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# Short article

# Cross-lingual numerical distance priming with second-language number words in native- to third-language number word translation

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An important question in research about bilingualism is whether translation from a second language (L2) to the native language (L1) is semantically mediated or whether it occurs through word associations at the lexical level. Recent research has shown that both L1 and L2 number word translation imply semantic access, suggesting strong L2 lexicosemantic mappings for number words (Duyck & Brysbaert, 2004). In the present study, this assumption was further explored by means of a cross-lingual number distance priming paradigm with Dutch–English–French trilinguals. We found that number word translation from L1 to the third language (L3), and vice versa, was facilitated by L2 number masked word primes that represented the same magnitude as the target (translation equivalents), relative to primes that are numerically less close. This confirms the existence of strong L2 lexicosemantic mappings for number words and generalizes previous semantic effects in L1–L2 translation to translation processes between L1 and L3.

*Keywords*: Numbers; Priming; Translation; Semantic mediation.

A central question in the literature on bilingualism is whether translation from one's second language (L2) to the native language (L1) relies on direct word–word associations in the lexicon, or whether it requires activation of the meaning of the words. This question originates from a crucial assumption of Kroll and Stewart's revised hierarchical model (RHM; see Figure 1, e.g., Kroll &

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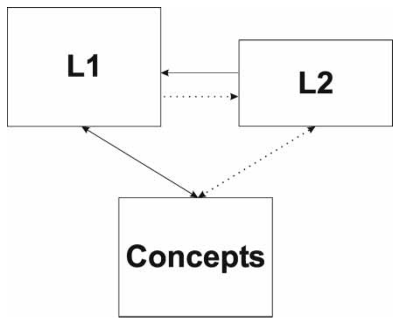


**Figure 1.** *The revised hierarchical model of bilingual memory (Kroll & Stewart, 1994). Solid lines represent stronger links than dotted lines.*



Stewart, 1994), which provides the literature's dominant view on bilingual lexicosemantic organization. The RHM assumes that L2 words do not have direct access to semantics (unlike L1 words), but only indirectly activate their meaning through lexical associations with their L1 translation equivalents. This asymmetry is only expected to disappear in very high levels of proficiency, as L2 lexicosemantic connections are assumed to develop late in L2 word acquisition. As a consequence of this assumption, for regular L2 proficiency levels, backward translation (from L2 to L1) is assumed to occur through fast and direct links at the lexical level, whereas forward translation (from L1 to L2) requires mandatory semantic access. Typically, this asymmetric architecture has been supported by demonstrating semantic effects in forward translation, in the absence of semantic effects for backward translation. For instance, Sholl, Sankaranarayanan, and Kroll (1995) reported that forward word translation was facilitated when the involved concepts had been primed by the earlier presentation of pictures. This effect was not present in the backward translation condition, suggesting a less conceptually mediated translation process. For a more detailed review of findings supporting the different assumptions of the RHM, we refer to Kroll and Tokowicz (2005).

Recently, the strong asymmetric assumption of the RHM has been challenged by a number of semantic effects observed in backward translation tasks. For instance, La Heij, Hooglander, Kerling, and Van der Velden (1996) found that the translation of target words (e.g., CHAIR) is facilitated by distractor pictures depicting an object (e.g., a table) belonging to the same semantic category. This semantic facilitation effect was stronger for translation than for naming and emerged in both translation directions. More recently, similar symmetric effects were obtained by Duyck and Brysbaert (2004), who applied the monolingual number magnitude effect, commonly investigated in the numerical cognition domain, as a semantic marker to a word translation task. Following this approach, Duyck and Brysbaert found that it takes longer to translate number words representing larger quantities (e.g., *eight*) than number words representing smaller quantities (e.g., *four*), independent of word length and frequency effects. Because this semantic number magnitude effect was not present in intralingual naming, but still emerged in both directions of translation, this strongly suggests that both directions of translation may involve mandatory semantic access. Importantly, Duyck and Brysbaert replicated these effects with artificial number words that were acquired only a few minutes before the translation task, providing evidence for the development of strong L2 lexicosemantic mappings early during the word acquisition process. Based on these findings, Duyck and Brysbaert proposed an alternative model of bilingual lexicosemantic organization, which differs from the RHM in two important ways. First, in this model, the strength and speed of development of intralexical and lexicosemantic connections is no longer a function only of language, but also of word-level variables. For instance, as can be seen in Figure 2, the model assumes that L2 lexicosemantic connections will be stronger (and develop earlier) for words from which the semantic representations are almost completely overlapping across languages (such as number words). Second, translation is no longer the output of either the lexical or semantic route. Instead, it is the result of relative activation forwarded from both lexical and semantic representations, which may more or less be involved depending on variables such as cross-lingual semantic overlap.

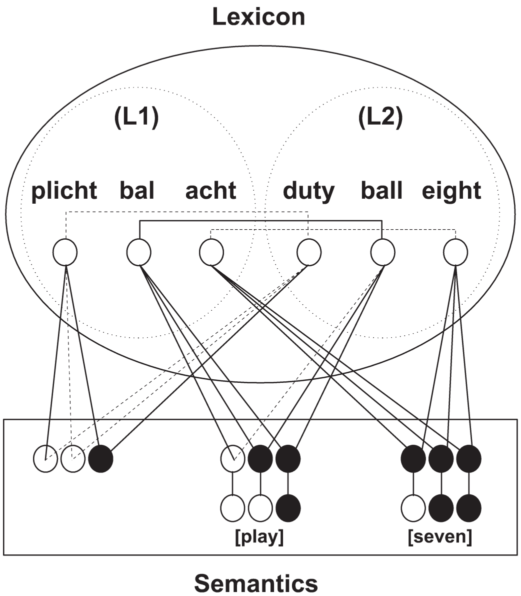


**Figure 2.** *Duyck and Brysbaert's model of lexicosemantic organization (as published in Duyck & Brysbaert, 2004), with differently weighted lexicosemantic and intralexical connections. Solid lines represent stronger links than dotted lines. Depicted words and semantic representations are illustrative examples for Dutch–English bilinguals.*

The goal of the present study is twofold. First, we want to provide further evidence for this model's assumption of strong L2 lexicosemantic connections for words that have almost maximal semantic overlap across languages. Because Duyck and Brysbaert (2004) have shown that number words are excellent candidates to test the existence of strong and fast L2 lexicosemantic connections, these words should also yield other markers of semantic access, other than the number magnitude effect previously investigated. This will be investigated using the numerical distance priming paradigm with masked L2 number word primes. Because this paradigm uses very briefly presented primes, it is especially interesting that it allows direct investigation of the time course by which L2 word forms may activate underlying semantics. In the monolingual version of this paradigm, it is generally found that the naming of a number target is facilitated by number primes of a close magnitude. For instance, the digit *7* is named faster after digit prime *6* than after prime *5* (e.g., Brysbaert, 1995). This effect is generally interpreted as evidence for the hypothesis that the prime quickly and automatically accesses an abstract ordinal number line, on which activation spreads from one semantic representation to magnitudes nearby (e.g., Brysbaert, 1995; Reynvoet & Brysbaert, 2004). Importantly for the present study, this distance priming effect also emerges with number word primes and even across number word and Arabic digit notations (i.e., naming *seven* is primed by the digit *7* and vice versa, e.g., Reynvoet, Brysbaert, & Fias, 2002) providing evidence for the semantic origin of the effect. Also, even across notations, the effect is obtained with masked primes at very short stimulus onset asynchronies (SOAs), which excludes a strategic origin of the effect and supports its automaticity (Reynvoet & Brysbaert, 2004). Additional monolingual evidence has shown that this distance effect may not easily be explained in terms of associative priming due to the fact that subsequent numbers are often produced serially in counting. First, Koechlin, Naccache, Block, and Dehaene (1999) have shown that distance priming is symmetrical (i.e., the target *6* is primed equally well by the prime *5* than by *7*) and not stronger in the forward prime–target direction, as an associative hypothesis would predict. Second, it has been shown (Reynvoet & Brysbaert, 1999) that the numerical distance effect is the same for naming as for semantic tasks such as number comparison or parity judgement, which also supports its semantic locus. Third, Van Opstal, Gevers, De Moor, and Verguts (in press) showed that letters, which are also serially, but not semantically, associated (as numbers), do not elicit a distance priming effect.

Given these findings in monolingual distance priming studies, L2 words that have strong lexicosemantic connections (such as number words, e.g., Duyck & Brysbaert, 2004) should also facilitate processing of subsequent number words that are numerically close, just as L1 number words. Because this effect relates to an abstract representation of magnitude, this effect should also occur when prime (L2) and target (L1 or L3) belong to a different language, similar to the cross-notation priming observed between Arabic and verbal numerals. To test the RHM's asymmetry hypothesis in word translation, it is of crucial interest to see whether such a semantic cross-lingual numerical distance priming effect occurs not only when these L1 and L3 number word targets have to be named (as in Reynvoet & Brysbaert, 2004), but also when they are translated.

As a second goal, the present study generalizes the earlier symmetric semantic mediation effects obtained in L1–L2 translation to translation processes between L1 and a third language (L3). First, this approach has a methodological advantage. Using L1–L3 translation in combination with L2 primes guarantees that any priming effect originates from the semantic relation between the L2 prime and the L1 or L3 target and not, for example, from perceptual overlap between L2 primes and L2 targets, or from compatibility between a L2 prime and a L2 response. Second, this is also of theoretical relevance. At present, there are only a few studies that have investigated L1–L3 translation in trilinguals. The first is that of de Groot and Hoeks (1995). They investigated translation with Dutch–English–French trilinguals, but only looked at forward translation, so that this study does not allow to compare semantic mediation in forward versus backward translation. To our knowledge, the only other trilingual translation study is that of Francis and Gallard (2005). Using a repetition priming paradigm, they investigated L1–L3 translation by English–Spanish–French trilinguals and found that both backward and forward L1–L3 translation were semantically mediated (for similar findings with Dutch–English–German bilinguals, see also Duyck & Brysbaert, 2008).

Similar to the monolingual distance priming effects (e.g., Reynvoet & Brysbaert, 2004; Reynvoet et al., 2002), we expect that the present study will yield the strongest facilitation effects when the magnitudes represented by the L2 prime and the L1 or L3 target are identical, relative to when they are not (although additional effects between prime–target distances 1 and 2, or 2 and 3, may also occur). From a different viewpoint, this situation corresponds to the translation priming paradigm—for example, for a Dutch–English–French trilingual, respectively, prime *two* (L2) targets *twee* (L1) or *deux* (L3). In the literature on bilingualism, it has often been investigated with nonnumerical stimuli whether it is possible to prime processing of L1 word targets with L2 translation equivalents, and vice versa. Generally, these studies have shown that L2 targets are primed by L1 translations in a lexical decision task, whereas processing L1 targets is not facilitated by L2 primes (e.g., Gollan, Forster, & Frost, 1997; Jiang & Forster, 2001). In terms of the RHM, this asymmetry is generally explained by the absence of strong L2 lexicosemantic connections: Assuming a semantic locus for translation priming (e.g., Finkbeiner, Forster, Nicol, & Nakamura, 2004), the null effect is generally interpreted as evidence that the L2 primes could not strongly activate their underlying semantic representation. This translation priming asymmetry for lexical decision was also reported in a French–English study by Grainger and Frenck-Mestre (1998). However, they did report L2–L1 translation priming in a semantic categorization task (see also Finkbeiner et al., 2004). In the context of the present study, these findings suggest that, if translation between L1 and L3 involves semantic activation, and if L2 number words indeed have strong lexicosemantic connections (Duyck & Brysbaert, 2004), translation priming from L2 number word primes on L1 or L3 targets should occur in a translation task. To our knowledge, this is the first study ever to investigate translation priming from L2 masked primes to L3 targets.

To conclude, the present study uses a cross-lingual version of the numerical distance paradigm with L2 number word primes and L1/L3 number word targets, in order to assess (a) the existence of strong L2 lexicosemantic connections, and (b) the degree of semantic involvement in translation processes between L1 and L3.

## EXPERIMENT

### Method

#### *Participants*

A total of 17 university students participated for course requirements. Mean age was 21.5 years

**Table 1.** *Self-assessed ratings of L1, L2, and L3 proficiency on a 7-point Likert scale*

| *Skill* | *L1 (Dutch)* | *L2 (English)* | *L3 (French)* |
|---|---|---|---|
| Writing | 6.5 (0.5) | 4.5 (1.1) | 3.8 (0.8) |
| Speaking | 6.6 (0.5) | 4.9 (1.0) | 4.2 (0.7) |
| Reading | 6.5 (0.5) | 5.3 (1.0) | 4.7 (1.1) |
| General proficiency | 6.5 (0.5) | 4.9 (1.0) | 4.3 (0.7) |

*Note:* Scale ranges from 0 (very bad) to 7 (very good). Standard deviations in parentheses.

($SD = 2.0$). They were all Dutch–English–French trilinguals, living in an L1-dominant environment, speaking Dutch at home, at school, with friends, and so on. All participants started to learn English and French in a scholastic setting (formal English and French courses are mandatory in Belgian high school). In everyday life, they are much more exposed to English than to French through Belgian popular media and entertainment, such as music, internet, films, television, and so on. Because of this high exposure, and because of the larger similarity between Dutch and English, selected participants reported English, rather than French, as their L2. Participants were asked to rate their L1, L2, and L3 proficiency on a 7-point Likert scale ranging from "very bad" to "very good". Means are reported in Table 1. Self-reported, general L1 ($M = 6.5$) proficiency differed significantly from that for L2 ($M = 4.9$), $F(1, 16) = 54.59$, $p < .001$, which in turn differed from that for L3 ($M = 4.3$), $F(1, 16) = 4.93$, $p < .05$. Ratings for specific language skills also differed significantly between L1, L2, and L3 (all $p$s $< .05$).

### *Stimuli and procedure*

The materials and procedure were as similar as possible to those of Reynvoet et al. (2002), who also investigated distance priming with number word primes, except that we used L1, L2, and L3 stimuli. Targets were L1 (Dutch) and L3 (French) number words representing magnitudes *four, five*, and *six* (respectively, *vier, vijf, zes*, and *quatre, cinq, six*). All L1 and L3 targets had to be named in L1 and L3, so that each participant completed two naming blocks and two translation blocks (forward and backward). Naming blocks were included to compare any priming effects in naming with those in translation, following the original formulation of the RHM (Kroll & Stewart, 1994). The order of these blocks was counterbalanced across participants. In all blocks, targets were preceded by L2 number word primes that varied with respect to the numerical distance from the target (7 levels from −3, identical, to +3). Each prime–target combination was presented three times, so that each block contained 63 experimental trials and 27 additional filler trials, in order to increase the number of possible responses for the participants. Each of the filler targets (magnitudes 7, 8, and 9) was shown nine times with a magnitude 8 prime. The order of experimental and filler trials within each block was randomized. Before each block, participants completed 20 practice trials in the respective stimulus and naming languages. Targets in practice trials ranged from 11 to 13 and always had magnitude 12 primes (see also Reynvoet et al., 2002).

Before each block, participants received instructions to name or translate the number word targets. Similar to Reynvoet and Brysbaert (2004; 115-ms SOA condition), each trial started with the presentation of a forward mask during 71 ms, synchronized with the refresh cycle of the screen (70 Hz). This mask consisted of six hash marks (#) of the same size and font as those of the primes and targets. It was replaced by the L2 prime, which was shown for 43 ms, followed by a backward mask (71 ms) and the L1 or L3 number word target.[1] Targets stayed on the screen until the response triggered a high-accuracy voice-key (Duyck, Anseel, Szmalec, Mestdagh, Tavernier, & Hartsuiker, in press). During the

[1] Note that Reynvoet and Brysbaert (2004) have shown that this masked priming procedure does not render primes completely invisible. However, as argued by Reynvoet and Brysbaert (see also Reynvoet & Brysbaert, 1999; Reynvoet, Brysbaert, & Fias, 2002), this does not mean that resulting priming effects are not automatic, as Neely (1991) showed that strategic expectancy effects require SOAs of more than 250 ms to influence the results, which is much more than the present 115-ms SOA.

intertrial interval (1,700 ms), the experimenter noted whether the response was correct. After the experiment, participants completed proficiency and hypothesis awareness questionnaires, which revealed that none of the participants was aware of the purpose of the experiment.

## Results

Filler trials and trials that yielded voice-key errors (5.44% of all trials) were not included in the analyses. The proportion of naming/translation errors on the remaining trials was extremely low (1.73%). Because naming/translation accuracy was virtually at a maximum in all conditions, it showed no significant effects. Mean reaction times (RTs) on correct trials (displayed in Figure 3) were analysed by means of a repeated measures analysis of variance (ANOVA) with naming language (Dutch-L1 vs. French-L3), stimulus language (Dutch-L1 vs. French-L3), and absolute-value prime–target distance (0, 1, 2, or 3) as independent variables. All RTs that deviated more than 3 standard deviations from the participant's overall RT were considered as outliers and were removed from this analysis (1.09% of the remaining data).

As expected, there was a main effect of naming language, $F(1,\ 16) = 14.82$, $p < .01$, $MSE = 5{,}576$. Responses in French (L3) were significantly slower than responses in Dutch (L1), respectively, $M = 507$ and $M = 542$. There was no effect of stimulus language, $F < 1$. The interaction effect between naming language and stimulus language was significant, $F(1,\ 16) = 60.58$, $p < .001$,



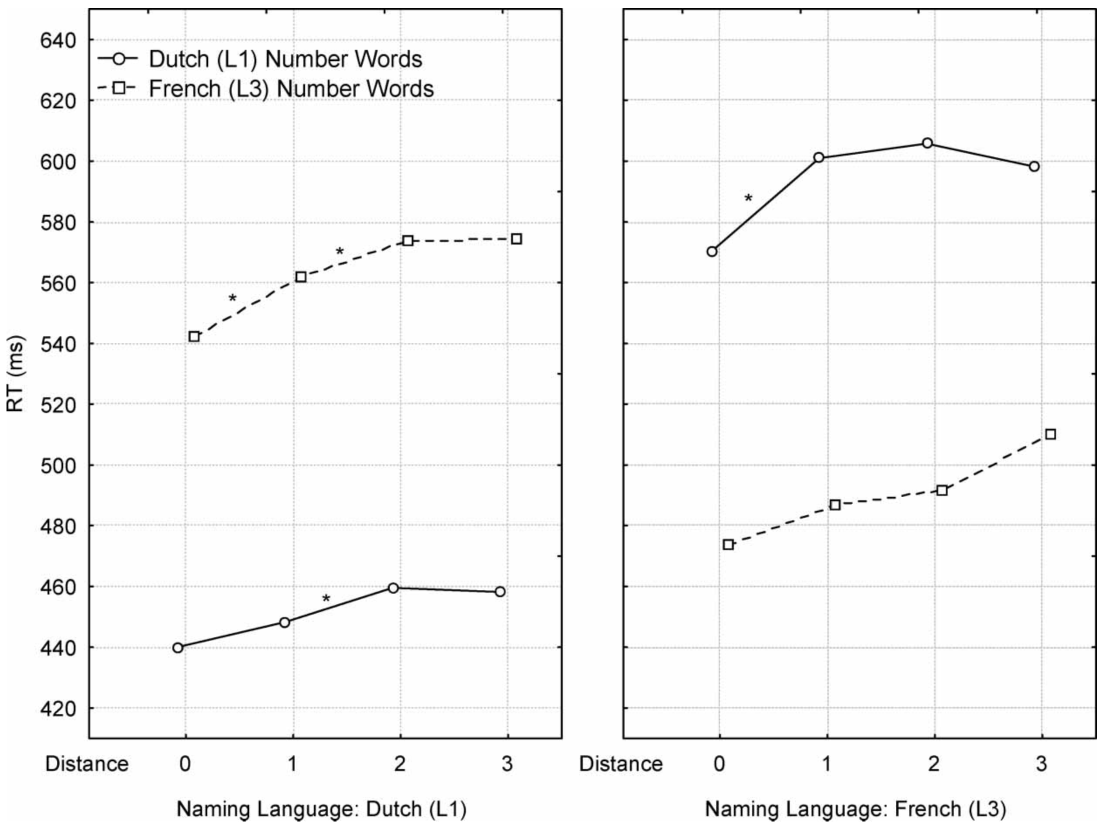


**Figure 3.** *Mean reaction times as a function of naming language, stimulus language, and prime–target distance. Asterisks indicate significant planned comparisons between consecutive prime–target distances within Naming Language × Stimulus Language conditions (*p < .05).*

$MSE = 12{,}956$. Translation trials ($M = 578$) were significantly slower than within-language naming trials ($M = 471$). Also, forward translation trials ($M = 594$) were significantly slower than backward translation trials ($M = 563$), $F(1, 16) = 4.55$, $p < .05$, $MSE = 7{,}057$.

The overall main effect of prime–target distance was significant, $F(3, 8) = 13.70$, $p < .001$, $MSE = 825$. Respective means for distances 0, 1, 2, and 3 were 507 ms, 524 ms, 533 ms, and 535 ms. As can be seen in Figure 3, planned comparisons showed that RTs were significantly faster on distance 0 trials (translation priming) than on distance 1 trials in the forward translation condition, $F(1, 16) = 8.02$, $p < .05$, $MSE = 987$. Interestingly, this effect was also significant in backward translation, $F(1, 16) = 4.80$, $p < .05$, $MSE = 681$. This significant 20-ms translation priming effect for backward translation was not smaller than the 31-ms effect obtained in forward translation, $F < 1$. For within-language naming in L1 and L3, the difference between distance 0 and distance 1 trials was not significant: respectively, $F < 1$ and $F(1, 16) = 2.48$, $p > .13$, $MSE = 581$. Interestingly, in the backward translation condition, additional to the translation priming effect (distance 0 vs. distance 1), RTs were also significantly faster on distance 1 than on distance 2 trials, $F(1, 16) = 7.99$, $p < .05$, $MSE = 153$. This additional distance priming effect was not significant in forward translation, $F < 1$. For within-language L1 naming, there was also a significant difference between distance 1 and distance 2 trials, $F(1, 16) = 6.09$, $p < .05$, $MSE = 177$. As can be seen in Figure 3, all other planned comparisons between consecutive prime–target distances were not significant.

## GENERAL DISCUSSION

Using a bilingual version of the numerical distance priming paradigm with L2 number word primes and L1/L3 targets, we obtained clear evidence for semantic access in both forward and backward translation of number words. Forward translation of L1 number words (e.g., *vier*) to L3 (e.g., *quatre*) was significantly faster when the L1 number word was preceded by its L2 translation equivalent (e.g., *four*). Similarly, backward translation of L3 target number words to L1 was also facilitated by L2 translations. Interestingly, backward translation of L3 targets (e.g., *quatre*) was also significantly faster when the numerical distance from the target to the L2 number word primes was 1 (e.g., *three*) than when it was 2 (e.g., *two*).[2] This adds further support to the semantic origin of the numerical distance effects. Finally, we obtained no translation priming from L2 primes on the L1 or L3 naming of number words. We now subsequently discuss the theoretical implications of these findings for the fields of bilingualism and numerical cognition.

Duyck and Brysbaert's (2004) model of bilingual lexicosemantic organization assumes that the existence, strength, and speed of development of L2 lexicosemantic connections depends not only on language, but also on the degree of semantic overlap of translation equivalents. Because Duyck and Brysbaert have shown that number words are excellent candidates to test this assumption, we implemented their number word translation task in a numerical distance priming paradigm, as a new marker of semantic access during word translation. Because this paradigm uses very briefly presented primes, the first aim of the present study was to directly tap into the time course by which L2 word forms activate their underlying semantic representations. Following Brysbaert's (1995) account of numerical distance priming (see also, e.g., Reynvoet & Brysbaert, 2004), the effects reported above for both forward and backward translation conditions indicate that the L2 number word primes quickly

[2] To assess whether any of these priming effects were confounded by word frequency, we also carried out some regression analyses for repeated measures designs (see also Duyck & Brysbaert, 2004), including prime–target distance, target magnitude, and frequency as the independent variables. These exploratory analyses showed that taking frequency into account did not nullify any of the reported priming effects. Also, removing all trials with the French target word *six*, a cognate of the English prime word *six*, did not nullify priming effects in backward and forward translation. We thank an anonymous reviewer for these suggestions.

and automatically activated their underlying semantic representation, even though they were only presented very briefly (43 ms). This suggests strong lexicosemantic mappings for L2 number words and supports Duyck and Brysbaert's assumption that L2 form-to-meaning mappings may be very strong and may be activated rapidly, if translation equivalents' word meaning overlaps maximally across languages. In this view, it may be important to note that the adopted full-factorial within-subject design only allowed a limited number of critical targets and responses (i.e., three in each Stimulus Language × Naming Language condition). Although this adds strength to the statistical robustness of the present findings, it remains important to generalize these conclusions to other (types of) word stimuli.

As a second goal, we wanted to provide empirical evidence for semantic mediation in translation between L1 and L3. The semantic facilitation effects of L2 translation primes on the translation of L1 and L3 number words offer strong evidence that semantic access may occur in both forward and backward translation between L1 and L3. This shows that the symmetric semantic mediation findings of Duyck and Brysbaert (2004) for L1–L2 translation may be generalized to L1–L3 translation. This conclusion is consistent with the only other study that has reported semantic mediation in L3–L1 translation (but see Duyck & Brysbaert, 2008). Using a repetition priming paradigm, Francis and Gallard (2005) investigated L1–L3 translation by English–Spanish–French trilinguals and also found that both backward and forward translation were semantically mediated.

As noted in the Introduction, earlier studies have consistently failed to find translation priming from L2 masked primes to L1 targets in word recognition tasks such as lexical decision. However, such L2–L1 priming has been found when the experimental task explicitly requires access to semantics, such as semantic categorization (Finkbeiner et al., 2004; Grainger & Frenck-Mestre, 1998). In this view, the priming effects of L2 primes on L1 (and even L3) targets in the present study are consistent with these earlier translation priming findings if one assumes that translation requires semantic access. In fact, the present study also offers an important contribution to the literature, as no study has ever investigated translation priming from L2 primes to L3 translation targets.

Finally, these data also have some implications for the numerical cognition domain. First, our data are consistent with those of Reynvoet et al. (2002) and Reynvoet and Brysbaert (2004), who also obtained numerical distance priming with number word primes. Because the present effects were obtained with primes and target that belong to different languages, they offer further evidence for a semantic origin of identity and distance priming, together with the cross-notational Arabic-verbal priming effects reported earlier (Reynvoet et al., 2002). Further evidence for a semantic locus of the distance effect comes from the observation (e.g., Koechlin et al., 1999) that the distance priming effect is symmetrical, and not asymmetric (with stronger priming in the forward prime–target direction) as an associative hypothesis would predict.[3] Second, we also obtained some evidence for semantic involvement in L1 number word naming. Although semantic effects were certainly weaker than in translation conditions, we still found that naming of L1 words was significantly faster when preceded by L2 distance 2 primes than by distance 1 primes. This is consistent with Reynvoet et al. (2002; see also Reynvoet & Brysbaert, 2004), who also obtained evidence for semantic involvement in number word naming. They explained these effects, and the apparent contradiction with evidence for nonsemantic naming of number words (e.g., Fias, Reynvoet, & Brysbaert, 2001), within

[3] Priming effects were also symmetrical in the present study. Reanalysing our data with prime–target distance as an independent variable with 7 levels (−3 to +3) showed that the priming effects obtained in both forward and backward translation were not stronger for primes smaller than the target than for primes larger than the target (all $p$s > .12). Similarly, an analysis with direction as an independent variable (2 levels, comparing distances −3, −2, −1 vs. +1, +2, +3), showed that translation responses to targets following smaller primes were not faster than responses to targets following larger primes (all $p$s > .23).

an interactive cascaded model of number processing with a semantic and nonsemantic route that may continuously influence each other. Within this model, by default, orthographic input of number words directly activates phonology, similar to the direct grapheme–phoneme conversion route present in many models of word naming (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). However, if the semantic route is preactivated by a related prime, it will be activated fast and strongly enough to influence the naming process. Although this model may explain the distance 1 versus distance 2 effect obtained in the present study, it is less clear why L1 number word naming yielded no translation priming. Of course, due to the large within-subject design with relatively few participants, the present study was not optimized to detect weak (gradual) priming effects in within-language naming, nor to detect a significant triple interaction between Naming Language × Stimulus Language × Prime–Target Distance (with significantly stronger distance priming in translation conditions than in naming conditions). However, even with this limited number of participants, significant distance priming effects were obtained in both translation conditions, which were of primary interest to the present study.

To summarize, the present study used a bilingual version of the numerical distance priming paradigm with L2 number word primes and L1/L3 targets. We obtained clear evidence for semantic access in both forward and backward translation of number words between L1 and L3. Translation was significantly faster when L1 or L3 number words were preceded by masked L2 translation equivalent primes.

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## REFERENCES

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.

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.

de Groot, A. M. B., & Hoeks, J. C. J. (1995). The development of bilingual memory: Evidence from word translation by trilinguals. *Language Learning*, *45*, 683–724.

Duyck, W., Anseel, F., Szmalec, A., Mestdagh, P., Tavernier, A., & Hartsuiker, R. (in press). Improving accuracy in detecting acoustic onsets. *Journal of Experimental Psychology: Human Perception and Performance.*

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 cross-lingual lexical similarity. *Experimental Psychology*, *55*, 102–112.

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

Finkbeiner, M., Forster, K., Nicol, J., & Nakamura, K. (2004). The role of polysemy in masked semantic and translation priming. *Journal of Memory and Language*, *51*, 1–22.

Francis, W. S., & Gallard, S. L. K. (2005). Concept mediation in trilingual translation: Evidence from response time and repetition priming patterns. *Psychonomic Bulletin & Review*, *12*, 1082–1088.

Gollan, T. H., Forster, K. I., & Frost, R. (1997). Translation priming with different scripts: Masked priming with cognates and noncognates in Hebrew–English bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *23*, 1122–1139.

Grainger, J., & Frenck-Mestre, C. (1998). Masked priming by translation equivalents in proficient bilinguals. *Language and Cognitive Processes*, *13*, 601–623.

Jiang, N., & Forster, K. I. (2001). Cross-language priming asymmetries in lexical decision and episodic recognition. *Journal of Memory and Language*, *44*, 32–51.

Koechlin, E., Naccache, L., Block, E., & Dehaene, S. (1999). Primed numbers: Exploring the modularity of numerical representations with masked and unmasked semantic priming. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 1882–1905.

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.

Kroll, J. F., & Tokowicz, N. (2005). Models of bilingual representation and processing: Looking back and to the future. In J. F. Kroll & A. M. B. de Groot (Eds.), *Handbook of bilingualism: Psycholinguistic approaches* (pp. 531–553). New York: Oxford University Press.

La Heij, W., Hooglander, A., Kerling, R., & Van der Velden, E. (1996). Nonverbal context effects in forward and backward word translation: Evidence for concept mediation. *Journal of Memory and Language*, *35*, 648–665.

Neely, J. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G. W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 264–336). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

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. (2004). Cross-notation number priming investigated at different stimulus onset asynchronies in parity and naming tasks. *Experimental Psychology*, *51*, 81–90.

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

Sholl, A., Sankaranarayanan, A., & Kroll, J. F. (1995). Transfer between picture naming and translation: A test of asymmetries in bilingual memory. *Psychological Science*, *6*, 45–49.

Van Opstal, F., Gevers, W., De Moor, W., & Verguts, T. (in press). Dissecting the symbolic distance effect: Comparison and priming effects in numerical and non-numerical orders. *Psychonomic Bulletin and Review*.