Roman Digit Naming

Evidence for a Semantic Route

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Abstract. Earlier research with monolinguals and bilinguals showed that numbers may be named through both a semantic and a phonological route, depending on the number's language and format (Arabic or verbal), task demands, and naming language. The present study investigated the importance of the semantic route for the processing of a third representation of magnitude, namely Roman digits. Using an interference paradigm, we showed that the processing of Roman target digits is influenced by Arabic digit distractors, both in a naming task and a parity judgment task. Roman digits were processed faster if the target and distractor were of the same magnitude. If this was not the case, processing speed slowed down as the numerical distance between target and distractor increased. This strongly suggests that semantic access is mandatory when naming Roman digits. Implications are discussed for the number processing domain and for models of translation in bilinguals.

Keywords: Roman digits, numbers, semantic mediation, naming, translation, bilingualism

Bilingual people have different lexical/form representations, belonging to their native (L1) and second language (L2), to express the same (or highly similar) meaning. In psycholinguistic studies of bilingualism, an important question is whether L2 lexical representations have equally strong form-to-meaning mappings as L1 lexical representations. Typically, this is investigated by checking whether translation from L2 to L1 lexical representations (and vice versa) involves semantic access or not. Interestingly, a similar parallel debate has been conducted in the (monolingual) number processing domain. Here, a key question is whether the processing of Arabic digits and number words requires mandatory semantic access or not. Because even a monolingual has more than one form of representation (i.e., Arabic digits or number words) for the same magnitude-related meaning, the research question in the monolingual number-processing literature is related to the translation question in bilinguals. Therefore, it is no surprise that a few previous studies of bilingualism (Duyck & Brysbaert, 2002, 2004, 2007) have applied the semantic markers that are commonly used to investigate semantic access in number processing to translation tasks. Following this line of research, the present study will use a marker of semantic access in number processing to learn more about the processing of yet another, infrequent, form representation of magnitude, namely Roman digits. From the bilingual perspective, these stimuli offer an interesting opportunity to see whether strong lexicosemantic connections exist for form representations that do not belong to L2, and are used very infrequently. Like regular L2 (number) words, Roman digits are symbolic form representations that represent the same meaning as their L1 translation equivalents. Before going into details about the present study, we will discuss what is known already about semantic access in Arabic/Roman digit and L1 number-word processing. Theoretical implications of the present study for the domain of bilingualism will be addressed in the General Discussion.

Arabic Digits and L1 Number Words

The meaning of a number primarily refers to the magnitude represented by the number. In the numerical cognition literature, these magnitudes are commonly conceived as a mental number line (Brysbaert, 1995; Dehaene, 1992), on which all integers form an ordered continuum oriented from left (small) to right (large). On this number line, activation spreads to other representations that are close in magnitude. This offers the opportunity to use several magnitude effects as markers of semantic access in number processing. For instance, it is easier to perform a magnitude comparison task when two numbers are further apart. Similarly, the processing of a number is facilitated when a number with a close magnitude has been presented before than when a number with a more distant magnitude has been presented (Reynvoet & Brysbaert, 1999).

An interesting aspect of numbers is that even a monolingual has more than one form (orthographic) representation of the same magnitude related meaning: Magnitude can be represented through both Arabic digits and L1 number words. As indicated earlier, it is especially interesting for the literature on bilingualism that these two representations seem to differ in the way that they interact with the semantic system. Although there still is some discussion whether Arabic digits may be named without semantic mediation (e.g., Campbell, 1994; Cipolotti & Butterworth, 1995; Dehaene, 1992; Ra-

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tinckx, Brysbaert, & Fias, 2005) or not (e.g., Brysbaert, 1995, see earlier; Fias, Reynvoet, & Brysbaert, 2001; McCloskey, 1992), there is a consensus that number magnitude is less rapidly activated from verbal input than from Arabic digit input (Brysbaert, 2005). Semantic activation from number words depends to a larger extent on (semantic) task demands. For instance, Fias et al. (2001) showed that the word "five" was read equally fast when it was displayed together with the distractor digit 3 (incongruent) than when it was presented together with the distractor 5 (congruent). When the targets were Arabic digits, however, naming responses were faster with magnitude-congruent verbal distractors than with incongruent distractors. Hence, whereas Arabic digits automatically accessed semantics, number words were named without semantic mediation. This is in line with most models of visual word recognition, which assume the existence of nonsemantic routes for word naming (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Note that a control experiment of Fias et al. (2001) showed that responses to the number word "five" were still faster when the word was presented together with a congruent Arabic distractor than with an incongruent one in a parity judgment task (i.e., participants indicate whether the target is odd or even). This shows that the earlier null effect for number words was not a result of the fact that participants were able to completely ignore the Arabic distractors.

Further evidence for the hypothesis that Arabic digits activate semantics earlier and stronger than number words comes from Stroop-like phenomena. It has repeatedly been shown that the meaning of Arabic digits influences performance in a font size judgment task. For instance, Ito and Hatta (2003; see also, for example, Henik & Tzelgov, 1982; Pansky & Algom, 1999) showed that it is easier to detect the physically larger stimulus in the digit pair 3–9 than in the pair 3–9. Such a size congruency effect is not found for L1 number words (i.e., detecting the physically larger stimulus in three-nine is equally fast as in three-nine), suggesting slower/weaker access to semantics. Further evidence for automatic semantic activation in the processing of Arabic digits comes from Pavese and Umilta (1998). Using a similar Stroop paradigm with a counting task, they showed that it is more difficult to say that four digits are present in the stimulus 3 3 3 3 than in the stimulus 4 4 4 4.

Finally, using the same interference paradigm as Fias et al. (2001), Roelofs (2006) has shown that L1 number-word naming may still be influenced by Arabic-digit distractors that are physically larger that the ones used by Fias et al. (those digits were approximately as large as a single number-word character). Similarly, priming studies such as that of Reynvoet, Brysbaert, and Fias (2002) showed that the naming of L1 number words is faster if the targets are preceded by primes that are closer in magnitude. This shows that the semantic route in L1 number-word naming may still be activated quickly and strongly enough to affect naming performance under certain circumstances, even though semantic activation is generally stronger for Arabic digits (Brysbaert, 2005).

Processing Roman Digits

There are surprisingly few studies that have investigated the processing of another, infrequently used representation of magnitude information, namely Roman digits (but see Gonzalez & Kolers, 1982; Noel & Seron, 1992, 1997; Sokol, Mccloskey, Cohen, & Aliminosa, 1991). Sokol et al. (1991) showed that Roman digits are processed slower than Arabic digits, and that this difference is larger for larger quantities than for smaller quantities. These results may be explained by the distinctive nature of Roman digits, in which four structures can be distinguished (Noel & Seron, 1992, 1997). The first is the analogical structure, which is present in the Roman digits I, II, and III. This structure entails a one-to-one mapping between the number of orthographic units and the meaning. The second structure is called symbolic, because an arbitrary symbol is used to represent a certain quantity. This structure is present in the Roman digits V, X, L, C, D, and M. The following two structures are more complex, because they constitute a combination of the analog and symbolic structures. This combination can either correspond to an addition (e.g., VI), or a subtraction (e.g., IV). From a psychological perspective, the symbolic structures, or lexical primitives, constitute a very small lexicon. According to Noel and Seron, the encoding of these lexical primitives is, similar to the encoding of letters, based on visual feature analysis, which triggers the activation of a Roman symbol recognition unit. Encoding of the complex Roman digits requires recognition of its lexical primitives and a supplementary syntactic processing step in which the relative position of the primitives is converted into an additive or subtractive relation. Because of this extra step, the complex Roman digits are processed slower than their verbal or Arabic counterparts (Noel & Seron, 1992). For small quantities (i.e., I, II, and III), the underlying magnitude can directly be retrieved through subitizing, equally fast as for other number formats. Note that this combinatorial Roman digit system has some similarities with the number word system. In English for example, number words starting from "thirteen" also use combinations of lexical primitives that follow hybrid sequences of multiplicative/additive rules. The number word to express the magnitude 203, for example, consists of the lexical primitives "two," "hundred," and "three." The former two constitute a multiplicative combination, whereas the latter are an additive combination. As another example, in Dutch the order of the lexical primitives in number words does not necessarily correspond to the order of the numbers that constitute the compound Arabic digit. For example, the number word to express the magnitude 253 is twee honderd [two hundred] drie [three] en [and] vijftig [fifty].

To our knowledge, there are no studies that have used Roman digits in this semantic number debate. No study has tested whether the naming of Roman digits will involve semantic access, even though they are used much more in-

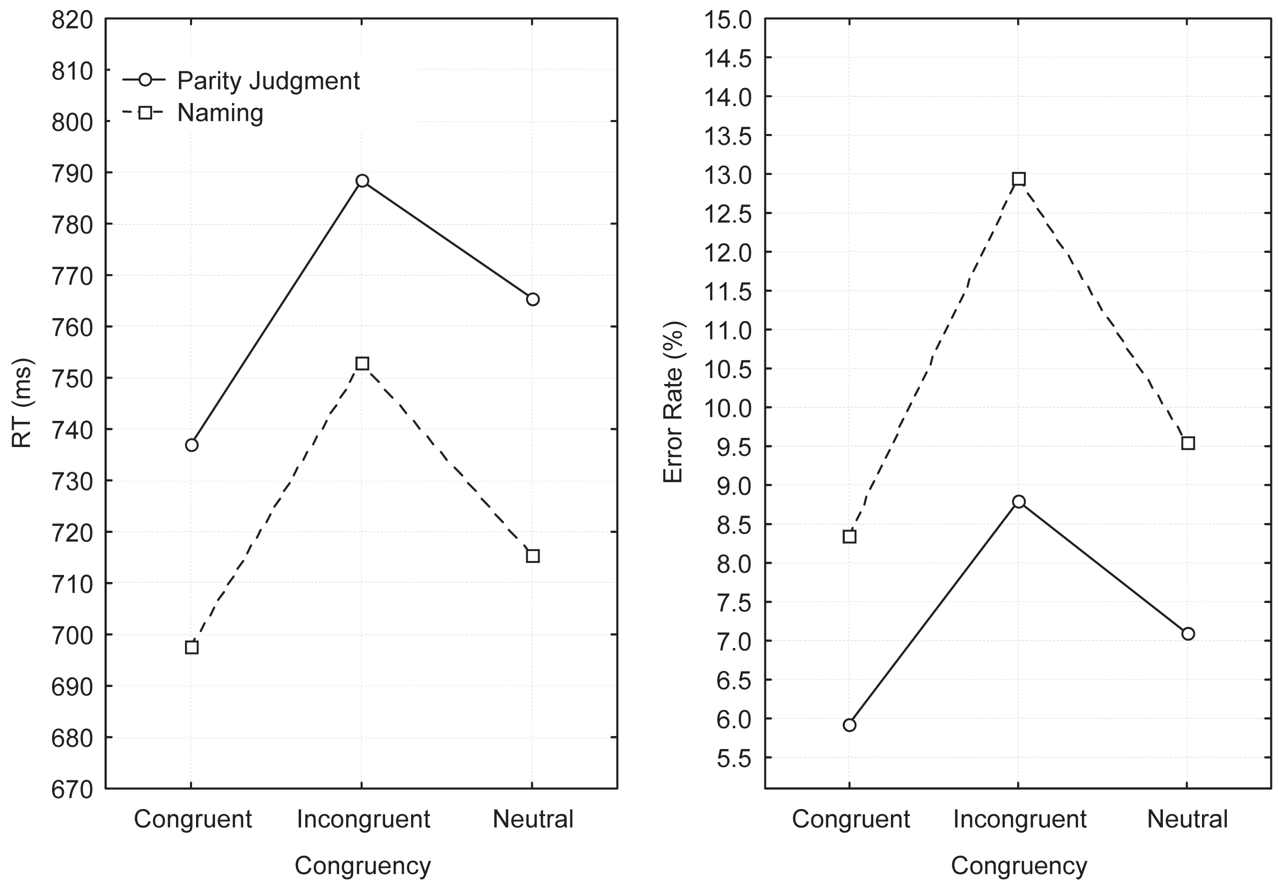

Figure 1. Median RTs and error rates as a function of target-distractor congruency and task (parity judgment vs. naming).

frequently than Arabic digits, or whether they are primarily named through a nonsemantic route, as number words. This was the goal of the present study.

The Present Study

The present study investigated whether semantic access occurs in the L1 (Dutch) naming of Roman digits or not. To this end, we used the same interference paradigm that Fias et al. (2001) drew upon to investigate the existence of a nonsemantic route in the naming of number words and Arabic digits (see earlier). In order to be sure that participants would not be able to simply ignore the Arabic-digit distractors in the naming task (which might compromise interpretation of a possible semantic null effect), we also included the same parity judgment control task as Fias et al. (2001) used. Because this task explicitly requires access to the meaning of the Roman digit, it should always yield a semantic distractor effect similar to the effects observed by Fias et al. (2001).

Experiment

Method

Participants

Thirteen females and seven males participated as a course requirements. All of them were native Dutch speakers. Mean age was 20.2.

Materials

The materials and procedure were as similar as possible to that of Fias et al. (2001), except that we included Roman digit targets. The Roman targets and Arabic distractors were the eight digits with a magnitude ranging from 1 to 9, excluding 5 (to have an equal number of even and odd stimuli). The distractor stimulus was either an Arabic digit (congruent or incongruent) or a small horizontal line (neutral condition). For each task (parity judgment and L1 naming), each of the eight Roman digit targets was displayed 14 times with the Arabic distractor representing the same magnitude (112 congruent trials) in the congruent condi-

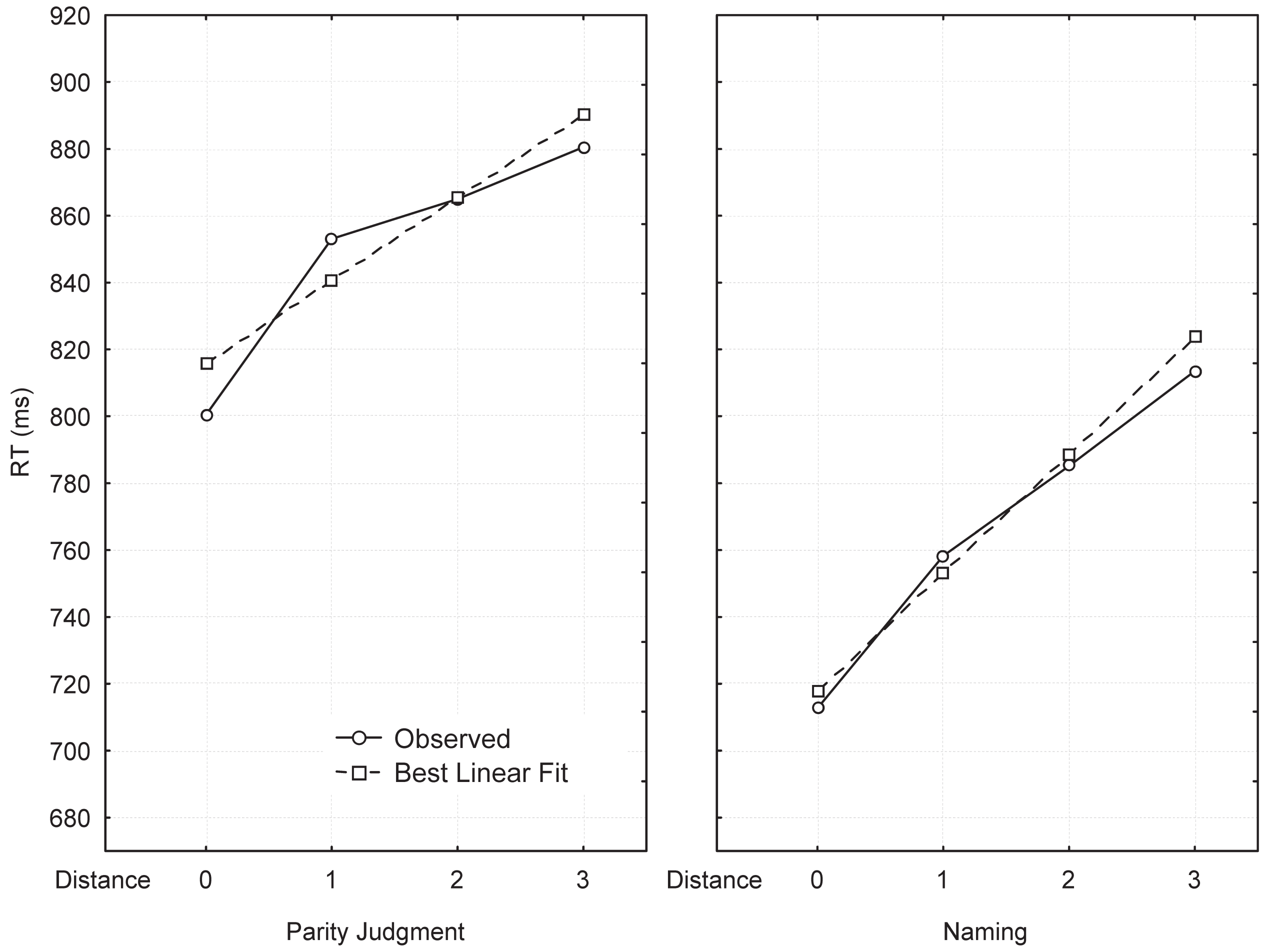

Figure 2. RTs as a function of task and numerical distance between target and distractor.

tion. In the incongruent condition, each of the eight Roman targets was presented twice with all of the seven incongruent Arabic distractors (112 incongruent trials). In the 112 neutral trials, each of the Roman targets was presented 14 times with the neutral distractor.

Procedure

All participants completed 336 experimental trials, randomly ordered, for both the parity judgment and naming tasks. The order of tasks was counterbalanced across participants. Experimental trials were always preceded by 32 practice trials, in which all eight Roman digits were presented four times, half of them with an Arabic distractor, and half with the neutral distractor. Each trial started with the presentation of a fixation point for 500 ms. This display was replaced by the Roman digit target and an Arabic distractor. In half of the trials (counterbalanced over conditions), the Roman target was in the position above the fixation point. In the parity judgment block, participants were instructed to judge the parity (odd/even) of the Roman target by pressing one of two buttons on a response box. The mapping of parity status to the buttons was counterbalanced over participants. In the naming task, participants were instructed to name the Roman target as quickly as possible in their L1. Naming latencies were measured through a voicekey connected to the computer's gameport. The interstimulus interval was 1000 ms.

Parity Judgment Results

The mean percentage of errors was 7.28%. The positive correlation between median response times (RTs) and error rates shows that there was no speed-accuracy tradeoff, $r = 0.19$, $p > .42$. Similar to Fias et al. (2001), we analyzed median RTs and error rates through a repeated measures ANOVA with Congruency (between target and distractor; 3 levels: congruent vs. incongruent vs. neutral) as the within-subjects factor. Median RTs and error rates are depicted in Figure 1 (respectively in the left and right panel, solid lines). All RTs that deviated more than three standard deviations from the participant's overall RT were considered as outliers and were removed from the analysis (1.67% of the data).

Latencies

The effect of Congruency on median RTs was significant, $F(2, 38) = 13.52$, $p < .001$, $MSE = 981$. Planned comparisons showed that incongruent trials ($M = 788$) were significantly slower than neutral trials ($M = 766$), which in turn were slower than congruent trials ($M = 737$), respectively $F(1, 19) = 5.79$, $p < .05$, $MSE = 902.37$ and $F(1, 19) = 5.72$, $p < .05$, $MSE = 1423.78$.

Accuracy

A similar congruency effect could be observed in the accuracy analysis. This also yielded a significant effect of Congruency, $F(2, 38) = 4.29$, $p < .05$, $MSE = 9.631$. Planned comparisons showed that participants made more errors on incongruent trials ($M = 8.79$) than on neutral trials ($M = 7.10$), which in turn yielded more errors than congruent trials ($M = 5.94$). These comparisons only reached marginal significance, respectively $F(1, 19) = 3.05$, $p < .10$, $MSE = 9.436$ and $F(1, 19) = 2.17$, $p < .16$, $MSE = 6.214$.

Latencies Target-Distractor Distance Effect

The analysis above shows a clear semantic congruency effect in the parity judgment of Roman digits. However, a more fine-grained analysis of the influence of the exact magnitude difference between the distractor and the target would provide additional, even stronger, evidence for the semantic origin of the distractor effect. We limited this analysis of the distance effect to a maximal distance of three because semantic-related priming does not extend to numerical distances larger than three (see for instance, Reynvoet et al., 2002). We analyzed this distance effect using a regression analysis for repeated measures data described by Lorch and Myers (1990, Method 3). Distances between targets and distractors served as predictor values, ranging from 0 (identical magnitude) to 3. This yielded the following equation: RT = 816 + 24.88*Distance. Importantly, the regression weight of Distance differed significantly from zero, $t(19) = 5.09$, $p < .001$, showing that the observed RTs are linearly related to the distance between target and distractor (see also Figure 2, left panel).

Naming Results

The mean percentage of naming and voicekey errors was 10.28%. The positive correlation between median RTs and error rates shows that there was no speed-accuracy tradeoff ($r = 0.19$, $p > .42$). Again, we analyzed median RTs and error rates through a repeated measures ANOVA with Congruency as the repeated factor. Median RTs and error rates are also depicted in Figure 1 (dotted lines). The outlier removal criterion (0.9% of the data) was identical to that used for parity judgment.

Latencies

Again, the effect of Congruency on median RTs was significant, $F(2, 38) = 28.48$, $p < .001$, $MSE = 556$. Planned comparisons showed that incongruent trials ($M = 753$) were significantly slower than neutral trials ($M = 715$), which were, in turn, slower than congruent trials ($M = 698$), respectively $F(1, 19) = 20.96$, $p < .001$, $MSE = 671.03$ and $F(1, 19) = 7.88$, $p < .05$, $MSE = 393.31$.

Accuracy

A similar congruency effect could be observed in the accuracy analysis, $F(2, 38) = 16.72$, $p < .001$, $MSE = 6.799$. Planned comparisons showed that participants made more errors on incongruent trials ($M = 12.95$) than on neutral trials ($M = 9.55$), $F(1, 19) = 20.84$, $p < .001$, $MSE = 5.522$. The difference between neutral trials and congruent trials was only marginally significant, $F(1, 19) = 2.72$, $p < .12$, $MSE = 5.34$.

Latencies Target-Distractor Distance Effect

Similar to the findings for parity judgment, the analysis above shows a clear semantic congruency effect for the naming of Roman digits. One could argue, however, that this congruency effect arises from the fact that congruent distractors and targets activate the same phonological representation, resulting in a nonsemantic phonological facilitation effect[1]. Therefore, we again carried out a more detailed analysis of the numerical distance between targets and distractors to provide further evidence for the semantic origin of the obtained distractor effects. A similar regression analysis for repeated measures (Lorch & Myers, 1990, Method 3) yielded the following regression equation: RT = 718 + 35.34*Distance. Again, the regression weight of Distance differed significantly from zero, $t(19) = 6{,}99$ $p < .001$, showing that the observed RTs are linearly related to the distance between target and distractor (see also Figure

[1] Note that this alternative account of the congruency effect in terms of nonsemantic phonological facilitation also needs the presupposition that there is a direct route from Arabic digits (distractors) to phonology. Whereas some studies have, indeed, argued that Arabic digits may be named through such a nonsemantic route (e.g., Cipolotti & Butterworth, 1995; Dehaene, 1992; for the naming of 2-digit Arabic digits, see Ratinckx et al., 2005), other studies have argued for the automaticity of a semantic route (Brysbaert, 1995; Fias, Brysbaert, Geypens, & d'Ydewalle, 1996; McCloskey, 1992; Noel & Seron, 1995). In general, there seems to be a consensus that there is relatively less support for nonsemantically mediated processing of Arabic digits (Brysbaert, 2005, see also the Introduction).

2, right panel). This offers strong evidence for the semantic origin of the obtained distractor effects[2].

Comparison Parity Judgment vs. Naming

Finally, to compare the strength of the semantic effects across tasks, we also conducted an ANOVA combining the RT results of parity judgment and naming. Task and Congruency were included as repeated measures factors. There was a significant main effect of Congruency across tasks, $F(2, 38) = 32.23$, $p < .001$, $MSE = 885$. The congruency effect did not interact with Task, $F < 1$. The main effect of Task was also not significant, $F(1, 19) = 1.64$, $p > .21$, $MSE = 31779$. Similarly, a paired samples t-test revealed that the weights for the regression analyses reported above also did not differ significantly across tasks, $t(19) = 1.38$, $p > .18$.

General Discussion

We obtained clear evidence for semantic access in L1 Roman digit naming. Both parity judgment and naming of Roman digits yielded a significant congruency effect. Participants were slower to name Roman digits that were presented with an Arabic distractor that differed in magnitude than with a neutral distractor. Also, participants were faster to name Roman targets with magnitude congruent distractors than with neutral distractors. We also found that naming RTs increased as a linear function of the numerical distance between the Roman targets and the Arabic distractors: This provides strong evidence for semantic mediation and argues against the possibility that the observed congruency effects were solely the result of a nonsemantic facilitation effect originating from the fact that congruent distractors and targets activate the same phonological representation (see also Footnote 1). Importantly, although the naming task does not explicitly require access to the semantic system, the degree of semantic activation did not differ between naming and parity judgment. We will subsequently discuss the implications of these findings for the number processing domain and for the semantic translation debate in bilingualism.

Number Processing

These results are similar to the results obtained by Fias et al. (2001) for Arabic digits. Using the same interference paradigm, they showed that the processing of Arabic digits was always influenced by a magnitude-related distractor, both in parity judgment and in a naming task, suggesting that Arabic digits quickly and strongly activate their underlying semantic representations. Our results show that the processing of Roman digits is very similar to the processing of Arabic digits. This is no surprise, because both number formats essentially constitute orthographic codes that are arbitrary symbolic representations of the same underlying meaning. If anything, the relation between Roman digits and semantics is a bit more transparent than the mapping from Arabic digits to semantics, given the fact that Roman digits may partly be composed of an analogical structure (see above, e.g., Noel & Seron, 1992), which has a direct relation with the underlying meaning (e.g., the number III consists of three lexical primitives). In this view, it would be surprising to find evidence for weaker mappings from orthography to meaning for Roman digits than for Arabic digits.

Just as the results of Fias et al. (2001), our results argue against models that assume a direct, nonsemantic route from orthographic symbols representing magnitude to phonological output. In the number processing models of Dehaene (1992) and Cipolotti and Butterworth (1995), for example, there is a direct conversion route from Arabic digit print to phonological output. If such a route also existed for Roman digits, naming Roman digits should not have yielded the congruency effects observed in this study. Hence, because there is no apparent reason why these models would include such a direct route for Arabic digits, but not for Roman digits, the present data strongly argue against such a direct route. Therefore, our data are more in line with models that do not assume such a direct naming route for nonverbal number formats (e.g., Brysbaert, 1995; McCloskey, 1992; Noel & Seron, 1995). Finally, following Fias et al.'s (2001; but see Roelofs, 2006) comments on Arabic digits, we would like to note that there are also some similarities between Roman digit naming and picture naming. Whereas most models of word naming assume the existence of a nonsemantic naming route in one form or another (e.g., Besner, 1999; Coltheart et al., 2001; Plaut, Mcclelland, Seidenberg, & Patterson, 1996), most models of picture naming assume that semantic access in naming is mandatory (e.g., Glaser, 1992; Humphreys, Price, & Riddoch, 1999).

In the present study, we only investigated Roman digits with magnitudes 1 to 9. Of course, one may wonder how larger, more complex Roman digits e.g., CLXIV [164]) are processed. Historically, the difficulty of processing such complex symbols is assumed to be the reason why Romans did not attain the mathematical degree of development that they reached in other knowledge domains (e.g., try solving a multiplication like CMIX × LI, Brysbaert, 2005). From a psychological perspective, this difficulty probably origi-

[2] In this view, it may be interesting to note that the study of Fias et al. (2001) yielded a similar congruency effect for Arabic-digit naming (see also Roelofs, 2006), but not an effect of target-distractor distance, as acknowledged by the authors. So, one can not exclude an alternative account of their congruency effect in terms of phonological facilitation. However, a semantic interpretation is consistent with the large body of evidence for semantically mediated Arabic-digit processing (see the Introduction).

nates from the syntactic decomposition that is first needed to further process these complex symbols. It is plausible to assume that such decomposition is also necessary for complex number words such as "two hundred and three," whereas number words such as "twelve" are likely to be processed holistically (Brysbaert, 2005) However, at present, there is virtually no empirical evidence on this issue. As for Arabic digits, there is a similar ongoing debate whether two-digit numerals are processed as a whole (e.g., Dehaene, Dupoux, & Mehler, 1990) or as a combination of powers of 10 (e.g., McCloskey, 1992), which also entails decomposition into number constituents. Evidence for the latter view comes, for example, from a masked priming study by Ratinckx et al. (2005). They showed that Arabic-digit naming is facilitated by primes that share a single digit in the tens or units position (e.g., primes 27 and 61 for target 67), independent of the classical distance priming effect. To our knowledge, the only data on decomposition of Roman digits comes from Noël and Seron (1997). They showed that verification of equations is easier if the calculation is congruent with the Roman digit's structure (e.g., VII = 5 + 2). These findings suggest that even small Roman digits are decomposed during processing (into what Noël and Seron called intermediate representations). Future research will be needed to learn more about the processing of syntactically complex Roman digits, and the extent to which semantics is involved in these processes.

Bilingualism

We started this paper by referring to the fact that bilinguals have even more form representations (besides Arabic/Roman digits and L1 number words) of magnitude than monolinguals, namely L2 number words. To conclude this discussion, we will briefly discuss what is known already about the processing of these number words. This line of research originates from a debate about semantic access in the literature on bilingualism. In psycholinguistic studies of bilingualism, an important question is whether L2 lexical representations have equally strong form-to-meaning mappings as L1 lexical representations. Typically, the existence of L2 form-to-meaning mappings is investigated by checking whether translation from L2 to L1 lexical representations (and vice versa) involves semantic access or not. Some models of bilingualism (e.g., the revised hierarchical model of Kroll and colleagues, e.g., Kroll & Stewart, 1994) assume that L2 word forms do not have direct access to semantics, but only indirectly activate their meaning through their L1 translation equivalents (except in very high levels of L2 proficiency). These models predict no semantic effects in backward translation (from L2 to L1). Other models, such as the model of Duyck and Brysbaert (2004) assume that L2 (and even L3, e.g., Duyck & Brysbaert, 2007) word forms may still develop strong form-to-meaning mappings (early), if the represented meaning is well confined and overlaps maximally across languages, as is the case for number words. Evidence for this assumption was reported by Duyck and Brysbaert (2004), applying a semantic marker from the monolingual numerical cognition domain to a number word translation (and naming) task with L1 and L2 number words. Following earlier monolingual studies, which showed that it takes longer to process larger numbers than smaller numbers (see earlier, e.g., Brysbaert, 1995), they found that it takes longer to translate number words representing larger quantities (e.g., huit [eight]) than number words representing smaller quantities (e.g., quatre [four]) (independent of word frequency, length, etc.). There was no such magnitude effect for L2 and L1 naming of, respectively, L2 and L1 number words, which shows that processing L2 number words, just as L1 number words (see the Introduction), does not always imply semantic mediation. However, the magnitude effect observed in backward (and forward) translation shows that L2 (and L1) number word processing may still yield semantic access in certain semantic tasks such as word translation (see also, for example, the semantic interference effect obtained for number words by Fias et al., 2001, in a semantic parity judgment task). This strongly suggests that L2 number words have strong form-to-meaning mappings. Importantly, Duyck and Brysbaert (2004) also replicated these semantic translation effects with a set of newly learned Estonian number words, suggesting that strong form-to-meaning connections develop early when acquiring new (L2) form representations of magnitude.

With respect to the present study, it is important to realize that Roman digits, just as L2 number words, are essentially lexical (form) representations of the same meaning as their L1 (or L2) translation equivalent(s). The present semantic effects in Roman digit naming, similar to the semantic magnitude effects in L1 naming of L2 number words (Duyck & Brysbaert, 2004), can, therefore, also be considered evidence for strong form-to-meaning mappings of non-L1 orthographic representations. This is especially important because Roman digits are used very infrequently. In the bilingual revised hierarchical model (e.g., Kroll & Stewart, 1994), but also in models of naming such as that of Coltheart et al. (2001), direct mappings from orthography to meaning are only expected to be important for words that have been frequently encountered. However, the present findings are consistent with the strong lexicosemantic connections observed by Duyck and Brysbaert (2004) for newly learned (not frequently encountered) Estonian number words.

Of course, there are also important differences between Roman digits and L2 words. First, this lexical representation is only an orthographic representation. Unlike other L2 words, which also have a phonological presentation (more or less similar to the associated L1 phonological representation), Roman digits constitute an exclusively orthographic code. Their only associated phonological representation is that of their L1 counterpart. Second, although Roman digits are also made up of so-called lexical primitives (see above, Noel & Seron, 1992), unlike words, they are not composed of orthographic units (letters) that have a (more or less) transparent mapping from orthography to phonology. Because of this difference, it may seem a bit strange to even consider a nonsemantic conversion route for symbols such as Roman digits. However, some models of word naming (e.g., Besner, 1999) assume that such a direct conversion route may consist of a direct link between an orthographic input lexicon and speech output. Such a route may be very useful, for example, for the naming of logographic languages such as Japanese Kanji, in which the unitary symbol-like orthographic representations also are arbitrarily mapped onto phonology. Also, as previously indicated, a nonsemantic direct route for Arabic digits is present in some models of number processing (Cipolotti & Butterworth, 1995; Dehaene, 1992), even though there is also no clear relation between Arabic digit forms and their associated L1 phonology.

To summarize, we have obtained clear evidence for semantic mediation in L1 naming of Roman digits. This strongly suggests that Roman digits have strong form-to-meaning mappings, just as Arabic digits. This is consistent with models of bilingual lexicosemantic organization (e.g., Duyck & Brysbaert, 2004) that assume that non-L1 form representations may develop strong lexicosemantic connections, even if they are used infrequently.

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References

Besner, D. (1999). Bias processes in reading: Multiple routines in localist and connectionist models. In R.M. Klein & P.A. McMullen (Eds.), *Converging methods for understanding reading and dyslexia. Language, speech, and communication* (pp. 413–458). Cambridge, MA: MIT Press.

Brysbaert, M. (1995). Arabic number reading: On the nature of the numerical scale and the origin of phonological recoding. *Journal of Experimental Psychology: General, 124*, 434–452.

Brysbaert, M. (2005). Number recognition in different formats. In J.I.D. Campbell (Ed.), *Handbook of mathematical cognition* (pp. 23–42). Hove, UK: Psychology Press.

Campbell, J.I.D. (1994). Architectures for numerical cognition. *Cognition, 53*, 1–44.

Cipolotti, L., & Butterworth, B. (1995). Toward a multiroute model of number processing: Impaired number transcoding with preserved calculation skills. *Journal of Experimental Psychology: General, 124*, 375–390.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual-route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*, 204–256.

Dehaene, S. (1992). Varieties of numerical abilities. *Cognition, 44*, 1–42.

Dehaene, S., Dupoux, E., & Mehler, J. (1990). Is numerical comparison digital: Analogical and symbolic effects in two-digit number comparison. *Journal of Experimental Psychology: Human Perception and Performance, 16*, 626–641.

Duyck, W., & Brysbaert, M. (2002). What number translation studies can teach us about the lexicosemantic organisation in bilinguals. *Psychologica Belgica, 42*, 151–175.

Duyck, W., & Brysbaert, M. (2004). Forward and backward number translation requires conceptual mediation in both balanced and unbalanced bilinguals. *Journal of Experimental Psychology: Human Perception and Performance, 30*, 889–906.

Duyck, W., & Brysbaert, M. (2008). Semantic access in number word translation: The role of crosslingual lexical similarity. *Experimental Psychology, 55,* 102–112.

Fias, W., Brysbaert, M., Geypens, F., & d'Ydewalle, G. (1996). The importance of magnitude information in numerical processing: Evidence from the SNARC effect. *Mathematical Cognition, 2*, 95–110.

Fias, W., Reynvoet, B., & Brysbaert, M. (2001). Are Arabic numerals processed as pictures in a Stroop interference task? *Psychological Research, 65*, 250–259.

Glaser, W.R. (1992). Picture naming. *Cognition, 42*, 61–105.

Gonzalez, E.G., & Kolers, P.A. (1982). Mental manipulation of arithmetic symbols. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8*, 308–319.

Henik, A., & Tzelgov, J. (1982). Is 3 greater than 5: The relation between physical and semantic size in comparison tasks. *Memory and Cognition, 10*, 389–395.

Humphreys, G.W., Price, C.J., & Riddoch, M.J. (1999). From objects to names: A cognitive neuroscience approach. *Psychological Research-Psychologische Forschung, 62*, 118–130.

Ito, Y., & Hatta, T.H. (2003). Semantic processing of Arabic, Kanji, and Kana numbers: Evidence from interference in physical and numerical size judgments. *Memory and Cognition, 31*, 360–368.

Kroll, J.F., & Stewart, E. (1994). Category interference in translation and picture naming: Evidence for asymmetric connections between bilingual memory representations. *Journal of Memory and Language, 33*, 149–174.

Lorch, R.F., & Myers, J.L. (1990). Regression-analyses of repeated measures data in cognitive research. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*, 149–157.

McCloskey, M. (1992). Cognitive mechanisms in numerical processing: Evidence from acquired dyscalculia. *Cognition, 44*, 107–157.

Noel, M.P., & Seron, X. (1992). Notational constraints and number processing: A reappraisal of the Gonzalez and Kolers (1982) study. *Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology, 45*, 451–478.

Noel, M.P., & Seron, X. (1995). Lexicalization errors in writing Arabic numerals: A single-case study. *Brain and Cognition, 29*, 151–179.

Noel, M.P., & Seron, X. (1997). On the existence of intermediate representations in numerical processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*, 697–720.

Pansky, A., & Algom, D. (1999). Stroop and Garner effects in comparative judgment of numerals: The role of attention. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 39–58.

Pavese, A., & Umilta, C. (1998). Symbolic distance between numerosity and identity modulates Stroop interference. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 1535–1545.

Plaut, D.C., Mcclelland, J.L., Seidenberg, M.S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasiregular domains. *Psychological Review, 103*, 56–115.

Ratinckx, E., Brysbaert, M., & Fias, W. (2005). Naming two-digit Arabic numerals, evidence from masked priming studies. *Journal of Experimental Psychology: Human Perception and Performance, 31*, 1150–1163.

Reynvoet, B., & Brysbaert, M. (1999). Single-digit and two-digit Arabic numerals address the same semantic number line. *Cognition, 72*, 191–201.

Reynvoet, B., Brysbaert, M., & Fias, W. (2002). Semantic priming in number naming. *Quarterly Journal of Experimental Psychology, 55A*, 1127–1139.

Roelofs, A. (2006). Functional architecture of naming dice, digits, and number words. *Language and Cognitive Processes, 21*(1–3), 78–111.

Sokol, S.M., Mccloskey, M., Cohen, N.J., & Aliminosa, D. (1991). Cognitive representations and processes in arithmetic: Inferences from the performance of brain-damaged subjects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*, 355–376.

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