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The SNARC effect in the processing of second-language number words: Further evidence for strong lexico-semantic connections

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We present new evidence that word translation involves semantic mediation. It has been shown that participants react faster to small numbers with their left hand and to large numbers with their right hand. This SNARC (spatial-numerical association of response codes) effect is due to the fact that in Western cultures the semantic number line is oriented from left (small) to right (large). We obtained a SNARC effect when participants had to indicate the parity of second-language (L2) number words, but not when they had to indicate whether L2 number words contained a particular sound. Crucially, the SNARC effect was also obtained in a translation verification task, indicating that this task involved the activation of number magnitude.

As a lot of people have knowledge of two or even more languages, there is an increasing interest in research on the cognitive processes involved in translation from the first language (L1) to the second language (L2; forward translation) and from L2 to L1 (backward translation). One of the main questions here is to what extent these translations are based on word–word associations and to what extent they require semantic mediation.

The organization of this Introduction is as follows. First, we present the dominant model of word translation. Then, we summarize the evidence pointing to a pivotal role of semantic mediation. Finally, we indicate why number translation can shed further light on the issue by looking at the SNARC effect.

The revised hierarchical model of bilingualism

The dominant view of bilingual lexicosemantic organization and word translation is the revised hierarchical model (RHM) of Kroll and Stewart (1994; see also Kroll & de Groot, 1997). In this model, L1 and L2 words are represented in two separate lexicons that access a common conceptual system. There are connections between the word forms that are each other's translations and between the word forms of each language and the underlying meaning of the words. It is further assumed that the word–word connections are stronger from L2 to L1 than from L1 to L2, because L2 words are essentially learned by

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associating them with their translation. It is also assumed that the connections from L1 to the semantic system are stronger than those from L2 to the semantic system, up to a very high level of L2 proficiency. Evidence for this asymmetry was reported, for instance, by Sholl, Sankaranarayanan, and Kroll (1995). They showed that pictures of words that had to be translated later in the experiment were effective primes in forward, but not in backward, translation, suggesting a bigger involvement of semantic information in forward translation than in backward translation. Similar asymmetric semantic effects in translation tasks have been reported by Kroll and Stewart (1994) and Cheung and Chen (1998; see also Kroll & de Groot, 1997, and Kroll & Tokowicz, 2005, for reviews of evidence supporting the RHM).

Much of the criticism against the RHM has focused on the question of whether L1 and L2 word forms are stored in separated lexicons or constitute a unitary lexicon (e.g., Brysbaert, 1998; Brysbaert & Dijkstra, 2006; for a review, see Dijkstra & Van Heuven, 2002). The consensus is growing that there is more evidence for a single lexicon than for two distinct lexicons, as Kroll also acknowledged in later writings (e.g., Kroll & Dijkstra, 2002). Figure 1 shows how the RHM would look if a single lexicon is assumed. The figure also takes into account the insight that the meanings of translation equivalents are rarely completely the same. This is captured by assuming that words activate semantic features, rather than unitary concepts (see the distributed feature model of de Groot and colleagues; de Groot, 1992; Kroll & de Groot, 1997; Van Hell & de Groot, 1998).

A bigger role for the semantic system in word translation?

Because of the asymmetry of the connections in RHM, the basic message from the model has been that backward translation often is nonsemantic and is purely based on the strong lexical connections from L2 words to their L1 translations, up to a high level of L2 proficiency. Because of the strong links between L1 word forms and meaning, the model predicted more semantic involvement in forward translation.

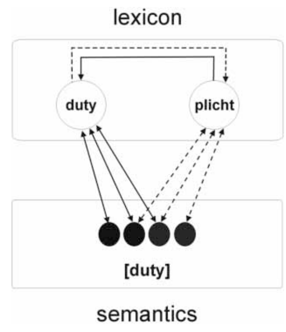

Figure 1. *Revised hierarchical model, taking into account the evidence that there are no separate lexicons for the first language (L1) and the second language (L2). The English word "duty" and its Dutch translation "plicht" are part of the same lexicon and are connected to each other with asymmetric weights (stronger from L2 to L1 than from L1 to L2). Both words activate overlapping semantic features (though not all features need to be shared as the meanings of translation equivalents are rarely completely the same). The connections between L1 words and semantic features are stronger than those between L2 words and semantic features.*

La Heij, Hooglander, Kerling, and Van der Velden (1996) were among the first to question the nonsemantic nature of backward translation. They found that participants translated a word faster if there was a picture on top of the word, representing its concept (e.g., a picture of a dog when the word DOG had to be translated) than when a picture of an unrelated concept was presented (e.g., a picture of an axe when the word DOG had to be translated). Importantly, the facilitation effect was found for both backward and forward translation and was of the same magnitude, suggesting that semantic mediation was involved to the same extent in both tasks. Later, Altarriba and Mathis (1997) reported a similar effect with monolingual participants who were trained on a set of English–Spanish word pairs and consequently had a very low level of L2 proficiency.

Duyck and Brysbaert (2004; see also Duyck & Brysbaert, 2002, in press) reported another semantic effect in backward translation for low proficiency levels. They made use of the number magnitude effect to investigate semantic mediation in number translation. The number magnitude effect implies that large numbers take longer to activate their meaning than do small numbers (Brysbaert, 1995). Duyck and Brysbaert (2004) showed that participants needed more time to translate the number word "nine" than the number word "three". Importantly, the effect was found in both forward and backward translation, even at very low levels of proficiency. Interestingly, the number magnitude translation effect also emerged for participants who learned a set of new L2 number words at the beginning of the experiment.

In order to reconcile these findings with the earlier research supporting the RHM, Duyck and Brysbaert (2004) proposed a connectionist model (see Figure 2), which differs from the RHM in a number of ways.

First, the relative contribution of the lexical and semantic routes for translation is no longer an all-or-none process (as assumed in classical horse-race models). Instead, activation of the units in the model increases or decreases over processing cycles. In each cycle, there is activation both from the direct word–word connections and from the semantically mediated connections. The relative weights of the two routes depend on the change of activation that they introduce on each cycle. Secondly, the asymmetry of the weights of the two routes in the model depends not only on the proficiency of the bilingual, but also on the word type. The contribution of the semantic route will be stronger for words that have very similar meanings in both languages (e.g., concrete nouns, number words) than for words that have less overlapping meanings (e.g., abstract nouns, adjectives).

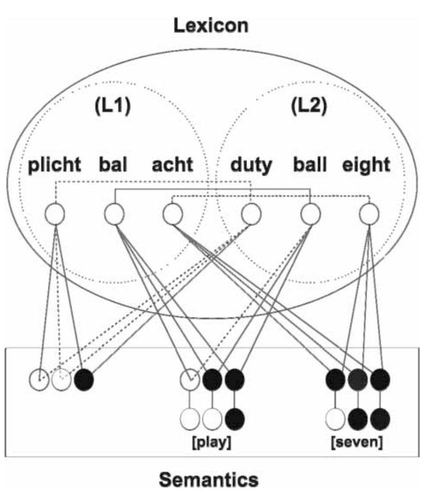

Figure 2. *The connectionist model as proposed by Duyck and Brysbaert (2004), with varying semantic overlap and differently weighted lexico-semantic and intralexical connections. Solid lines represent stronger links than dotted lines. Depicted words and semantic representations are illustrative examples for Dutch–English bilinguals. L1 ¼ first language; L2 ¼ second language.*

In the present study we test Duyck and Brysbaert's (2002, 2004) claim that semantic mediation always plays a role in number translation, by making use of another semantic effect in numerical cognition, the SNARC effect. As we will see, this effect is particularly interesting because it allows us to show with a single technique the existence of a nonsemantic route for word naming and the involvement of semantics in meaning-related tasks.

The SNARC effect

Dehaene, Bossini, and Giraux (1993) showed that in a number parity task, participants react faster with the left hand to small numbers and with the right hand to large numbers. They called this effect the SNARC effect (spatial-numerical association of response codes; for reviews, see Fias & Fischer, 2005; Gevers & Lammertyn, 2005) and attributed it to the fact that in Western cultures, the small numbers are placed on the left-hand side of a mental number line (a left–right-oriented abstract representation of magnitude on which activation spreads to nearby magnitudes) and large numbers on the right-hand side. This results in a kind of stimulus–response compatibility effect: Responses are faster when the response side agrees with the position on the number line than when it does not.

The SNARC effect gained additional interest when it was discovered that it is also found in situations that do not explicitly require access to the meaning of the numbers. Fias, Brysbaert, Geypens, and d'Ydewalle (1996) showed that the

SNARC effect is also obtained when participants have to indicate whether the name of an Arabic digit includes a certain sound or not. So, participants were faster to indicate with their left hand than with their right hand that the digit 2 contained a /t/ sound, whereas they responded faster with their right hand than with their left hand when the same decision had to be made about the digit 8. Fias et al. (1996) interpreted this finding as evidence that digits require semantic mediation to activate their pronunciation.

In a later study, Fias (2001) showed that the SNARC effect was not found when participants had to indicate whether a number word contained a particular sound or not. So, there were no differences in reaction times between the left and the right hand, when participants had to indicate whether the words "two" and "eight" contained a /t/ sound. He interpreted this finding as evidence that orthography–phonology conversions do not require semantic mediation, in line with many existing models of word naming (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001).

The research by Fias and colleagues (Fias, 2001; Fias et al., 1996) suggests that the SNARC effect provides an interesting approach to study the issue of semantic mediation in number translation. With number words, the effect is found when the number meaning is relevant (parity judgement) and not when the meaning is assumed not to be involved (phoneme monitoring). This opens the way to examine where on the continuum number translation is situated: more towards the nonsemantic phoneme monitoring or more towards the semantic parity judgement? To find out, we first investigated whether we could replicate Fias's findings in L2, given that all findings on the SNARC effect thus far have been limited to the participants' native language.

EXPERIMENT 1

In previous research, the SNARC effect has been obtained in number parity tasks, both with French and Dutch stimulus words (Dehaene et al., 1993, Exp. 8; Fias, 2001, Exp. 1). Importantly, in all studies so far, the words have been presented in the participants' native language. Here, we examine whether we obtain a SNARC effect when unbalanced Dutch–French bilinguals have to make a parity decision to French (L2) number words.

Method

Participants

A total of 20 Dutch-speaking first-year psychology students (4 male, 16 female) participated for course credit. All participants were native Dutch speakers and mainly used this language in everyday life. They all started to learn French at elementary school. They reported having acquired their first French words at an average age of 8.7 years (*SD* ¼ 2.3 years). Average age was 19.3 years (*SD* ¼ 1.2 years). A total of 3 participants were left-handed.

Instructions

Participants were asked to judge the parity of written French number words by pressing a button with the left or right hand. They were explicitly informed about the range of the numbers, and both speed and accuracy were emphasized.

Stimuli

The numbers ranged from 3 to 10. They were presented as written French number words ("trois", "quatre", "cinq", "six", "sept", "huit", "neuf", and "dix"). In this range, half of the numbers are even, and half contain an /s/ sound. In this way, we were able to use the same stimuli in Experiment 2, where a phoneme monitoring task was used.

Apparatus

All number words were presented on a standard colour computer monitor, using the ERTS experimental software (Beringer, 1999). Reaction times were measured by means of a response box that was connected to the game port of the PC through an Exkey Logic Box.

Design

The experiment had a full factorial 2 (parity: odd or even) × 2 (side of response: left or right) × 8 (number magnitude: 3–10) design. All variables were manipulated within subjects.

Procedure

We tried to keep the procedure as close as possible to that of Fias (2001). Participants had to go through two blocks: one in which even numbers were assigned to the left hand and odd numbers to the right hand, and one block in which this response mapping was reversed. The order of both blocks was counterbalanced across participants. Each block started with a practice session in which each number within the stimulus range was presented once. In each response mapping block, all eight number words were presented 20 times each. As a result, each block consisted of 160 trials. Order was randomized within each block, but repetition of the same number on two subsequent trials was avoided. Stimuli were presented in yellow against a dark-grey background as characters sized 16 points in the standard ERTS font. A trial started with an empty rectangular frame (48.9 mm × 24.8 mm) presented in the centre of the screen for 300 ms. Then the target word appeared for 1,300 ms or until a response was given. The screen was erased before the intertrial interval of 1,500 ms.

Results

Average error rate was 5.9%. There was no speed–accuracy trade-off, as indicated by the positive correlation between reaction time and number of errors, computed over the 16 cells of the design (8 numbers, separately for left and right responses), r ¼ .67, n ¼ 16, $p < .01$. Overall mean response time of all correct responses was 596 ms. Following Dehaene et al. (1993), we checked for the presence of a SNARC effect by evaluating the interaction between number magnitude and side of response in a 2 (parity: odd or even) × 2 (side of response: left or right) × 4 (number magnitude: 3–4, 5–6, 7–8, 9–10) analysis of variance (ANOVA) on the medians of the correct responses. This effect was significant, $F(3, 57)$ ¼ 5.09, MSE ¼ 732, $p < .01$.

Following the standard SNARC analysis procedure (e.g., Fias, 2001; Fias et al., 1996) we used a regression analysis to evaluate the SNARC effect in more detail. Because the SNARC effect arises from an association between side of response and the position of the number on the left-to-right-oriented number line, a negative relation between number magnitude and the difference in reaction time between right-hand responses and left-hand responses (dRT) is expected. Left-hand responses are faster on small numbers, resulting in a positive dRT, while right-hand responses are faster on large numbers, resulting in a negative dRT. In the case that a majority of the participants are right-handed, a SNARC effect can also be present if all dRTs are negative. This means that, overall, right-hand responses are faster and that the SNARC effect consists of a modification of this advantage as a function of the number magnitude. Following earlier studies (e.g., Fias, 2001; Fias et al., 1996), we made use of the regression analysis for repeated measures data as recommended by Lorch and Myers (1990; see Fias et al., 1996, for a more detailed explanation of the method).

In the first step, we computed median reaction times of the correct responses, for each number and for all participants, separately for left and right responses. On the basis of these medians, we computed dRTs by subtracting the median reaction time for the left-hand responses from the median reaction time for the right-hand responses. In the second step, for each participant, a multiple regression analysis on the dRTs was run with number magnitude as the predictor variable (see Lorch & Myers, 1990). In the third step, t tests were done to see whether the regression weight of the number magnitude differed significantly from zero. Figure 3 shows the dRTs as a function of the magnitude of the stimulus. As can be seen, there was a negative correlation between the difference in RT between right and left hand (dRT) and number magnitude, which corresponds to the SNARC effect. Most importantly, the coefficient of number magnitude differed significantly from zero, $t(19)$ ¼ −3.19, SD ¼ 6.85, $p < .01$.

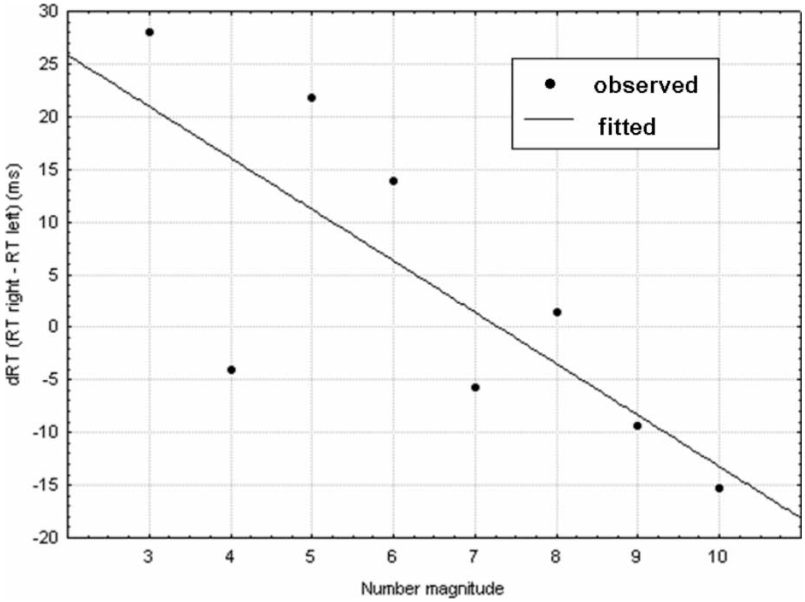

Figure 3. *Observed data and regression line representing reaction time differences between right-hand and left-hand responses as a function of number magnitude in Experiment 1. dRT ¼ 35.62 − 4.89 (number magnitude).*

To make sure that the SNARC effect was present throughout the complete range of RTs, we followed Fias's (2001) recommendation and split the data of each participant in the faster and the slower half. We then calculated the regression lines for the fast and the slow responses. These were the results:

Fast half (RT ¼ 505 ms):

dRT ¼ 25.5 − 3.3 number magnitude

Slow half (RT ¼ 651 ms):

dRT ¼ 68.3 − 9.0 number magnitude

The negative slope (SNARC) was significant both for the fast, *t*(19) ¼ −2.17, *SD* ¼ 6.73, *p* < .05, and for the slow RTs, *t*(19) ¼ − 3.61, *SD* ¼ 11.11, *p* < .01, although the slope was more distinct for the slow trials; *t*(19) ¼ 2.64, *SD* ¼ 9.66, *p* < .05.

Discussion

We obtained a SNARC effect when Dutch–French bilinguals judged the parity of French number words: Responses to small numbers were faster with the left hand, whereas responses to large numbers were faster with the right hand. This is in line with the monolingual studies of Dehaene et al. (1993) and Fias (2001), who observed a SNARC effect with L1 French and Dutch number words, respectively, in the same task. Although we should be cautious about comparisons across experiments, comparing the regression coefficients of number magnitude can be indicative of the strength of the SNARC effect. Fias et al. (1996) reported a weight of −7 in the same task with Arabic numerals as stimuli, whereas Fias (2001) reported a weight of −3.5 in the same task with Dutch number words (− 2.6 on the fast trials and −3.0 on the slow trials). We obtained a weight of −4.9 with French L2 number words, suggesting that the SNARC effect with L2 number words is not smaller than the one found with L1 number words. Furthermore, it is interesting to note that the overall mean response time in our experiment (596ms) was similar to that reported by Fias (2001, Exp. 1) for Dutch–French bilinguals responding to L1 number words (RTs ranging from 530 ms to 630 ms, with a mean around 575 ms). This makes it very unlikely that the participants used a translation to L1 to decide about the parity of the L2 number words. In the number word translation study of Duyck and Brysbaert (2004) for example, RTs were 85 and 88 ms slower (respectively for unbalanced and balanced bilinguals) for backward translation of L2 number words than for naming of the same L2 number words (Duyck & Brysbaert, 2004, Exp. 1), suggesting that the additional translation process takes about 100 ms. So, if participants in the present study were using a translation strategy to perform parity judgement on L2 number words, one would expect RTs that are (somewhat less than) 100 ms slower than those of Fias (2001), which is clearly not the case.

EXPERIMENT 2

In Experiment 1, we showed that the L2 SNARC effect is very similar to L1 when a parity judgement task is used. This was expected, given that parity judgement requires access to the semantic information. In the present experiment, we investigate whether participants are able to name visually presented L2 words without semantic mediation (see Van Wijnendaele & Brysbaert, 2002, for a comparison of word naming in L1 and L2). To do this, we repeated the phoneme-monitoring task, used by Fias (2001). Participants had to indicate whether a written word contained a certain sound or not. Importantly, this task could not be done on the basis of a simple letter–sound conversion, as is explained in the Stimuli section.

Method

Participants

The same students that participated in Experiment 1 participated in this experiment. Half of them started with Experiment 1 and the other half with Experiment 2.

Instructions

Participants were asked to judge whether the presented French number word had an /s/ sound in it by pressing one of two response buttons. Participants had to go through two blocks, which differed with respect to the left–right response mapping. The order of the blocks was counterbalanced across participants. They were explicitly informed about the range of the numbers. Speed and accuracy were emphasized.

Stimuli

Stimuli were the same as those in Experiment 1. The /s/ sound is present in “cinq” (5), “six” (6), “sept” (7), and “dix” (10) and absent in “trois” (3), “quatre” (4), “huit” (8), and “neuf” (9). This was explicitly mentioned in the instructions. The number word “trois” (3, trwa) contains the letter “s” but not the /s/ sound. Similarly, the numbers “cinq” and “dix” contain the /s/ sound but not the letter “s”. Consequently, the task could not be performed on the basis of a simple letter search; the number words had to be converted to their spoken form.

Apparatus, design, and procedure

Apparatus, design and procedure were the same as those in Experiment 1.

Results

A total of 3 participants were removed from the analyses because they consistently made errors on “dix” (10), despite the detailed instructions. The other 17 participants showed an average error rate of 5.0%. There was no speed–accuracy trade-off, as indicated by the positive correlation between reaction time and number of errors, computed over the 16 cells of the design (8 numbers, separately for left and right responses), r ¼ .85, n ¼ 16, $p < .01$.

Overall response time of correct responses was 563 ms. As in Experiment 1, the effect of number magnitude and side of response was first evaluated in an 8 (number magnitude) $\times$ 2 (side of response) ANOVA. (The 2 $\times$ 2 $\times$ 4 design of Experiment 1 was not possible because the presence of an /s/ sound does not alternate for successive numbers.) The main effect of number magnitude was significant, $F(7, 112)$ ¼ 23.50, *MSE* ¼ 2,681, $p < .01$. Mean reaction times are 640, 534, 580, 502, 527, 533, 529, and 543 ms for each magnitude, in ascending order. However, more importantly, the interaction between number magnitude and side of response did not reach significance, $F(7, 112)$ ¼ 1.63, *MSE* ¼ 2,417, demonstrating the absence of a SNARC effect. As in Experiment 1, regression weights were computed according to the method of Fias et al. (1996). The best fitting regression line is described by the following equation: dRT ¼ 18.34 − 0.99 (number magnitude), see also Figure 4. The coefficient of number magnitude did not differ significantly from zero, $t(16)$ ¼ −0.35, *SD* ¼ 11.70.

A division between the slow and fast half of the RTs for each participant indicated that the SNARC effect was absent for both the fast and the slow RTs. These are the regression lines:

Fast half (RT ¼ 485 ms; $t(16)$ ¼ −0.66):
dRT ¼ 18.5 − 1.7 number magnitude

Slow half (RT ¼ 630 ms; $t(16)$ ¼ 0.16):
dRT ¼ 7.4 + 0.6 number magnitude

Discussion

In line with Fias (2001), we did not observe a SNARC effect in a phoneme-monitoring task on number words. This suggests that, similar to L1, semantic access is not needed to detect a phoneme in an L2 word.[1] The absence of a SNARC effect is in line with the hypothesis that the direct, nonsemantic route for number word naming, as proposed by Noël, Fias, and Brysbaert (1997) and Blankenberger and Vorberg (1997) and demonstrated by Fias (2001), not only exists for L1 number words but also for L2 number words.

EXPERIMENT 3

Experiments 1 and 2 showed that the SNARC effect is obtained in tasks that require semantic access (parity judgement) and not in tasks that do not require semantic access (phoneme monitoring), both in L1 and in L2. This allows us to run a powerful test about whether semantic mediation is used in a simple translation judgement (yes/no) task: Participants were asked to indicate whether two presented number words were each other's translation. If this is done on the basis of straightforward word–word associations at the lexical level, we do not expect a SNARC effect. If, however, number translation always involves meaning because the meaning is activated very rapidly, as argued by Duyck and Brysbaert (2004), then we would expect to see a SNARC effect in this task.

In this experiment, participants had to perform a translation recognition task (i.e., they had to decide whether a simultaneously presented L1 and L2 word pair consisted of translation equivalents or not). By definition, the presence of a SNARC effect could only be evaluated for the "translation" trials (in which both number words were each other's translation), as "no translation" trials (or "incongruent" trials, in which both number words were not each other's translation) contained multiple magnitudes. In the "no translation" (incongruent) trials, we manipulated the distance between the magnitudes of the numbers. The distance effect is another robust effect found

[1] It might be objected that the significant effect of number magnitude in Experiment 2 is evidence for semantic mediation. However, the effect we observed is not a "regular" semantic number magnitude effect (i.e., longer RTs at the upper end of the scale). RTs were especially long for the word "trois" (three). This is probably due to the incompatibility between the orthographic representation of the word (which includes the letter "s") and the phonological representation (which does not include the phoneme /s/, as the end-letter "s" is a silent letter in French). Participants had to give a "no" response, despite the presence of the letter "s" in the orthographic stimulus, which resulted in longer RTs. A similar incompatibility was present for the stimuli "cinq" and "dix" (five, ten): These stimuli do not contain the letter "s" but do contain the sound /s/.

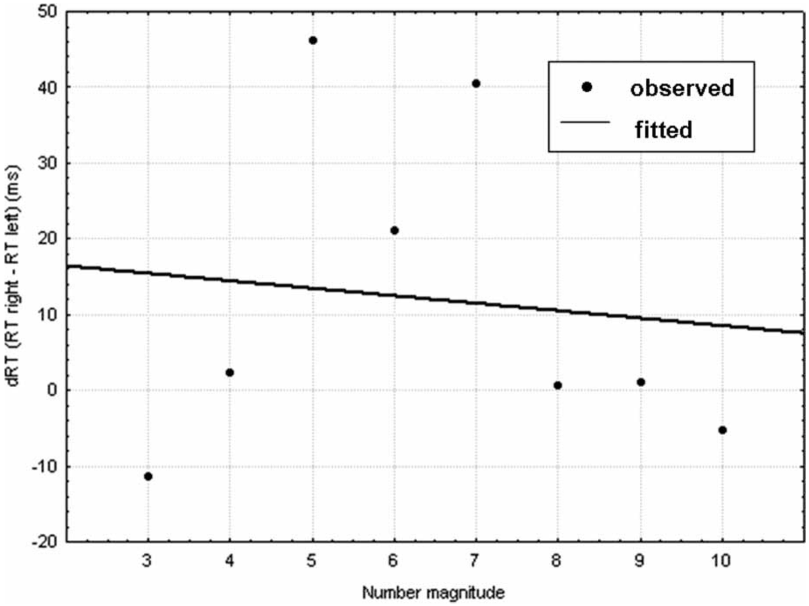

Figure 4. *Observed data and regression line representing reaction time differences between right-hand and left-hand responses as a function of number magnitude in Experiment 2. dRT ¼ 18.34 − 0.99 (number magnitude).*

in number comparison tasks. It was first reported by Moyer and Landauer (1967). It implies that it takes longer to judge the equality of two numbers as the distance between them decreases. The presence of a distance effect is another indication for the activation of number magnitude.

According to the RHM, the translation recognition task will occur through the fast and direct lexical links between L2 and L1. This route is supposed to be faster because it does not require the extra step of semantic access. This is why the RHM also predicts that L2–L1 translation will be faster than L1–L2 translation in production. Contrastingly, if a semantic SNARC effect is obtained in this translation recognition task, this offers strong evidence that semantic mediation is involved in the translation of number words.

Method

Participants

A total of 25 Dutch-speaking students (4 male, 21 female) participated in this experiment either for course credit or for financial gain. All participants were native Dutch speakers and mainly used this language in everyday life. They all learned French at school. They reported having acquired their first French words at an average age of 7.5 years (*SD* ¼ 2.6 years). Average age was 19.9 years (*SD* ¼ 1.6 years). A total of 4 participants were left-handed.

Instructions

Participants were instructed to judge whether pairs of Dutch and French number words were translation equivalents or not by pressing one of two response buttons. They were explicitly informed about the range of the numbers, and both speed and accuracy were emphasized.

Stimuli

We used the same range of numbers as that in Experiments 1 and 2. Numbers from 3 to 10 were presented as Dutch and French number words. These are the pairs "drie–trois", "vier–quatre", "vijf–cinq", "zes–six", "zeven–sept", "acht–huit", "negen–neuf", "tien–dix".

Apparatus
Apparatus was the same as that in Experiments 1 and 2.

Design
The experiment had an 8 (number magnitude of the upper number) × 3 (numerical distance between the two number words: 0, 1, or 2) × 2 (side of response: left or right) design. All factors were manipulated within subjects.

Procedure
Participants completed two blocks. In one block right-hand responses had to be given if both words were each other's translation and left-hand responses if both words were not each other's translation. In the second block the response mapping was reversed. The order of both blocks was counterbalanced across participants. Each block consisted of 256 trials and was preceded by 4 practice trials. Stimuli appeared in yellow against a dark-grey background in standard ERTS font, with a font size of 16 points. Each trial started with two empty rectangular frames (48.9 mm × 24.8 mm) for 300 ms; one frame appeared 2 cm above the screen centre and the other 2 cm beneath the screen centre. Then a Dutch and a French number word appeared for 1,300 ms in the frames, so that each Dutch number word appeared 16 times (8 times in the upper position and 8 times in the lower position) with the correct translation in the other position. As a result, each block consisted of 128 "translation" (congruent) trials. The other 128 trials were "no-translation" (incongruent) trials, in which we manipulated the distance between both numbers. Each of the 26 possible number pairs with distance 1 or 2 within our stimulus range was presented 4 times, 2 times with the Dutch word in the upper position and 2 times with the Dutch word in the lower position. The number of "no translation" (incongruent) trials was equal to the number of "translation" (congruent) trials by adding 24 filler trials with distance 3 between both numbers. Trials were presented in a randomized order with the restriction that no repetitions were allowed. Between trials the screen was blank for an intertrial interval of 1,500 ms.

Results

Filler trials (distance 3) were excluded from all subsequent analyses. Average error rate was 5%. No speed–accuracy trade-off was present as indicated by the nonsignificant correlation between RT and error rate, computed over the 24 cells of the design (8 numbers and 3 distances: 0, 1, and 2), *r* ¼ − .32, *n* ¼ 24, *p* ¼ .13.

Overall response time for correct responses was 644 ms. To evaluate the presence of a SNARC effect, an 8 (number magnitude) × 2 (side of response) ANOVA was performed on the "translation" (congruent) trials. The main effect of number magnitude was significant, *F*(7, 168) ¼ 7.97, *MSE* ¼ 2,322, $p < .01$, as was the interaction between number magnitude and side of response, *F*(7, 168) ¼ 2.17, *MSE* ¼ 1,495, $p < .05$. As in Experiments 1 and 2, regression weights were computed according to the method of Fias et al. (1996). The best fitting regression line was described by the following equation: dRT ¼ 16.7 − 4.9 (number magnitude), see Figure 5. The coefficient of number magnitude differed significantly from zero, *t*(24) ¼ −2.56, *SD* ¼ 9.50, $p < .05$.[2]

To check whether the SNARC effect could be due to the longer overall RTs in Experiment 3 relative to Experiment 2, we again split the RTs

[2] As expected, the position of the L1 word on the screen did not make a difference for the presence of the SNARC effect. The coefficient of number magnitude for the trials with L1 in the upper position, dRT ¼ 19.38 − (4.92 × number magnitude), did not differ significantly from the coefficient of number magnitude for the trials with L2 in the upper position, dRT ¼ 17.29 − (5.21 × number magnitude), *t*(24) ¼ 0.14.

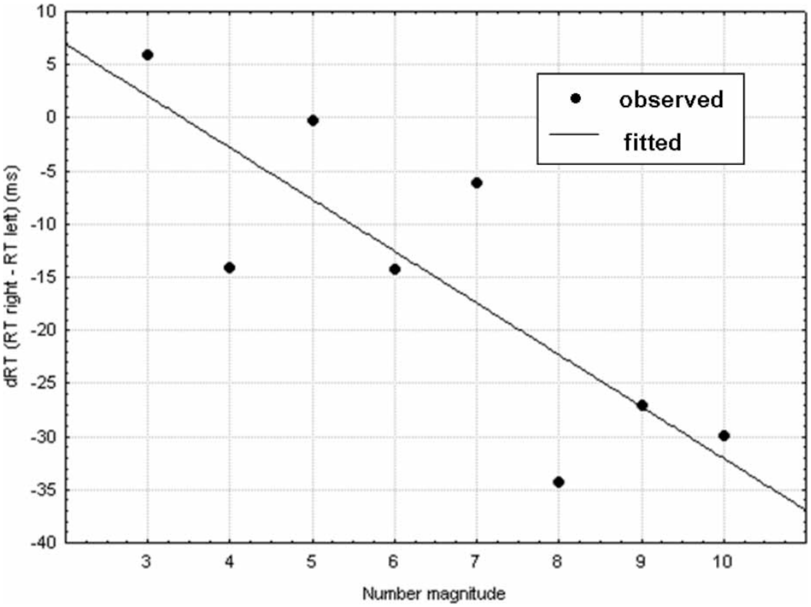

Figure 5. *Observed data and regression line representing reaction time differences between right-hand and left-hand responses as a function of number magnitude in Experiment 3. dRT ¼ ¼ 16.7 − 4.9 (number magnitude).*

in the fast and the slow half of each participant. These are the regression lines:

Fast half (RT ¼ 586 ms; $t(24)$ ¼ −2.14, $p < .05$):

dRT ¼ 11.8 − 3.4 number magnitude

Slow half (RT ¼ 728 ms; $t(24)$ ¼ − 3.16, $p < .05$):

dRT ¼ 32.0 − 7.9 number magnitude

Because there were two different numbers on the screen on each "no-translation" (incongruent) trial, SNARC analyses were by definition not possible on these trials. Therefore we investigated semantic access for these trials by looking at a magnitude effect and a distance effect. This was done by means of an 8 (number magnitude of the upper number) by 2 (distance 1 or 2) ANOVA. The main effect of number magnitude was significant, $F(7, 168)$ ¼ 4.79, *MSE* ¼ 2,366, $p < .01$. Mean RTs were 722, 748, 742, 746, 765, 756, 769, and 760 ms for magnitudes 3 to 10, respectively, and a polynomial linear contrast showed that RTs increased with increasing magnitude, $F(1, 24)$ ¼ 23.54, *MSE* ¼ 2,365, $p < .01$. The main effect of distance was also significant, $F(1, 24)$ ¼ 4.70, *MSE* ¼ 2,861, $p < .05$. Responses to distance 2 trials (*M* ¼ 743 ms, *SD* ¼ 167 ms) were faster than responses to distance 1 trials (*M* ¼ 759 ms, *SD* ¼ 164 ms), which is consistent with the distance effects reported earlier in the unilingual numerical cognition literature (Moyer & Landauer, 1967).

Discussion

On translation (congruent) trials, a SNARC effect was observed: Responses to small numbers were faster with the left hand, and responses to large numbers were faster with the right hand. On no-translation (incongruent) trials, participants were slower to reject responses to numbers that were close in magnitude (distance 1) as translation equivalents than numbers that were further (distance 2) apart. This is in line with the monolingual finding that the time to compare two number magnitudes is an inverse function of the numerical distance (Moyer & Landauer, 1967). These two semantic effects provide strong evidence that the translation was not based on the fast L2–L1 word links, but involved the meaning of the number words that were presented.

GENERAL DISCUSSION

In a series of three experiments, we showed that number translation involves access to the meaning of the numbers, even though the task can easily be done by relying on direct lexical connections between L1 and L2 words. First, we showed that access to the meaning of L2 number words elicits a SNARC effect. It is easier to respond with the left hand to small numbers and with the right hand to large numbers. Then we showed that the effect is not obtained in a phoneme-monitoring task, in line with the evidence showing that participants can name words even when they no longer understand the meaning of the words, suggesting the existence of a nonsemantic naming route (Coltheart, 2004; Coltheart et al., 2001; Gerhand, 2001). Finally, we showed that a SNARC effect is obtained in a translation judgement task. Because the overall RT was slower in the translation task, we verified whether the SNARC effect was present for the fast response times as well. By comparing the fast RTs in the translation task to the slow RTs in the parity judgement task and the phoneme-monitoring task, we can gauge the SNARC effect in the three tasks, independent of overall RT. These are the findings:

Slow trials parity (RT ¼ 651 ms):

dRT ¼ 68.3 − 9.0 number magnitude

Slow trials phoneme (RT ¼ 630 ms):

dRT ¼ 7.4 + 0.6 number magnitude

Fast trials translation (RT ¼ 586 ms):

RT ¼ 11.8 − 3.4 number magnitude

On the basis of these findings, it is clear that the phoneme-monitoring task gave rise to a different pattern of results from that of the two other tasks. In the phoneme-monitoring task, there was no evidence whatsoever for the presence of a SNARC effect when deciding whether an L2 word contained a particular sound or not, even though this response could not be made on the basis of direct letter–sound mappings. Contrastingly, in the number word translation recognition task, semantic access occurred, as shown by the SNARC effect, even though the translation judgement could in principle be based on simple word–word associations. As an additional marker of semantic access, this translation recognition task also yielded a semantic distance effect on the incongruent trials. It took longer to reject number word pairs that were closer in magnitude, which is consistent with the number distance effects observed in unilingual numerical cognition studies (Moyer & Landauer, 1967).

The present findings, in line with those of Duyck and Brysbaert (2002, 2004), provide further evidence for the claim that the revised hierarchical model underestimates the importance of word meaning in translation tasks. An objection against this claim, however, might be that the results only apply to integer numbers and do not generalize to other stimulus words. The advantage of numerical stimuli is that they allow us to draw on the extensive experience with this particular type of stimulus to design straightforward and valid tests of the semantic mediation hypothesis. The drawback is that the findings may be limited to numerical stimuli.

Fortunately, in parallel with our work, Sunderman and Kroll (2006) have obtained data that are very similar to ours with another type of stimulus (see also Altarriba & Mathis, 1997, and La Heij et al., 1996, mentioned in the Introduction). They also used the translation verification task and asked English–Spanish bilinguals whether Spanish–English word pairs were each other's translation or not—for example, cama–bed (yes), cama–scholar (no). There were two types of no-trials: trials with semantically related words (cama–blanket) and trials with unrelated words of the same length and frequency as the unrelated words (cama–scholar). Sunderman and Koll (2006) observed that for all proficiency levels participants took longer to say "no" to the trials with semantically related words (cama–blanket) than they did to trials with unrelated words (cama–scholar). This finding corroborates our data, suggesting that meaning activation is an essential component of translation verification for all types of words (or at least all types of concrete words).

So, it looks like the classical RHM indeed underestimates the importance of word meaning in translation tasks. Interestingly, a similar evolution can be noticed in the literature on monolingual language processing. Even though it has been assumed for decades that the semantically mediated route was much too slow to influence lexical decision and word naming, it is now becoming increasingly clear that this view seriously underrates the importance of semantic information for those tasks (for a review, see Lupker, 2005). For instance, semantic variables have been shown to influence the naming times of words with inconsistent spelling–sound correspondences (Strain, Patterson, & Seidenberg, 1995). Similarly, variables like semantic feedback consistency have been found to influence lexical decision times (Pexman, Lupker, & Hino, 2002). So, even though there are nonsemantic routes from written input to spoken output in visual word recognition (as attested by the lack of a SNARC effect in phoneme monitoring), this by no means implies that the activation of semantic information is too slow to have any impact. As soon as the nonsemantic route is slightly delayed (e.g., by inconsistent mappings) or the impact of the semantic route is slightly increased (e.g., by semantic priming or by using stimuli with semantic features that are easy to activate), the impact of the semantic system can readily be observed. To some extent, this should come as no surprise, because most of the time people read words for meaning, and the reason why word meaning is slow to be incorporated in models of language processing has more to do with the difficulty of implementing this variable in a computational model than with the conviction that word processing can be understood without a semantic system. We are convinced that very much the same conclusion will be reached about word translation.

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