				Distance 3–4		
Target	Congruent	Incongruent	Neutral	Target	Congruent	Incongruent	Neutral
DEDAL	D3DAL-DED4L	D3DAL-DED4L	DED4L-DED4L	CESTA	C3STA-CES7A	C3STA-CES7A	CES7A-CES7A
RETAL	R3TAL-RET4L	R3TAL-RET4L	RET4L-RET4L	COLECTIVO	COL3CTIVO-COLEC7IVO	COL3CTIVO-COLEC7IVO	COLEC7IVO-COLEC7IVO
CAJERA	CAJ3RA-C4JERA	CAJ3RA-C4JERA	C4JERA-C4JERA	TARTA	T4RTA-TAR7A	T4RTA-TAR7A	TAR7A-TAR7A
CAMELO	CAM3LO-C4MELO	CAM3LO-C4MELO	C4MELO-C4MELO	ACEITE	AC3ITE-ACEI7E	AC3ITE-ACEI7E	ACEI7E-ACEI7E
CANELA	CAN3LA-C4NELA	CAN3LA-C4NELA	C4NELA-C4NELA	BATUTA	B4TUTA-BATU7A	B4TUTA-BATU7A	BATU7A-BATU7A
DEBATE	D3BATE-DEB4TE	D3BATE-DEB4TE	DEB4TE-DEB4TE	CRESTA	CR3STA-CRES7A	CR3STA-CRES7A	CRES7A-CRES7A
ESCAMA	ESC4MA-E5CAMA	ESC4MA-E5CAMA	E5CAMA-E5CAMA	EVENTO	EV3NTO-EVEN7O	EV3NTO-EVEN7O	EVEN7O-EVEN7O
MALETA	MAL3TA-M4LETA	MAL3TA-M4LETA	M4LETA-M4LETA	FACTOR	F4CTOR-FAC7OR	F4CTOR-FAC7OR	FAC7OR-FAC7OR
PATERA	PAT3RA-P4TERA	PAT3RA-P4TERA	P4TERA-P4TERA	GUANTE	GU4NTE-GUAN7E	GU4NTE-GUAN7E	GUAN7E-GUAN7E
PAYASO	PAY4SO-PAYA5O	PAY4SO-PAYA5O	PAYA5O-PAYA5O	ALIENTO	ALI3NTO-ALIEN7O	ALI3NTO-ALIEN7O	ALIEN7O-ALIEN7O
APLAUSO	APL4USO-APLAU5O	APL4USO-APLAU5O	APLAU5O-APLAU5O	AZAFATO	AZ4FATO-AZAFA7O	AZ4FATO-AZAFA7O	AZAFA7O-AZAFA7O
BANDEJA	BAND3JA-B4NDEJA	BAND3JA-B4NDEJA	B4NDEJA-B4NDEJA	DECRETO	DECR3TO-DECRE7O	DECR3TO-DECRE7O	DECRE7O-DECRE7O
ESTABLO	EST4BLO-E5TABLO	EST4BLO-E5TABLO	E5TABLO-E5TABLO	INVENTO	INV3NTO-INVEN7O	INV3NTO-INVEN7O	INVEN7O-INVEN7O
DETALLE	D3TALLE-DET4LLE	D3TALLE-DET4LLE	DET4LLE-DET4LLE	RASTREO	R4STREO-RAS7REO	R4STREO-RAS7REO	RAS7REO-RAS7REO
PALMERA	PALM3RA-P4LMERA	PALM3RA-P4LMERA	P4LMERA-P4LMERA	VACANTE	VAC4NTE-VACAN7E	VAC4NTE-VACAN7E	VACAN7E-VACAN7E
TECLADO	T3CLADO-TECL4DO	T3CLADO-TECL4DO	TECL4DO-TECL4DO	ARTESANA	ARTES4NA-AR7ESANA	ARTES4NA-AR7ESANA	AR7ESANA-AR7ESANA
DUALISMO	DU4LISMO-DUALI5MO	DU4LISMO-DUALI5MO	DUALI5MO-DUALI5MO	CAPÍTULO	C4PÍTULO-CAPÍ7ULO	C4PÍTULO-CAPÍ7ULO	CAPÍ7ULO-CAPÍ7ULO
PERSIANA	P3RSIANA-PERSI4NA	P3RSIANA-PERSI4NA	PERSI4NA-PERSI4NA	ETIQUETA	ETIQU3TA-ETIQUE7A	ETIQU3TA-ETIQUE7A	ETIQUE7A-ETIQUE7A
TRASPASO	TRASP4SO-TRASPA5O	TRASP4SO-TRASPA5O	TRASPA5O-TRASPA5O	MODESTIA	MOD3STIA-MODES7IA	MOD3STIA-MODES7IA	MODES7IA-MODES7IA
GENERADOR	GEN3RADOR-GENER4DOR	GEN3RADOR-GENER4DOR	GENER4DOR-GENER4DOR	PIANISTA	PI4NISTA-PIANIS7A	PI4NISTA-PIANIS7A	PIANIS7A-PIANIS7A
HISTORIAL	HISTORI4L-HI5TORIAL	HISTORI4L-HI5TORIAL	HI5TORIAL-HI5TORIAL	TURBANTE	TURB4NTE-TURBAN7E	TURB4NTE-TURBAN7E	TURBAN7E-TURBAN7E
NAVEGADOR	NAV3GADOR-NAVEG4DOR	NAV3GADOR-NAVEG4DOR	NAVEG4DOR-NAVEG4DOR	COBERTURA	COB3RTURA-COBER7URA	COB3RTURA-COBER7URA	COBER7URA-COBER7URA
TELEGRAMA	TEL3GRAMA-TELEGR4MA	TEL3GRAMA-TELEGR4MA	TELEGR4MA-TELEGR4MA	EXPONENTE	EXPON3NTE-EXPONEN7E	EXPON3NTE-EXPONEN7E	EXPONEN7E-EXPONEN7E
MUSCULAR	MUSCUL4R-MU5CULAR	MUSCUL4R-MU5CULAR	MU5CULAR-MU5CULAR	LABERINTO	LAB3RINTO-LABERIN7O	LAB3RINTO-LABERIN7O	LABERIN7O-LABERIN7O
PARALELO	PARAL3LO-PAR4LELO	PARAL3LO-PAR4LELO	PAR4LELO-PAR4LELO	SACERDOTE	SAC3RDOTE-SACERDO7E	SAC3RDOTE-SACERDO7E	SACERDO7E-SACERDO7E
CABALLERO	CABALL3RO-CAB4LLERO	CABALL3RO-CAB4LLERO	CABALL3RO-CABALL3RO	CANTIDAD	CANTID4D-CAN7IDAD	CANTID4D-CAN7IDAD	CANTID4D-CANTID4D
CABELLO	CAB3LLO-C4BELLO	CAB3LLO-C4BELLO	CAB3LLO-CAB3LLO	CAPITÁN	C4PITÁN-CAPI7ÁN	C4PITÁN-CAPI7ÁN	C4PITÁN-C4PITÁN
PLACER	PLAC3R-PL4CER	PLAC3R-PL4CER	PLAC3R-PLAC3R	SEÑORITA	S3ÑORITA-SEÑORI7A	S3ÑORITA-SEÑORI7A	S3ÑORITA-S3ÑORITA
CARRERA	CARR3RA-C4RRERA	CARR3RA-C4RRERA	CARR3RA-CARR3RA	CENTRO	C3NTRO-CEN7RO	C3NTRO-CEN7RO	C3NTRO-C3NTRO
DESAYUNO	D3SAYUNO-DES4YUNO	D3SAYUNO-DES4YUNO	D3SAYUNO-D3SAYUNO	DESTINO	D3STINO-DES7INO	D3STINO-DES7INO	D3STINO-D3STINO
DESCANSO	D3SCANSO-DESC4NSO	D3SCANSO-DESC4NSO	D3SCANSO-D3SCANSO	CLIENTE	CLI3NTE-CLIEN7E	CLI3NTE-CLIEN7E	CLI3NTE-CLI3NTE
GENERAL	GEN3RAL-GENER4L	GEN3RAL-GENER4L	GEN3RAL-GEN3RAL	MAESTRO	M4ESTRO-MAES7RO	M4ESTRO-MAES7RO	M4ESTRO-M4ESTRO
HERMANO	H3RMANO-HERM4NO	H3RMANO-HERM4NO	H3RMANO-H3RMANO	PARTIDO	P4RTIDO-PAR7IDO	P4RTIDO-PAR7IDO	P4RTIDO-P4RTIDO
IMAGEN	IMAG3N-IM4GEN	IMAG3N-IM4GEN	IMAG3N-IMAG3N	VESTIDO	V3STIDO-VES7IDO	V3STIDO-VES7IDO	V3STIDO-V3STIDO
MANERA	MAN3RA-M4NERA	MAN3RA-M4NERA	MAN3RA-MAN3RA	TARJETA	T4RJETA-TARJE7A	T4RJETA-TARJE7A	T4RJETA-T4RJETA
MENSAJE	M3NSAJE-MENS4JE	M3NSAJE-MENS4JE	M3NSAJE-M3NSAJE	SITUACIÓN	SITU4CIÓN-SI7UACIÓN	SITU4CIÓN-SI7UACIÓN	SITU4CIÓN-SITU4CIÓN
NECESARIO	NEC3SARIO-NECES4RIO	NEC3SARIO-NECES4RIO	NEC3SARIO-NEC3SARIO	VENTANA	V3NTANA-VEN7ANA	V3NTANA-VEN7ANA	V3NTANA-V3NTANA
OPERACIÓN	OP3RACIÓN-OPER4CIÓN	OP3RACIÓN-OPER4CIÓN	OP3RACIÓN-OP3RACIÓN	RESPUESTA	RESPU3STA-RESPUES7A	RESPU3STA-RESPUES7A	RESPU3STA-RESPU3STA
PAPEL	PAP3L-P4PEL	PAP3L-P4PEL	PAP3L-PAP3L	RESULTADO	R3SULTADO-RESUL7ADO	R3SULTADO-RESUL7ADO	R3SULTADO-R3SULTADO
PASEO	PAS3O-P4SEO	PAS3O-P4SEO	PAS3O-PAS3O	VUELTA	VU3LTA-VUEL7A	VU3LTA-VUEL7A	VU3LTA-VU3LTA
PEDAZO	P3DAZO-PED4ZO	P3DAZO-PED4ZO	P3DAZO-P3DAZO	EFECTO	EF3CTO-EFEC7O	EF3CTO-EFEC7O	EF3CTO-EF3CTO
SOCIEDAD	SOCI3DAD-SOCIED4D	SOCI3DAD-SOCIED4D	SOCI3DAD-SOCI3DAD	ENTRADA	ENTR4DA-EN7RADA	ENTR4DA-EN7RADA	ENTR4DA-ENTR4DA
VISTAZO	VIST4ZO-VI5TAZO	VIST4ZO-VI5TAZO	VIST4ZO-VIST4ZO	ESTRELLA	ESTR3LLA-ES7RELLA	ESTR3LLA-ES7RELLA	ESTR3LLA-ESTR3LLA
MERCADO	M3RCADO-MERC4DO	M3RCADO-MERC4DO	M3RCADO-M3RCADO	FALTA	F4LTA-FAL7A	F4LTA-FAL7A	F4LTA-F4LTA
SEMANA	S3MANA-SEM4NA	S3MANA-SEM4NA	S3MANA-S3MANA	PREGUNTA	PR3GUNTA-PREGUN7A	PR3GUNTA-PREGUN7A	PR3GUNTA-PR3GUNTA
REALIDAD	R3ALIDAD-RE4LIDAD	R3ALIDAD-RE4LIDAD	R3ALIDAD-R3ALIDAD	MOMENTO	MOM3NTO-MOMEN7O	MOM3NTO-MOMEN7O	MOM3NTO-MOM3NTO
REGALO	R3GALO-REG4LO	R3GALO-REG4LO	R3GALO-R3GALO	PRESENTE	PRES3NTE-PRESEN7E	PRES3NTE-PRESEN7E	PRES3NTE-PRES3NTE
SEÑAL	S3ÑAL-SEÑ4L	S3ÑAL-SEÑ4L	S3ÑAL-S3ÑAL	SIGUIENTE	SIGUI3NTE-SIGUIEN7E	SIGUI3NTE-SIGUIEN7E	SIGUI3NTE-SIGUI3NTE
VERANO	V3RANO-VER4NO	V3RANO-VER4NO	V3RANO-V3RANO	SECRETO	SECR3TO-SECRE7O	SECR3TO-SECRE7O	SECR3TO-SECR3TO
VELOCIDAD	V3LOCIDAD-VELOCID4D	V3LOCIDAD-VELOCID4D	V3LOCIDAD-V3LOCIDAD	RESPETO	RESP3TO-RESPE7O	RESP3TO-RESPE7O	RESP3TO-RESP3TO

(*Appendices continue*)

Appendix B

Stimuli in Experiment 2

Target	Congruent	Incongruent_LF	Neutral	Target	Congruent_HF	Incongruent_HF	Neutral
Distance 1							
DEDAL	D3DAL-DED4L	D3DAL-DED4L	DED4L-DED4L	CABALLERO	CABALL3RO-CAB4LLERO	CABALL3RO-CAB4LLERO	CABALL3RO-CABALL3RO
RETAL	R3TAL-RET4L	R3TAL-RET4L	RET4L-RET4L	CABALLO	CAB3LLO-C4BELLO	CAB3LLO-C4BELLO	CAB3LLO-CAB3LLO
CAJERA	CAJ3RA-C4JERA	CAJ3RA-C4JERA	C4JERA-C4JERA	PLACER	PLAC3R-PL4CER	PLAC3R-PL4CER	PLAC3R-PLAC3R
CAMELO	CAM3LO-C4MELO	CAM3LO-C4MELO	C4MELO-C4MELO	CARRERA	CARR3RA-C4RRERA	CARR3RA-C4RRERA	CARR3RA-CARR3RA
CANELA	CAN3LA-C4NELA	CAN3LA-C4NELA	C4NELA-C4NELA	DESAYUNO	D3SAYUNO-DES4YUNO	D3SAYUNO-DES4YUNO	D3SAYUNO-D3SAYUNO
DEBATE	D3BATE-DEB4TE	D3BATE-DEB4TE	DEB4TE-DEB4TE	DESCANSO	D3SCANSO-DESC4NSO	D3SCANSO-DESC4NSO	D3SCANSO-D3SCANSO
ESCAMA	ESC4MA-E5CAMA	ESC4MA-E5CAMA	E5CAMA-E5CAMA	GENERAL	GEN3RAL-GENER4L	GEN3RAL-GENER4L	GEN3RAL-GEN3RAL
MALETA	MAL3TA-M4LETA	MAL3TA-M4LETA	M4LETA-M4LETA	HERMANO	H3RMANO-HERM4NO	H3RMANO-HERM4NO	H3RMANO-H3RMANO
PATERA	PAT3RA-P4TERA	PAT3RA-P4TERA	P4TERA-P4TERA	IMAGEN	IMAG3N-IM4GEN	IMAG3N-IM4GEN	IMAG3N-IMAG3N
PAYASO	PAY4SO-PAYA5O	PAY4SO-PAYA5O	PAYA5O-PAYA5O	MANERA	MAN3RA-M4NERA	MAN3RA-M4NERA	MAN3RA-MAN3RA
APLAUSO	APL4USO-APLAU5O	APL4USO-APLAU5O	APLAU5O-APLAU5O	MENSAJE	M3NSAJE-MENS4JE	M3NSAJE-MENS4JE	M3NSAJE-M3NSAJE
BANDEJA	BAND3JA-B4NDEJA	BAND3JA-B4NDEJA	B4NDEJA-B4NDEJA	NECESARIO	NEC3SARIO-NECES4RIO	NEC3SARIO-NECES4RIO	NEC3SARIO-NEC3SARIO
ESTABLO	EST4BLO-E5TABLO	EST4BLO-E5TABLO	E5TABLO-E5TABLO	OPERACIÓN	OP3RACIÓN-OPER4CIÓN	OP3RACIÓN-OPER4CIÓN	OP3RACIÓN-OP3RACIÓN
DETALLE	D3TALLE-DET4LLE	D3TALLE-DET4LLE	DET4LLE-DET4LLE	PAPEL	PAP3L-P4PEL	PAP3L-P4PEL	PAP3L-PAP3L
PALMERA	PALM3RA-P4LMERA	PALM3RA-P4LMERA	P4LMERA-P4LMERA	PASEO	PAS3O-P4SEO	PAS3O-P4SEO	PAS3O-PAS3O
TECLADO	T3CLADO-TECL4DO	T3CLADO-TECL4DO	TECL4DO-TECL4DO	PEDAZO	P3DAZO-PED4ZO	P3DAZO-PED4ZO	P3DAZO-P3DAZO
DUALISMO	DU4LISMO-DUALI5MO	DU4LISMO-DUALI5MO	DUALI5MO-DUALI5MO	SOCIEDAD	SOCI3DAD-SOCIED4D	SOCI3DAD-SOCIED4D	SOCI3DAD-SOCI3DAD
PERSIANA	P3RSIANA-PERSI4NA	P3RSIANA-PERSI4NA	PERSI4NA-PERSI4NA	VISTAZO	VIST4ZO-VI5TAZO	VIST4ZO-VI5TAZO	VIST4ZO-VIST4ZO
TRASPASO	TRASP4SO-TRASPA5O	TRASP4SO-TRASPA5O	TRASPA5O-TRASPA5O	MERCADO	M3RCADO-MERC4DO	M3RCADO-MERC4DO	M3RCADO-M3RCADO
GENERADOR	GEN3RADOR-GENER4DOR	GEN3RADOR-GENER4DOR	GENER4DOR-GENER4DOR	SEMANA	S3MANA-SEM4NA	S3MANA-SEM4NA	S3MANA-S3MANA
HISTORIAL	HISTORI4L-HI5TORIAL	HISTORI4L-HI5TORIAL	HI5TORIAL-HI5TORIAL	REALIDAD	R3ALIDAD-RE4LIDAD	R3ALIDAD-RE4LIDAD	R3ALIDAD-R3ALIDAD
NAVEGADOR	NAV3GADOR-NAVEG4DOR	NAV3GADOR-NAVEG4DOR	NAVEG4DOR-NAVEG4DOR	REGALO	R3GALO-REG4LO	R3GALO-REG4LO	R3GALO-R3GALO
TELEGRAMA	TEL3GRAMA-TELEGR4MA	TEL3GRAMA-TELEGR4MA	TELEGR4MA-TELEGR4MA	SEÑAL	S3ÑAL-SEÑ4L	S3ÑAL-SEÑ4L	S3ÑAL-S3ÑAL
MUSCULAR	MUSCUL4R-MU5CULAR	MUSCUL4R-MU5CULAR	MU5CULAR-MU5CULAR	VERANO	V3RANO-VER4NO	V3RANO-VER4NO	V3RANO-V3RANO
PARALELO	PARAL3LO-PAR4LELO	PARAL3LO-PAR4LELO	PAR4LELO-PAR4LELO	VELOCIDAD	V3LOCIDAD-VELOCID4D	V3LOCIDAD-VELOCID4D	V3LOCIDAD-V3LOCIDAD
Distance 3–4							
LF_Target	Congruent	Incongruent	Neutral	HF_Target	Congruent	Incongruent	Neutral
CESTA	C3STA-CES7A	C3STA-CES7A	C3STA-C3STA	CANTIDAD	CANTID4D-CAN7IDAD	CANTID4D-CAN7IDAD	CAN7IDAD-CANTID4D
COLECTIVO	COL3CTIVO-COLEC7IVO	COL3CTIVO-COLEC7IVO	COL3CTIVO-COL3CTIVO	CAPITÁN	C4PITÁN-CAPI7ÁN	C4PITÁN-CAPI7ÁN	CAPI7ÁN-C4PITÁN
TARTA	T4RTA-TAR7A	T4RTA-TAR7A	T4RTA-T4RTA	SEÑORITA	S3ÑORITA-SEÑORI7A	S3ÑORITA-SEÑORI7A	SEÑORI7A-S3ÑORITA
ACEITE	AC3ITE-ACEI7E	AC3ITE-ACEI7E	AC3ITE-AC3ITE	CENTRO	C3NTRO-CEN7RO	C3NTRO-CEN7RO	CEN7RO-C3NTRO
BATUTA	B4TUTA-BATU7A	B4TUTA-BATU7A	B4TUTA-B4TUTA	DESTINO	D3STINO-DES7INO	D3STINO-DES7INO	DES7INO-D3STINO
CRESTA	CR3STA-CRES7A	CR3STA-CRES7A	CR3STA-CR3STA	CLIENTE	CLI3NTE-CLIEN7E	CLI3NTE-CLIEN7E	CLIEN7E-CLI3NTE
EVENTO	EV3NTO-EVEN7O	EV3NTO-EVEN7O	EV3NTO-EV3NTO	MAESTRO	M4ESTRO-MAES7RO	M4ESTRO-MAES7RO	MAES7RO-M4ESTRO
FACTOR	F4CTOR-FAC7OR	F4CTOR-FAC7OR	F4CTOR-F4CTOR	PARTIDO	P4RTIDO-PAR7IDO	P4RTIDO-PAR7IDO	PAR7IDO-P4RTIDO
GUANTE	GU4NTE-GUAN7E	GU4NTE-GUAN7E	GU4NTE-GU4NTE	VESTIDO	V3STIDO-VES7IDO	V3STIDO-VES7IDO	VES7IDO-V3STIDO
ALIENTO	ALI3NTO-ALIEN7O	ALI3NTO-ALIEN7O	ALI3NTO-ALI3NTO	TARJETA	T4RJETA-TARJE7A	T4RJETA-TARJE7A	TARJE7A-T4RJETA
AZAFATO	AZ4FATO-AZAFA7O	AZ4FATO-AZAFA7O	AZ4FATO-AZ4FATO	SITUACIÓN	SITU4CIÓN-SI7UACIÓN	SITU4CIÓN-SI7UACIÓN	SI7UACIÓN-SITU4CIÓN
DECRETO	DECR3TO-DECRE7O	DECR3TO-DECRE7O	DECR3TO-DECR3TO	VENTANA	V3NTANA-VEN7ANA	V3NTANA-VEN7ANA	VEN7ANA-V3NTANA
INVENTO	INV3NTO-INVEN7O	INV3NTO-INVEN7O	INV3NTO-INV3NTO	RESPUESTA	RESPU3STA-RESPUES7A	RESPU3STA-RESPUES7A	RESPUES7A-RESPU3STA
RASTREO	R4STREO-RAS7REO	R4STREO-RAS7REO	R4STREO-R4STREO	RESULTADO	R3SULTADO-RESUL7ADO	R3SULTADO-RESUL7ADO	RESUL7ADO-R3SULTADO
VACANTE	VAC4NTE-VACAN7E	VAC4NTE-VACAN7E	VAC4NTE-VAC4NTE	VUELTA	VU3LTA-VUEL7A	VU3LTA-VUEL7A	VUEL7A-VU3LTA
ARTESANA	ARTES4NA-AR7ESANA	ARTES4NA-AR7ESANA	ARTES4NA-ARTES4NA	EFECTO	EF3CTO-EFEC7O	EF3CTO-EFEC7O	EFEC7O-EF3CTO
CAPÍTULO	C4PÍTULO-CAPÍ7ULO	C4PÍTULO-CAPÍ7ULO	C4PÍTULO-C4PÍTULO	ENTRADA	ENTR4DA-EN7RADA	ENTR4DA-EN7RADA	EN7RADA-ENTR4DA
ETIQUETA	ETIQU3TA-ETIQUE7A	ETIQU3TA-ETIQUE7A	ETIQU3TA-ETIQU3TA	ESTRELLA	ESTR3LLA-ES7RELLA	ESTR3LLA-ES7RELLA	ES7RELLA-ESTR3LLA
MODESTIA	MOD3STIA-MODES7IA	MOD3STIA-MODES7IA	MOD3STIA-MOD3STIA	FALTA	F4LTA-FAL7A	F4LTA-FAL7A	FAL7A-F4LTA
PIANISTA	PI4NISTA-PIANIS7A	PI4NISTA-PIANIS7A	PI4NISTA-PI4NISTA	PREGUNTA	PR3GUNTA-PREGUN7A	PR3GUNTA-PREGUN7A	PREGUN7A-PR3GUNTA
TURBANTE	TURB4NTE-TURBAN7E	TURB4NTE-TURBAN7E	TURB4NTE-TURB4NTE	MOMENTO	MOM3NTO-MOMEN7O	MOM3NTO-MOMEN7O	MOMEN7O-MOM3NTO
COBERTURA	COB3RTURA-COBER7URA	COB3RTURA-COBER7URA	COB3RTURA-COB3RTURA	PRESENTE	PRES3NTE-PRESEN7E	PRES3NTE-PRESEN7E	PRESEN7E-PRES3NTE
EXPONENTE	EXPON3NTE-EXPONEN7E	EXPON3NTE-EXPONEN7E	EXPON3NTE-EXPON3NTE	SIGUIENTE	SIGUI3NTE-SIGUIEN7E	SIGUI3NTE-SIGUIEN7E	SIGUIEN7E-SIGUI3NTE
LABERINTO	LAB3RINTO-LABERIN7O	LAB3RINTO-LABERIN7O	LAB3RINTO-LAB3RINTO	SECRETO	SECR3TO-SECRE7O	SECR3TO-SECRE7O	SECRE7O-SECR3TO
SACERDOTE	SAC3RDOTE-SACERDO7E	SAC3RDOTE-SACERDO7E	SAC3RDOTE-SAC3RDOTE	RESPETO	RESP3TO-RESPE7O	RESP3TO-RESPE7O	RESPE7O-RESP3TO

Note. LF_Target = Low frequency target words; HG_Target = High frequency target words.

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