Bilingualism: Language and Cognition 22 (1), 2019, 177–190 © Cambridge University Press 2017 doi:10.1017/S1366728917000669

Lexical and semantic connections in number words translation*

AMPARO HERRERA
University of Murcia, Spain

(Received: May 02, 2017; final revision received: October 26, 2017; accepted: November 15, 2017; first published online 29 December 2017)

The present study investigated the influence of lexical links and conceptual mediation in number word translation. In four experiments, a semantic blocking paradigm was used with numerical stimuli and stimuli from other non-number categories. The performance of Spanish L1–English L2 bilinguals was examined in backward and forward translation (Experiment 1 and 3), in naming Arabic digits and pictures (Experiment 2A) and in reading L1 and L2 words (Experiment 2B). The blocked context produced a facilitatory effect for numerical stimuli in the lower range. This result contrasts with the interference effect observed for stimuli from non-number categories in translation and naming tasks. These results are interpreted to mean that the translation of number words, particularly those in the lower range of the numeric sequence, takes place with a large influence of the lexical connections. It supports the suggestions that the influence of processing routes depends on the type of items.

Keywords: number words, translation, semantic blocking paradigm

Bilingualism is a common characteristic in today's society. Across the globe, the majority of people are either bilingual or multilingual. The level of language proficiency may be quite variable and, in many cases, bilinguals are not equally proficient in both languages. Research in cognitive psychology has been interested in understanding the representations and cognitive processes involved in manipulating two languages (or more), resulting in several theoretical proposals about bilingual language comprehension and production (for a review see, Kroll & Tokowicz, 2005).

One of the issues arising in the research is the way in which the two languages of a bilingual are interconnected, which is quite important to understanding translation activities. One theoretical proposal, which has been the prominent view over the last decades, is the REVISED HIERARCHICAL MODEL (Kroll & Stewart, 1994). This model resulted from studies contrasting two hypotheses: the WORD ASSOCIATION HYPOTHESIS and the CONCEPTUAL MEDIATION HYPOTHESIS (e.g., Chen & Leung, 1989; Kroll & Curley, 1988; Potter, So, Von Eckardt & Feldman, 1984). In both hypotheses, there are three types of representations: A conceptual representation, which is more-or-less common to the two languages; and two lexical representations, one for the first language (L1) and the other for the second language (L2). The difference stems from how these representations are connected. According to the word association hypothesis, the lexical representations in L1 and L2 are directly connected, but the conceptual representation only connects with the L1 lexical representation. According to the conceptual mediation hypothesis, the lexical representations in L1 and L2 are connected to the conceptual representation, but there are no direct connections between lexical representations. Although initial studies (Potter et al., 1984) supported the conceptual mediation hypothesis, the results of subsequent studies suggested that at the earliest stages of acquisition the word association hypothesis might be more appropriate (e.g., Chen & Leung, 1989; Kroll & Curley, 1988). Thus, Kroll and collaborators proposed the revised hierarchical model combining these previous hypotheses and suggesting some developmental changes in the initial stages of L2 learning.

More specifically, this model maintains the structure of the classical hierarchical models, which includes a common conceptual representation and two lexical representations, one for each language. The three representations are interconnected; however, the strength of the connections are asymmetric at several points. Thus, the lexical links are stronger from L2 to L1 than from L1 to L2, because the L2 words are usually learned through association to L1 words. Also, the links between lexical

* The work reported here was supported by the Programa de Generación de Conocimiento Científico de Excelencia de la Fundación Séneca-Agencia de Ciencia y Tecnología de la Región de Murcia (research project 08741/PHCS/08). I wish to thank Ana María Flores and Verónica Juárez for helping in testing participants. I wish to thank Pedro Macizo for his worthy comments about this work.

Address for correspondence:
Amparo Herrera, Departamento de Psicología Básica y Metodología, Facultad de Psicología, Universidad de Murcia, Campus de Espinardo, 30100, Murcia, Spain
aherrera@um.es

and conceptual representations are stronger for L1 than for L2. Therefore, there are two possible routes for translation, and the actual route taken depends on the relative strength of the links. The most extreme case of these asymmetries would imply that different routes are used for forward translation (L1 to L2) and for backward translation (L2 to L1), where the former occurs through the conceptual route, and the latter takes place by the direct lexical route. These differences would correspond to the earliest stages of L2 acquisition. However, when individuals become more proficient in L2, connections between L2 lexical representations and conceptual representations develop; and so the processes implied in both translation directions become more similar. Thus, the difference between the two translation directions would be quantitative rather than qualitative (e.g., de Groot, Dannenburg & van Hell, 1994).

The results from several studies, such as faster responses in backward than in forward translation, or a larger influence of semantic manipulations in forward than in backward translation, support the model (e.g., de Groot et al., 1994; Kroll & Stewart, 1994; Sholl, Sakaranarayanan & Kroll, 1995). Also, it has been found that words related in form are more difficult to reject as translation equivalents for lesser proficient bilinguals than for more proficient bilinguals, whereas words related in meaning are more difficult to reject for more proficient bilinguals than for less proficient bilinguals (Ferré, Sánchez-Casas & Guasch, 2006; Talamas, Kroll & Dufour, 1999). Nevertheless, other studies have shown results that are at odds with the model's predictions, such as similar effects of semantic manipulations in both translation directions, even at the early stages of L2 learning (e.g., Altarriba & Mathis, 1997; de Groot & Poot, 1997; Duyck & Brysbaert, 2008, 2004; La Heij, Hooglander, Kerling & van der Velden, 1996).

In addition to L2 proficiency, bilinguals may be different in other aspects that might influence processing routes. For example, the age of acquisition, the history of learning and the use of the L2 are aspects that may influence L2 cognitive organization and processing (see, for example, Ferré et al., 2006; Grosjean, 1998). Moreover, in addition to the characteristics of the bilingual, the type of word is important. Indeed, there have been several studies showing differences in processing as a function of word features such as lexical frequency, similarity between languages, cognate status (i.e., translation pairs that share similar form and meaning across two languages), concreteness, imaginability or the number of equivalent translations (e.g., Brysbaert & Duyck, 2010; de Groot, 1992; Kroll & Tokowicz, 2001; Sánchez-Casas, Davis & García-Albea, 1992; van Hell & de Groot, 1998). Kroll and collaborators (Kroll, van Hell, Tokowicz & Green, 2010) have argued that the accessibility of the processing components may vary depending on the properties of items and the context of the task. The ease or difficulty of accessing the conceptual representation may be different for different types of words and may determine the processing route.

The case of number words

Duyck and Brysbaert (2002, 2004; Brysbaert & Duyck, 2010) have argued that when there is a complete overlap of meaning between L1 and L2 words, the L2 words are acquired by early mapping to meaning, instead of by lexical connections to L1. For this type of word, semantic mediation should be stronger than the lexical connection for both translation directions. According to the authors, this would be the case with numerical words. Results from several studies (Brauwer, Duyck and Brysbaert, 2008; Duyk & Brysbaert, 2002, 2004, 2008) support the hypothesis that number translation is based on a conceptual route, irrespective of translation direction.

In one of those studies, Duyck and Brysbaert (2004) examined the effect of number size or number magnitude, which consists in small numbers being easier to process than large numbers (Moyer & Landauer, 1967). Dutch–French bilinguals were asked to translate number words. The authors found larger response times for larger numbers relative to smaller numbers. The effect was similar in forward and backward translations, regardless of the level of proficiency. The authors reasoned that in both translation directions, the conceptual links are strong for number words. In a subsequent study (Duyck & Brysbaert, 2008), they examined Dutch–English–German trilinguals in forward (L1 to L2 and L1 to L3) and backward (L2 to L1 and L3 to L1) translation tasks. In this case, the authors noted that the magnitude effect was less strong than in the previous study and was only present in backward translation, but not in forward translation. They argued that the difference between studies could be explained because the larger lexical forms overlap among translation equivalents in Dutch, English and German relative to translation equivalents in Dutch and French in the previous study. More similar translation equivalents have stronger word form connections than dissimilar translations.

Certainly, the magnitude or size effect is considered to be derived from the characteristics of the semantic representation of numbers. Concretely, the magnitude effect is assumed to reflect the decreasing precision of quantity as a function of increasing numerical value (e.g., Dehaene, 1992; Gallistel & Gelman, 1992). However, more recently, Verguts, Fias and Stevens (2005) have used a computational model to show that the magnitude effect may be a consequence of the connections between the number line to certain response systems, rather than an intrinsic characteristic of the magnitude representation. For example, since the size effect is only consistently found in the numerical comparison task, mapping from number line to the comparison output system could be the origin of the effect. However, for the naming and the parity output systems the connections are different, which explains why the size effect is not usually found in these tasks even though in the model it is assumed that both these tasks require access to semantic information. This argument does not exclude the participation of the semantic representation during the translation task, but it raises doubts over the use of the size effect as an indicator of semantic representation activation.

In another study, de Brauwer, Duyck and Brysbaert (2008) examined the numerical association of response codes (SNARC) effect, in which left-hand responses are faster for smaller numbers and right-hand responses are faster for larger numbers (Dehaene, Dupoux & Mehler, 1990), in translation verification task with Dutch–French bilinguals. A SNARC effect was observed for translation equivalent trials, and correct rejections of non-translation equivalents were faster for numerically closer pairs, consistent with the typically-observed distance effect (Moyer & Landauer, 1967) that is found in numerical tasks such as comparison and same-different judgments. They interpreted the observation of these two effects as evidence of semantic access in translation of numerical words. Nevertheless, there are some issues with this interpretation. On the one hand, the SNARC effect was initially related to the semantic magnitude representation, conceptualized as positions on an oriented mental number line (e.g., Dehaene et al., 1990; Dehaene, Bossini & Giraux, 1993). However, more recent studies have challenged this interpretation, relating the effect to short-term strategic representations during the task computations (e.g., Herrera, Macizo & Semenza, 2008; Santens & Gevers, 2008; van Dijck & Fias, 2011; van Dijck, Gevers & Fias, 2009). On the other hand, the distance effect has been traditionally explained by the tuning curves on the number representation. Numerically close numbers have greater overlap of the tuning curves than numerically distant numbers (e.g., Dehaene, 1992; Gallistel & Gelman, 1992; Restle, 1970).

Although the distance effect may reflect conceptual processing (although see van Opstal & Verguts, 2011; van Opstal, Gevers, de Moor & Verguts, 2008) it has recently been suggested that it only occurs when there is an intentional processing of the magnitude representation (e.g., Cohen-Kadosh & Walsh, 2009; Sasanguie, Defever, van den Bussche & Reynvoet, 2011). Thus, it might be argued that in the translation equivalent judgments task used by de Brauwer et al., there is an intentional processing of semantic representation of number words, which does not mean that the number translation task requires semantic mediation. This latter task is quite different from the former, so the processes and representations implied in each one might also differ.

Finally, Duyck and collaborators (Duyck & Brysbaert, 2002; Duyck, Depestel, Fias & Reynvoet, 2008) used the DISTANCE PRIMING paradigm to explore the conceptual mediation in a number translation task. In this paradigm, the numerical distance between prime target number pairs is manipulated. The priming effect is manifested by faster responses to a numerical stimulus when it is preceded by a numerically closer prime compared to a numerically distant prime. This result is usually interpreted in terms of semantic representation overlap between the prime and the target (e.g., Brysbaert, 1995; although see Roelofs, 2006).

Duyck and Brysbaert (2002) found a similar distance priming in forward and backward translation using Arabic digits as primes. They interpreted this to mean there were no indications of stronger semantic mediation in forward translation than in backward translation. In a subsequent study, Duyck and cols. (2008) asked Dutch–English–French trilinguals to perform a translation task from L1 to L3 (forward translation) and from L3 to L1 (backward translation). In both tasks, L2 number words were used as primes in a masked priming procedure and the numerical distance from prime to target was manipulated (distance 0, 1, 2 and 3). They found distance priming in both translation directions, which was interpreted as supporting the contribution of the semantic route regardless of the translation direction. Indeed, these results are consistent with other studies showing priming across the two bilingual's languages even when the two languages have different written scripts (e.g., Gollan, Forster & Frost, 1997; Jiang, 1999).

In summary, the reviewed studies have provided evidence of semantic processing in translation of number words regardless of the direction. However, some of the effects used as an indicator of conceptual mediation should be considered carefully.

In the present study, the influence of the conceptual route on the translation of number words was explored by using the semantic blocking paradigm which had been previously used to examine conceptual mediation in translation, in picture naming and in word reading (Damian, Vigliocco & Levelt, 2001; Herrera & Macizo, 2011; Kroll & Stewart, 1994). In this paradigm, the items to be translated or named are presented in two list conditions. In the mixed condition, the lists contain a mixed set of exemplars from different semantic categories; in the blocked condition, the items to be named are grouped by category. When the items are pictures, the blocked context produces an interference effect since the responses are slower in the blocked condition relative to the mixed condition. However, when the items are words the interference disappears; even blocked context produces facilitation. The interference produced by the blocked context has been interpreted as an index of conceptual mediation. Concepts of a common semantic category activate each other through activation spreading at the semantic level. In addition, each concept activates its own lemma in the mental lexicon and co-activated lemmas compete for lexical selection. In the blocked context, repeated access to concepts within the same semantic category leads to greater competition for lexical retrieval than when items pertain to unrelated categories. On the other hand, the absence of interference found in word reading is explained by the direct access of words to the word form level (e.g., Damian et al., 2001; Kroll & Stewart, 1994).

With this paradigm, Kroll and Stewart (1994) found an interference effect of the semantic blocking when bilinguals performed a forward translation task. Yet, when they performed a backward translation task there was no such interference effect. Initially, the authors considered those results as evidence of different routes for each translation direction; however, more recently, Kroll et al. (2010) have suggested that the observed difference between the two translation tasks could be due to the lower frequency of the words used in that experiment. Thus, fluent bilinguals might process lower frequency words, which may be more difficult to process, as if they were learners at early stages of L2 acquisition.

Although the semantic blocking paradigm has been used extensively in monolingual production studies (e.g., Belke, Meyer & Damian, 2005; Damian et al., 2001; Navarrete, Del Prato & Mahon, 2012), it has been used less frequently in bilingual production, and with mixed findings. For example, contrary to the results in Kroll and Stewart's (1994) study, in other studies (e.g., Sakaki, Hakoda & Kaminska, 2012; Vigliocco, Lauer, Damian & Levelt, 2002) an interference effect of the semantic context in backward translation has been found. Thus, the lack of sufficient studies and the inconsistent results make additional studies necessary. In the present study, the translation of number words was explored and to what extent the results found by Kroll and Stewart might be replicated while determining if there were differences in the semantic context effect between the two translation directions.

Experiment 1. Translation

In this experiment, the influence of the conceptual representation on forward and backward translations of number words was examined. The most widely used version of the semantic blocking paradigm, the cyclic semantic blocking paradigm (Damian et al., 2001), was used in this study. It included single digit numbers words and also words from other categories (i.e., vehicle, animal, body part and furniture) as items. Following the results of Kroll and Stewart's (1994) study, it was expected that the responses in blocked context would be slower than the responses in mixed context when participants performed the translation from L1 to L2, but not when they translated words from L2 to L1. However, if number words are acquired by mapping L2 word forms to meaning, as Duyck and collaborators have argued (e.g., Duyck & Brysbaert, 2004), the blocked context should produce a similar effect for both translation directions. Concretely, there should be an interference effect of the blocked context relative to the mixed context.

Table 1. *Characteristics of participants for each experiment*

	L1: Spanish		L2: English	
Experiment 1				
Speech fluency	9.60	(0.75)	7.30	(1.78)
Speech comprehension	9.95	(0.22)	8.00	(1.17)
Writing proficiency	9.50	(0.95)	7.75	(1.07)
Reading proficiency	9.80	(0.41)	8.45	(0.94)
Experiment 2A				
Speech fluency	10.00	(0.00)	8.10	(1.17)
Speech comprehension	10.00	(0.00)	8.30	(1.22)
Writing proficiency	10.00	(0.00)	8.15	(1.35)
Reading proficiency	10.00	(0.00)	8.60	(0.99)
Experiment 2B				
Speech fluency	10.00	(0.00)	8.35	(1.14)
Speech comprehension	10.00	(0.00)	8.55	(1.10)
Writing proficiency	10.00	(0.00)	7.70	(1.95)
Reading proficiency	10.00	(0.00)	8.70	(1.13)
Experiment 3				
Speech fluency	9.15	(0.93)	6.40	(1.67)
Speech comprehension	9.50	(0.61)	6.80	(1.47)
Writing proficiency	9.15	(0.99)	6.75	(1.29)
Reading proficiency	9.35	(0.75)	6.95	(1.32)

Note. Mean scores and standard deviation (in parenthesis) of Spanish/English bilinguals. The self-report ratings ranged from less to more on a ten-point scale for each dimension.

Method

Participants

Twenty students from the University of Murcia participated in the experiment for course credits (7 men and 13 women). They all had normal or corrected to normal visual acuity. Their mean age was 24.20 (SD = 4.40). All of them were Spanish–English bilinguals (L1/L2 respectively). They started to learn English at school between 3 and 12 years of age. After performing the experimental trials, each participant was asked to complete a language proficiency questionnaire on four dimensions: reading, writing, listening and speaking in their two languages (see Table 1). They rated their proficiency on a 10 point scale, where 1 was not fluent and

https://doi.org/10.1017/S1366728917000669 Published online by Cambridge University Press

10 was very fluent. The mean fluency in L1 was higher ($M = 9.71$, $SD = 0.53$) than the mean fluency in L2 ($M = 7.88$, $SD = 0.84$), $t(19) = 11.10$, $p < .001$, which suggests that participants were dominant in Spanish.

Stimuli and apparatus

The stimuli used in this experiment were 25 words from five semantic categories (animal, body part, furniture, vehicle and number, see Appendix) that were arranged in a matrix of 5 x 5 items such that rows corresponded to categories and formed the blocked category stimulus sets, and the columns formed the mixed stimulus sets. Five lists of stimuli with the items in the rows (blocked category lists) and another five lists with the items in the columns (mixed category lists) were created. The items were repeated five times in a pseudorandom order within each list, so that each item was sampled once before any item was repeated in the list, and the same item never appeared twice in succession. The mean of lexical frequency for English words using the Zipf scale (van Heuven, Mandera, Keuleers & Brysbaert, 2014) was 4.87 ($SD = 0.54$) (Brysbaert & New, 2009). For Spanish words, it was 4.82 ($SD = 0.44$) (Cuetos, Glez–Nosti, Barbón & Brysbaert, 2011). There was no significant difference in Zipf scale values between languages ($t < 1$, $p = .73$). However, the lexical frequency was significantly higher for number words in Spanish, $t(23) = 2.62$, $p < .05$ ($M = 5.24$ for number words and $M = 4.72$ for non-number words) and in English $t(23) = 2.44$, $p < .05$ ($M = 5.35$ for number words and $M = 4.75$ for non-number words).

The experiment was controlled by a Genuine-Intel compatible PC, using E-prime experimental software, 1.1 version (Schneider, Eschman & Zuccolotto, 2002). Instructions and stimuli were presented on a 17” screen. Viewing distance was approximately 60 cm. Response latencies were collected by using a PST Serial Response Box (Psychology Software Tools) with an accuracy of 1ms. Responses were recorded to eliminate trials with errors in the latency analyses.

Procedure and design

All the participants performed a forward translation task (from Spanish to English) and a backward translation task (from English to Spanish). The order of these tasks was counterbalanced. For each translation task, the participants performed four experimental blocks (two blocked and two mixed) that were presented in ABBA design. Half of the participants started with the blocked category condition and the other half with the mixed category condition. Within each blocked category block, the five blocked category lists (see above) were randomly presented. Within each mixed block, the five mixed category lists were randomly presented. Each block consisted of 125 trials. Therefore, there were a total of 500 experimental trials for each translation task. In each trial, a fixation cross was presented for 500 ms. After a blank period of 500 ms, the target item was shown for 500 ms. Latencies were measured from the onset of the target until the subject’s response, with a limit of 1500 ms. The next trial started after 1000 ms. There was a short break between lists and between blocks. Before the experimental trials, the participants were given a list of the words to be used in the experiment and asked to perform four practice trials.

Results

Analyses of reaction times (RT) were performed excluding trials with incorrect response (hesitation sounds like “eh” that triggered the voice key were included in the errors count) or with voice-key failures (4.79 %). In addition, for each participant, the trials that differed from the mean by more than three standard deviations were discarded from the RT analyses as outliers (1.5 %). Finally, the first occurrence of each stimulus on each block was also excluded (see Damian et al. 2001; Navarrete et al., 2012).

We assessed the semantic context effect in the usual way by computing the mean RT separately for number words and for non-number categories (see Table 2). The translation direction (forward vs. backward), the category (non-number vs. number) and the context (mixed vs. blocked) were submitted to analyses of variance (ANOVA) by participants (F_1) and by items (F_2). The responses in forward translation (607 ms) were slower than in backward translation (593 ms). This difference was significant in analyses by participants $F_1(1, 19) = 5.03$, $MSE = 1462$, $p < .05$, but not by items ($F_2 = 2.55$, $p = .12$). The responses in blocked context (597 ms) were faster than in mixed context (603 ms). Again, the difference was significant in analyses by participants $F_1(1, 19) = 4.60$, $MSE = 314$, $p < .05$, but not by items ($F_2 = 2.45$, $p = .13$). Finally, translations of number words (564 m) were faster than translations of non-number words (636 ms). It was significant by participants, $F_1(1, 19) = 136.60$, $MSE = 1530$, $p < .001$, and by items $F_2(1, 23) = 22.95$, $MSE = 3646$, $p < .001$.

These effects were qualified by a significant interaction between translation direction and context, $F_1(1, 19) = 4.73$, $MSE = 438$, $p < .05$, $F_2(1, 23) = 5.42$, $MSE = 162$, $p < .05$, which indicated that responses in backward translation were faster in blocked context (587 ms) than in mixed context (600 ms), $F_1(1, 19) = 9.21$, $MSE = 379$, $p < .01$, $F_2(1, 23) = 5.76$, $MSE = 253$, $p < .05$; however, in forward translation, responses were similar in both context conditions (608 ms and 606 ms, for blocked and mixed respectively). More importantly, the context by category interaction was also reliable, $F_1(1, 19) = 59.34$, $MSE = 390$, $p < .001$, $F_2(1, 23) = 39.10$, $MSE = 242$, $p < .001$. When participants translated numbers in

https://doi.org/10.1017/S1366728917000669 Published online by Cambridge University Press

Table 2. *Mean RTs (in milliseconds) and standard deviations (in parenthesis) as a function of Type of task, Type of context and Category in Experiment 1, 2A, 2B and 3.*

	Number		Non-number		Animal		Body-part		Furniture		Vehicle	
Context	RT	SD	RT	SD	RT	SD	RT	SD	RT	SD	RT	SD
Experiment 1												
Forward translation task (L1 to L2)												
Blocked	561	(83)	654	(80)	653	(81)	676	(88)	671	(93)	617	(80)
Mixed	581	(73)	631	(81)	642	(83)	639	(81)	639	(90)	605	(80)
Blocked - Mixed	−20		23		11		37		31		11	
Backward translation task (L2 to L1)												
Blocked	537	(71)	637	(80)	640	(86)	645	(83)	632	(83)	629	(80)
Mixed	577	(69)	623	(79)	626	(86)	627	(85)	613	(80)	627	(74)
Blocked - Mixed	−40		13		14		18		19		2	
Experiment 2A												
Naming in L1 (Spanish)												
Blocked	413	(64)	563	(76)	564	(83)	546	(80)	572	(85)	570	(73)
Mixed	468	(66)	538	(71)	536	(76)	528	(71)	533	(72)	556	(70)
Blocked - Mixed	−55		25		28		18		40		14	
Naming in L2 (English)												
Blocked	467	(66)	598	(75)	601	(77)	585	(79)	603	(74)	602	(84)
Mixed	492	(63)	564	(77)	555	(78)	568	(78)	566	(82)	565	(78)
Blocked - Mixed	−25		34		45		17		37		37	
Experiment 2B												
Reading in L1 (Spanish)												
Blocked	482	(66)	500	(60)	505	(58)	494	(64)	504	(73)	500	(64)
Mixed	508	(62)	506	(54)	509	(51)	500	(55)	501	(62)	512	(55)
Blocked - Mixed	−27		−5		−4		−7		3		−13	
Reading in L2 (English)												
Blocked	516	(73)	529	(64)	516	(65)	548	(65)	518	(69)	534	(69)
Mixed	532	(65)	531	(63)	524	(65)	551	(69)	526	(59)	524	(64)
Blocked - Mixed	−16		−2		−8		−3		−8		11	
Experiment 3												
Forward translation task (L1 to L2)												
Blocked	644	(76)	679	(64)	677	(70)	704	(75)	690	(65)	644	(64)
Mixed	636	(78)	659	(68)	659	(63)	683	(76)	665	(66)	628	(76)
Blocked - Mixed	8		20		18		21		25		16	
Backward translation task (L2 to L1)												
Blocked	603	(71)	645	(73)	651	(85)	641	(60)	644	(86)	644	(74)
Mixed	613	(74)	631	(75)	635	(77)	622	(71)	629	(82)	638	(77)
Blocked - Mixed	−10		14		16		19		15		6	

Note. Last row for each language condition shows the difference in RTs between Blocked and Mixed. The non-number column includes the average of the non-number categories.

the blocked context (549 ms) they were faster than in the mixed context (579 ms), $F_1(1, 19) = 38.29$, $MSE = 472$, $p < .001$, $F_2(1, 23) = 19.11$, $MSE = 242$, $p < .001$; however, for non-number categories the effect was the opposite (645 ms vs. 627 ms, for blocked and mixed context respectively), $F_1(1, 19) = 28.08$, $MSE = 232$, $p < .001$, $F_2(1, 23) = 27.48$, $MSE = 242$, $p < .001$. Therefore, there was a clear difference in the semantic context effect as a function of the type of item, which occurred in both translation directions.

The percentages of error were very low (1.10 % in forward translation and 0.94 % in backward translation).

https://doi.org/10.1017/S1366728917000669 Published online by Cambridge University Press

We correlated response latencies and percentages of error across the eight (2 x 2 x 2) conditions of the experiment, and we found no significant correlation (r = .01). Therefore, there was no evidence of a speed-accuracy trade-off.

Discussion

Experiment 1 showed two different patterns of results as a function of the types of stimuli. On the one hand, for non-number words there was an interference effect of the blocked context regardless of the translation direction. This result is at odds with those obtained by Kroll and Stewart (1994), as they found that the semantic blocking produced interference only in forward translation, and not in backward translation. Although they initially interpreted their results as evidence of different routes for each translation direction, more recently Kroll et al. (2010) have suggested that this effect may have been due to the low frequency of the items used in that experiment. In the present experiment, the items used were of higher lexical frequency than that which was reported in Kroll and Stewart's experiment, so this might explain the difference in the results between the two studies.

On the other hand, for number words the blocked context produced shorter latencies relative to the mixed context. The absence of interference has been interpreted as an indicator of non-semantic processing. In the case of word reading in monolingual studies, it is assumed that there is direct access from the orthographic input codes to the phonological codes (e.g., Damian et al., 2001). In the case of translation, it might be accounted for by direct lexical connections between L1 and L2 lexical representations, which is the asemantic route in this task (Kroll & Stewart, 1994). Therefore, the present findings support, as several other authors have suggested, the idea that the processing route depends on the type of word (e.g., Brysbaert & Duyck, 2010; Kroll et al., 2010; Sánchez-Casas et al., 1992). Nevertheless, the results are contrary to the suggestion of Duyck and collaborators (e.g., De Brauwer et al., 2008; Duyck & Brysbaert, 2004; 2008), since the lexical route seems to be more prominent than the conceptual route in the translation of number words.

It is worthy to note that the blocked semantic context produced a facilitation effect for number words. It was similar to previous studies of number processing with monolinguals (Herrera & Macizo, 2011; 2012), which was interpreted as an index of asemantic processing. However, before drawing any further conclusions, two more experiments were conducted in which the semantic blocking effect was examined in a picture naming task (which should not produce interference) and a reading task (which should produce interference).

Experiment 2A (Naming) and 2B (Reading)

The aim of Experiment 2A was to examine the effect of semantic blocking when bilinguals name Arabic digits and pictures of common objects in their two languages. As mentioned previously, when monolinguals name objects in a semantic blocking paradigm the usual finding is an interference effect of the blocked context. Arabic digits are logographic symbols used to represent numbers, and some authors (e.g., Brysbaert, 1995; Damian, 2004; Fias, Reynvoet & Brysbaert, 2001) have suggested that the processing required to name Arabic digits could be, in a certain sense, similar to the processing required to name pictures of objects. In fact, they are only arbitrarily related to the corresponding phonological form, but they also have an arbitrary relation with the meaning they convey. However, in a recent work, it was showed that when monolinguals named Arabic digits, the semantic blocking produced a facilitation effect relative to mixed context (Herrera & Macizo, 2011; 2012), which was interpreted as asemantic processing. For bilinguals, the same Arabic digits have two lexical representations and two different phonological representations, so the question in Experiment 2A was whether in this case the conceptual route might be implied differently for each language of naming.

In addition, Experiment 2B explored the semantic blocking for a reading word task in L1 and L2. Previous studies with monolingual participants have shown that there is no interference effect of the blocked context in this situation. This can be explained because the orthographic representation of a word specifies its pronunciation, and there are direct connections to the form-word level (e.g., Coltheart, Rastle, Perry, Langdon & Ziegler, 2001; Roelofs, 2003). Therefore, in Experiment 2B, it was expected that the interference effect would neither appear in L1 nor in L2.

Method

Participants

Forty students from the University of Murcia participated in Experiments 2A and 2B for course credits. Twenty of them (7 men and 13 women; mean age = 25.35, SD = 4.58) participated in Experiment 2A; the other 20 students participated in Experiment 2B (9 men and 11 women; mean age = 25.30, SD = 4.12). All of them were Spanish–English bilinguals (L1/L2 respectively). They started to learn English at school between the ages of 2 and 15. They filled out the same questionnaire about language proficiency as was used in Experiment 1, after performing the experiment (see Table 1). For participants in Experiment 2A, the mean fluency in L1 was higher (10.0, SD = 0.0) than the mean fluency in L2 (8.3, SD = 1.0), $t(19) = 7.39$, $p < .001$, which suggests that participants were fluent in English but

https://doi.org/10.1017/S1366728917000669 Published online by Cambridge University Press

dominant in Spanish. For participants in Experiment 2B, the comparison between fluency in L1 (10.0, $SD = 0.0$) and fluency in L2 (8.3, $SD = 1.0$), indicated that they were also dominant in L1, $t(19) = 7.44$, $p < .001$. The participants in these two experiments were similar in L2 fluency to those in Experiment 1 ($t = 1.38$, $p = .18$ for comparison between participants in Experiment 1 and 2A; $t = 1.53$, $p = .13$ for comparison between participants in Experiment 1 and 2B).

Stimuli and apparatus

In these experiments, we used the same items as in Experiment 1, but in Experiment 2A they were presented as line drawing of the common objects and Arabic numbers. The pictures were taken from Pérez and Navalón (2003) and from Snodgrass and Vanderwart (1980). The average size of the pictures was 7cm high and 7cm wide.

Procedure and design

In Experiment 2A, all the participants performed a naming task in English and in Spanish; and in Experiment 2B, all the participants performed a reading task in English and in Spanish. The order of the task language was counterbalanced across the participants. For each language, the participants performed four experimental blocks (two blocked and two mixed) that were presented in ABBA design. Half of the participants started with the blocked category and the other half with the mixed category. In all other aspects, the design and procedure were equal to those in Experiment 1.

In Experiment 2A, the participants were given a set of cards before the experimental trials. Each card contained one of the pictures with its name in Spanish and in English. Participants were told to examine the pictures and the names because they would have to name them later on. In Experiment 2B, the participants were given all words before the experimental trials and were told that during the experiment they would have to read them. All the participants performed four practice trials.

Results

Following the same criteria as in Experiment 1, for Experiment 2A, a total of 6.14% of the data points were excluded from the RTs analyses as errors or voice-key failures, and a total of 1.65% were excluded as outliers. For Experiment 2B, a total of 5.14% of the data points were excluded from the RTs analyses as errors or voice-key failures and a total of 1.63 % as outliers. In addition, the first occurrence of each stimulus on each block was also excluded. Mean RTs for each semantic category are shown in Table 2.

Similarly to Experiment 1, we grouped non-numerical categories. The language (L1: Spanish vs. L2: English), the semantic context (blocked vs. mixed) and the category (non-number vs. number) were introduced in ANOVAs by participants and by items. For Experiment 2A, the results showed a significant main effect for language, $F_1(1, 19) = 12.94$, $MSE = 3755$, $p < .01$, $F_2(1, 23) = 47.91$, $MSE = 442$, $p < .001$, indicating that responses in Spanish ($M = 495$ ms) were faster than in English ($M = 530$ ms). There was also a significant main effect for category, $F_1(1, 19) = 261.46$, $MSE = 1706$, $p < .001$, $F_2(1, 23) = 229.94$, $MSE = 752$, $p < .001$, reflecting that responses for Arabic digits ($M = 460$ ms) were faster than responses for non-number categories ($M = 566$ ms). The effect of context did not reach statistical significance ($F_1 = 2$, $p = .16$, $F_2 = 4$, $p = .05$). However, there were significant interactions between language and semantic context, $F_1(1, 19) = 12.67$, $MSE = 295$, $p < .01$, $F_2(1, 23) = 14.28$, $MSE = 123$, $p < .001$; and between semantic context and category, $F_1(1, 19) = 199.87$, $MSE = 242$, $p < .001$, $F_2(1, 23) = 129.58$, $MSE = 141$, $p < .001$. Finally, the three-way Language x Context x Category interaction was also reliable in the analysis by participants, $F_1(1, 19) = 7.54$, $MSE = 143$, $p < .05$, but not in analysis by items ($F_2 = 2.66$, $p = .11$). A series of *t*-tests showed significant longer responses in the blocked context than in the mixed context for naming pictures of non-numeric categories in L1, $t(19) = 5.11$, $p < .001$, and in L2, $t(19) = 8.19$, $p < .001$. However, for naming digits, the blocked context produced a significant advantage in L1, $t(19) = -9.48$, $p < .001$, and in L2, $t(19) = -3.79$, $p < .01$. Furthermore, the facilitative effect of the blocked context was significantly larger for naming digits in L1 than in L2, $t(19) = 4.02$, $p < .01$; however, there was no significant difference between L1 and L2 in the interference of the blocked context for naming pictures from non-number categories ($t = 1.55$, $p = .13$) .

For Experiment 2B, the results showed a significant effect for language, $F_1(1, 19) = 11.84$, $MSE = 3451$, $p < .01$, $F_2(1, 23) = 20.87$, $MSE = 543$, $p < .001$. Reading in L1 (499 ms) was faster than in L2 (527 ms). Response latencies in blocked context (507ms) were shorter than in mixed context (519 ms), $F_1(1, 19) = 6.99$, $MSE = 519$, $p < .01$, $F_2(1, 23) = 66.02$, $MSE = 43$, $p < .001$. In addition, responses to number words (509 ms) were faster than responses to non-number words (517 ms). This difference was significant by participants $F_1(1, 19) = 6.99$, $MSE = 295$, $p < .05$, but not in analysis by items ($F_2 = 1.76$, $p = .19$). Finally, the two-way Context x Category interaction was significant, $F_1(1, 19) = 15.30$, $MSE = 195$, $p < .001$, $F_2(1, 23) = 31.33$, $MSE = 43$, $p < .001$. The interaction resulted because the facilitation of the blocked context was larger for numbers than for non-number categories; in fact, the context effect was significant for numbers in analyses by participants, $F_1(1, 19) = 20.71$, $MSE = 427$, $p < .001$, and by items, $F_2(1, 23) = 58.85$, $MSE = 43$, $p < .001$; however, for non-number categories it was significant only in analysis by items, F_2 (1, 23) = 7.98,

$MSE = 43$, $p < .01$, ($F_1 < 1$). No other interaction was significant.

The percentages of error in Experiment 2A were 1.23 for naming in L1 and 2.38 for naming in L2. Similar to Experiment 1, we correlated response latencies and percentage of error across the eight conditions. There was a significant positive correlation ($r = .18$, $p < .05$). In Experiment 2B, the percentages of error were very low: 0.09% for L1 reading and 0.88% for L2 reading. There was a non-significant correlation between response latencies and percentages of error across the eight experimental conditions ($r = .06$). Therefore, there was no evidence of a speed-accuracy trade-off.

Discussion

The results of Experiment 2A showed that the semantic blocking produced an interference effect when participants named pictures. The effect was quite similar for both languages. This result is in line with the results in monolingual studies (e.g., Damian et al., 2001; Navarrete et al., 2012), indicating that regardless of the language, picture naming requires the activation of conceptual representation and a subsequent lexical selection. For Arabic digits, the semantic blocking produced a facilitative effect, which was larger for L1 responses. Therefore, the effect was of similar polarity to the effect in the translation tasks performed in Experiment 1 and in previous studies with monolingual participants (Herrera & Macizo, 2011; 2012). Following the previous line of reasoning, this result should be interpreted as a larger influence of the asemantic route.

On the other hand, in Experiment 2B, as expected, the semantic blocking did not produce an interference effect in word reading regardless of the semantic category or the language. This is in accord with the results from previous studies with monolinguals (Kroll & Stewart, 1994; Damian et al., 2001), indicating that reading printed words can be carried out by connections to the form level to a large extent and, therefore, there is no competition in selection of the lexical representation. For number words, as in previous experiments, there was a facilitation effect, which was somewhat larger for L1 reading than for L2 reading.

As a whole, the results of these three experiments seem to indicate that the translation of number words takes place, to a greater extent, through the asemantic route, therefore, through lexical connections. Nevertheless, as mentioned above, the characteristics of the words are important in determining the type of processing; thus, the effects observed in the present work might depend on the concrete numeric stimuli used. For example, it may be that the interference produced by the blocked context requires the activation of the conceptual representation but also requires a larger semantic feature overlap among the instances to be named[1]. Number words seem to be more frequently used than other words, especially in the smaller range; thus, there could be less semantic confusion among the numbers used in the present experiments than among other categories.

In order to check whether the present findings were due to the specific range of numbers used, an additional experiment was conducted with number words that correspond to larger numbers that are consecutive in the numerical sequence, composed of only one word (i.e., 8, 9, 10, 11, 12). By using these number words we tried to increase semantic confusion.

Experiment 3. Translating larger numbers

The aim of this experiment was to explore the effect of the blocked context on the translation of larger numbers than those used in previous experiments. The most prominent theories of number processing assume that the larger the numbers the larger the semantic overlap between numbers (e.g., Dehaene, 1992; Gallistel & Gelman, 1992, although see Verguts et al., 2005). Thus, it was expected that the use of larger numbers would increase the probability of the interference effect in the blocked context.

Method

Participants

Twenty students from the University of Murcia participated in the experiment for course credits (7 men and 13 women). All of them were Spanish–English bilinguals (L1/L2 respectively). The mean age was 21.25 ($SD = 3.85$) and they all had normal or corrected to normal visual acuity. The mean fluency in L1 was 9.3 ($SD = 0.8$) and in L2 it was 6.7 ($SD = 1.3$). This difference was significant, $t(19) = 8.23$, $p < .001$, indicating that participants were dominant in Spanish. The L2 fluency of the participants in this experiment was significantly lower than the L2 fluency of the participants in Experiment 1, $t(38) = 3.38$, $p < .01$.

Stimuli and apparatus

The stimuli were the same as in Experiment 1 except for the numbers. Here, the numerical items were ‘eight’, ‘nine’, ‘ten’, ‘eleven’ and ‘twelve’ . The lexical frequency in Zipf values for the number words in Spanish and English used in Experiment 3 ($M = 4.70$, $SD = 0.40$) was significantly lower than for the numbers words used in Experiment 1 ($M = 5.29$, $SD= 0.54$), $t(18) = 2.76$, $p < .01$ (see Appendix). In addition, in this experiment the comparison of lexical frequency between number

[1] We wish to thank Mark Brysbaert for suggesting this alternative explanation.

words and non-number words was not significant in either Spanish or English (both $t < 1$).

Procedure and design

All the participants performed a translation task from Spanish to English and from English to Spanish. The same procedure and design used in Experiment 1 were used here.

Results and discussion

A total of 5.31% of the data points were excluded from the RTs analyses as errors or voice-key failures and a total of 2.37 % were excluded as outliers. The first occurrence of each stimulus on each block was also excluded.

The items from non-number categories were grouped (see Table 2). The translation direction (forward vs. backward), the category (non-number vs. number) and the context (mixed vs. blocked) were submitted to ANOVAs by participants (F_1) and by items (F_2). Responses in forward translation (655 ms) were significantly slower than in backward translation (623 ms), $F_1(1, 19) = 17.07$, $MSE = 2328$, $p < .001$, $F_2(1, 23) = 12.30$, $MSE = 1181$, $p < .01$. The blocked context (643 ms) produced slower responses than the mixed context (635 ms). This difference was significant by participants, $F_1(1, 19) = 5.16$, $MSE = 484$, $p < .05$, but only marginal by items, $F_2(1, 23) = 3.99$, $MSE = 275$, $p = .05$. The translation of number words (624 ms) was faster than the translation of non-number words (653 ms). Again this difference was significant by participants, $F_1(1, 19) = 37.52$, $MSE = 913$, $p < .001$, and marginal by items $F_2(1, 23) = 3.55$, $MSE = 3402$, $p = .07$. Also, there was a significant Translation direction x Context interaction, $F_1(1, 19) = 4.60$, $MSE = 310$, $p < .05$, $F_2(1, 19) = 3.65$, $MSE = 100$, $p = .06$; and the Context x Category interaction was significant in the analysis by participants $F_1(1, 19) = 21.87$, $MSE = 144$, $p < .001$. These interactions indicated that the effect of the semantic context was significant in forward translation, $F_1(1, 19) = 11.45$, $MSE = 336$, $p < .01$, F_2, $(1, 23) = 11.20$, $MSE = 121$; $p < .01$, but it was not significant in backward translation ($F_1 < 1$, $F_2 < 1$). In addition, the context effect was significant for the non-number category, $F_1\ (1, 19) = 24.58$, $MSE = 229$, $p < .001$, but it was not for number words. Although the three-way interaction was not significant, in order to compare with the results from Experiment 1, we explored the effect of context on each translation direction for the number and non-number categories. The context effect was significant for non-numerical categories in forward translation $t(19) = 4.81$, $p < .001$, and in backward translation, $t(19) = 2.98$, $p < .01$. However, it was not statistically significant for numerical stimuli in either forward or backward translation ($p > .05$ for both comparisons).

Percent error rates were 0.84% in forward translation and 0.78% in backward translation. The correlation between response latencies and percentages of error across the eight conditions was not significant ($r = .11$). Therefore, there was no evidence of a speed-accuracy trade-off.

In summary, the results of Experiment 3 showed that while the blocked context produced an interference effect for non-number categories, for numerical items the blocked context did not produce this effect. In addition, the interference effect was larger in forward translation than in backward translation.

General discussion

Since the first proposals of hierarchical models, one issue of interest in bilingual processing studies has been the influence of lexical connections and semantic mediation on translation tasks. The results of previous research suggest that the larger influence of one or another route depends on several aspects, such as the bilingual's characteristics, the context of the translation and some properties of the words (for reviews, see Brysbaert & Duyck, 2010; Kroll et al., 2010; van Hell & Kroll, 2013). Regarding the properties of the words, Duyck and collaborators (de Brauwer et al., 2008; Duyck & Brysbaert, 2002; 2004; Duyck et al., 2008) argued that for number words, the semantic connections might be prominent and strong even at very early stages of L2 learning because the meaning of number words is completely overlapped across languages.

In the present work, the influence of the semantic and lexical routes on the translation of number words was explored by using the cyclic semantic blocking paradigm in four experiments. In Experiment 1, participants performed a translation task. It was found that the blocked context produced facilitation relative to the mixed context when participants translated number words, but, for no-numeric semantic categories, the blocked context produced interference. These results occurred regardless of the translation direction. In Experiment 2A, the participants named Arabic digits and pictures of common objects in L1 and L2. Regardless of the naming language, the blocked context produced facilitation for numerals, but interference for naming pictures of objects from the other categories. In Experiment 2B, the participants read the names of numbers and common objects in L1 and L2. This time, the blocked context produced facilitation for number words, but there was no effect for the other categories. Finally, in Experiment 3, participants performed a translation task with larger numbers, which are less frequently used and might be more semantically confusable. In this case, the blocked context did not produce either significant facilitation or significant interference for number words. It is, nevertheless, important to note that the participants in Experiment 3 had lower L2 fluency than the participants in Experiment 1. Therefore, some differences between these two experiments might be due to the participants' L2 proficiency.

In previous studies with monolingual participants, the interference of the semantic blocking on picture naming has generally been interpreted as the result of a competitive process in lexical selection. It is assumed that this interference effect arises because semantically related concepts co-activate one another through activation spreading in a semantic network and each concept activates its own lemma in the mental lexicon, which results in competition for lexical selection (e.g., Belke et al., 2005; Damian et al., 2001; Kroll & Stewart, 1994). More recently, an alternative account for semantic interference in terms of incremental learning has been suggested. In this proposal, the effect arises from changes in the connections' weights between semantic and lexical representations (Oppenheim, Dell & Schwartz, 2010); however, regarding the aim of the present study, it is assumed that there is a semantic activation which triggers the interference effect. Therefore, the finding of interference in translation words for the non-numerical categories might be interpreted as an indication of semantic representation being activated and having a strong influence on the translation output (e.g., Kroll & Stewart, 1994). This semantic effect was present for both translation directions, although it was somewhat larger in forward translation, which is in accordance with previous studies (e.g., de Groot et al., 1994; van Hell & de Groot, 1998, 2008). The results of Experiments 2A and 2B reinforced this hypothesis, since, in a task where semantic access is required such as picture naming, the interference effect occurred regardless of the language; whereas in the reading task, in which a direct route to phonological codes may be used, the interference effect disappeared.

For number words, however, the effect of the semantic blocking was in the opposite direction. There was facilitation regardless of the language or the task. This result was very similar to the results in previous studies with monolingual participants (Herrera & Macizo, 2011; 2012) where the blocked context produced facilitation when participants either named Arabic digits or read number words. In those studies, it was interpreted that for those numerical stimuli the retrieval of phonological information proceeds without semantic mediation. In some previous studies with non-numerical categories, a facilitative effect of the semantic blocking was found in reading words (e.g., Damian et al., 2001), and it was interpreted as a result of interactive processes between orthographic input and semantic codes, or even as a product of the participants' strategy because they probably noted the semantic block and developed expectations about the following items. However, if this were the case, it should be similar for numerical and non-numerical stimuli.

It might be argued that the facilitative effect of the semantic blocking originated at the semantic level, and represents a peculiarity of the numerical category. However, as reported previously (Herrera & Macizo, 2012), the blocked context produced an interference effect when the numerical items were either sets of dots or Roman numerals. Thus, when participants name physical numerosity or when they name symbols that are not frequently used, semantic representation is activated and the interference of the blocked context occurs.

The results of Experiment 3 indicated that the facilitation effect found with numbers is restricted to the first part of the numerical sequence, given that when somewhat larger numbers were used (i.e., eight, nine, ten, eleven and twelve) the blocked context did not produce effect. Certainly, most prominent theories of number processing (e.g., Dehaene, 1992; Gallistel & Gelman, 1992) assume that larger number have more semantic representation overlap. Thus, it could be argued that the absence of interference with smaller numbers was due to lesser semantic confusion. However, as asserted above, the blocked context produces interference when the same small numbers are presented as either a set of dots or as Roman numbers in a naming task. Therefore, the asemantic route explanation seems better suited for the present results.

It has been suggested (Herrera & Macizo, 2011, 2012) that the facilitative effect observed with numerical items might be the result of some kind of priming at a lexical level based on associative relatedness, defined as a normative description of the probability that one word will call a second word to mind (e.g., Ferrand & New, 2003). These associative relationships are assumed to reflect word use, the frequent co-occurrence of the items in language use, rather than word meaning. Although the locus of associative connections is not clear at this moment, some models of language production (e.g., Collins & Loftus, 1975; Levelt, 1989) have described direct connections between lexical representations to explain the effect of these associative relationships. In the case of the numbers, these connections may develop due to the sequential characteristic of these elements and the way in which they are learned and used. Children usually learn number words by reciting the numerical sequence, even when they do not understand their meaning (e.g., Wynn, 1992). Later, numbers continue to be used as a sequence when adults count or enumerate things in everyday situations. Nevertheless, in all this situations, it is not always necessary to retrieve the meaning of each number, but rather only the meaning of the last one to obtain the cardinality or the count of the set that is enumerated. Similarly, number words in L2 are also learned and frequently used as a sequence, so it is possible that the same processing characteristics are present for both languages.

Nevertheless, lexical frequency seems to have an important role in the pattern of results. As reported in Experiment 1, there were significant differences in lexical frequency between number and no-number stimuli. In order to explore the influence of this factor, the correlation between the context effect in Experiment 1 (RTs Blocked – RTs Mixed) and the word frequency mean in Zipf values was examined. There was a significant negative correlation in forward translation ($r = -.43$, $p < .05$) and backward translation ($r = -.65$, $p < .001$). The same analyses for Experiment 3 resulted in a significant negative correlation in backward translation ($r = -.50$, $p < .05$), but it was not reliable for forward translation ($r = -.05$). Therefore, this indicated that the larger the word frequency, the smaller the interference effect.

In summary, the absence of interference of the blocked context on number word translation indicates that the lexical links are very strong for this type of word regardless of the translation direction. Although the revised hierarchical model suggests that the lexical connections become weaker, even in early stages of L2 learning, recent studies using event related potentials (ERPs), which allow for a more precise analysis of the time course of processing words in two languages, suggest that the role of L2 to L1 lexical connections might be important even for fluent bilinguals (for a recent review of these studies, see van Hell & Kroll, 2013). The differences observed in the present study between number words and other categories, particularly in the lower range of the numerical sequence, reinforce the argument that the influence of the processing routes depends on the type of items (e.g., Brysbaert & Duyck, 2010; de Groot, 1992; Kroll et al., 2010; Sánchez-Casas et al., 1992; van Hell & de Groot, 2008).

Appendix

List of stimuli used in Experiment 1, 2A, 2B and 3. The frequency of each word is noted as Zipf values (van Heuven et al., 2014)

Spanish word	Zipf value	English word	Zipf value
	VEHICLE		
avión	5.09	airplane	4.04
motocicleta	3.92	motorcycle	3.95
barco	4.93	ship	5.00
coche	5.06	car	5.68
tren	4.85	train	4.98
	ANIMAL		
caballo	4.79	horse	4.97
perro	5.22	dog	5.29
cerdo	4.60	pig	4.59
gato	4.73	cat	4.82
vaca	4.29	cow	4.41
	BODY-PART		
nariz	4.73	nose	4.84
pie	5.01	foot	4.81
ojo	4.81	eye	5.05
dedo	4.66	finger	4.56
oreja	4.20	ear	4.51
	FURNITURE		
mesa	5.04	table	5.02
cama	5.25	bed	5.27
lámpara	4.01	lamp	4.11
armario	4.44	closet	4.43
silla	4.74	chair	4.69
	NUMBER		
ocho	4.98	eight	4.99
uno	5.97	one	6.49
cuatro	5.40	four	5.41
siete	5.03	seven	5.02
nueve	4.81	nine	4.83
	Additional numbers used in Experiment 3		
diez	5.16	ten	5.16
once	4.24	eleven	4.11
doce	4.47	twelve	4.27

References

Altarriba, J., & Mathis, K. M. (1997) Conceptual and lexical development in second language acquisition. *Journal of Memory and Language, 36,* 550–568.

Belke, E., Meyer, A. S., & Damian, M. F.(2005). Refractory effects in picture naming as assessed in a semantic blocking paradigm. *Quarterly Journal of Experimental Psychology, 58,* 667–669.

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., & Duyck, W. (2010). Is it time to leave behind the Revised Hierarchical Model of bilingual language processing after fifteen years of service? *Bilingualism: Language and Cognition, 13,* 359–371.

Brysbaert, M., & New, B. (2009). Moving beyond Kučera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior Research Methods, 41,* 977–990.

Chen, H.-C., & Leung, Y.-S. (1989). Patterns of lexical processing in a nonnative language. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 15,* 316–325.

Cohen-Kadosh, R., & Walsh, V. (2009). Numerical representation in the parietal lobes: Abstract or not abstract?. *Behavioral and Brain Sciences, 32,* 313–328.

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review, 82,* 407–428.

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

Cuetos, F., Glez–Nosti, M., Barbón, A., & Brysbaert, M. (2011). SUBTLEX-ESP: Spanish word frequencies based on film subtitles. *Psicológica, 32,* 133–143.

Damian, M.F. (2004). Asymmetries in the processing of Arabic digits and number words. *Memory & Cognition, 32,* 164.

Damian, M.F., Vigliocco, G., & Levelt, W. J. M. (2001). Effects of semantic context in the naming of pictures and words. *Cognition, 81,* 77–86.

de Brauwer, J., Duyck, W., & Brysbaert, M. (2008). The SNARC effect in the processing of second-language number words: Further evidence for strong lexico-semantic connections. *Quarterly Journal of Experimental Psychology, 61,* 444–458.

de Groot, A. M. B. (1992). Determinants of word translation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 1001–1018.

de Groot, A. M. B., Dannenburg, L., & van Hell, J. G. (1994). Forward and backward word translation by bilinguals. *Journal of Memory and Language, 33,* 600–629.

de Groot, A. M. B., & Poot, R. (1997).Word translation at three levels of proficiency in a second language: The ubiquitous involvement of conceptual memory. *Language Learning*, *47,* 215–264.

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

Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General, 122,* 371–396.

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

Duyck, W., Depestel, I., Fias, W., & Reynvoet, B. (2008). Cross-lingual numerical distance priming with second-language number words in native- to third-language number word translation. *Quarterly Journal of Experimental Psychology, 61,* 1281–1290.

Ferrand, L., & New, B. (2003). Semantic and associative priming in the mental lexicon. In P. Bonin (Ed.), *Mental Lexicon: Some words to talk about words* (pp.25–44). NY: Nova Science Publisher.

Ferré, P., Sánchez-Casas, R., & Guasch, M. (2006). Can a horse be a donkey? Semantic and form interference effects in translation recognition in early and late proficient and nonproficient Spanish-Catalan bilinguals. *Language Learning, 56,* 571–608.

Fias, W., Reynvoet, B., & Brysbaert, M. (2001). Are Arabic numerals processed as pictures in a Stroop interference task? *Psychological Research, 65,* 242–249

Gallistel, C. R., & Gelman, R. (1992). Preverbal and verbal counting and computation. *Cognition, 44,* 43–74.

Gollan, T., Forster, K. L., & 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.

Grosjean, F. (1998). Studying bilinguals: Methodological and conceptual issues. *Bilingualism: Language and Cognition, 1,* 131–149.

Herrera, A., & Macizo, P. (2011). Naming digits in a semantic blocking paradigm. *Quarterly Journal of Experimental Psychology, 64,* 328–338.

Herrera, A., & Macizo, P. (2012). Semantic processing in the production of numerals across notations. *Journal o Experimental Psychology: Learning, Memory, and Cognition, 38,* 40–51.

Herrera, A., Macizo, P., & Semenza, C. (2008). The role of working memory in the association between number magnitude and space. *Acta Psychologica, 128,* 225–237.

Jiang, N. (1999). Testing processing explanations for the asymmetry in masked cross-language priming. *Bilingualism: Language and Cognition, 2,* 59–75.

Kroll, J. F., & Curley, J. (1988). Lexical memory in novice bilinguals: The role of concepts in retrieving second language words. In M. M. Gruneberg, P. E. Morris, & R. N. Sykes (Eds.), *Practical aspects of memory* (Vol. *2,* pp. 389–395). London, England: Wiley.

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 and A. M. B. de Groot (Eds.), *Handbook of Bilingualism: Psycholinguistic Approaches*, (p. 531–553). Oxford UK: Oxford University Press.

Kroll, J. F., & Tokowicz, N. (2001). The development of conceptual representation for words in a second language. In J. Nicol (Ed.), *One mind, two languages: Bilingual language processing* (pp. 49–71). Malden, MA: Blackwell Publishers.

Kroll, J. F., van Hell, J. G., Tokowicz, N., & Green, D. W. (2010). The revised hierarchical model: A critical review. *Bilingualism: Language and Cognition, 13,* 373–381.

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.

Levelt, W. J. M. (1989). *Speaking: From intention to articulation*. Cambridge, MA: MIT Press.

Moyer, R. S., & Landauer, T. K. (1967). Time required for judgements of numerical inequality. *Nature, 215,* 1519–1520.

Navarrete, E., Del Prato, P., & Mahon, B. Z. (2012) Factors determining semantic facilitation and interference in the cyclic naming paradigm. *Frontiers in Psychology*, *3*:38.

Oppenheim, G. M., Dell, G. S., & Schwartz, M. F. (2010). The dark side of incremental learning: A model of cumulative semantic interference during lexical access in speech production. *Cognition, 114,* 227–252.

Pérez, M. A., & Navalón, C. (2003). Normas españolas de 290 nuevos dibujos: Acuerdo en la denominación, concordancia de la imagen, familiaridad, complejidad visual y variabilidad de la imagen [Spanish norms for 290 new pictures: Agreement in naming, picture agreement, familiarity, visual complexity and picture variability]. *Psicológica, 24,* 215–241.

Potter, M. C., So, K.-F., Von Eckardt, B., & Feldman, L. B. (1984). Lexical and conceptual representation in beginning and more proficient bilinguals. *Journal of Verbal Learning and Verbal Behavior, 23,* 23–38.

Restle, F. (1970). Speed of adding and comparing numbers. *Journal of Experimental Psychology, 83,* 274–278.

Roelofs, A. (2003). Goal-referenced selection of verbal action: Modeling attentional control in the Stroop task. *Psychological Review, 110,* 88–125.

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

Sakaki, Y., Hakoda, Y., & Kaminska, Z. (2012). Translation processes in bilinguals: Role of inter-lingual distance and second language proficiency. *Psychologia, 55,* 208–225.

Sánchez-Casas, R. M., Davis, C. W., & García-Albea, J. E. (1992). Bilingual lexical processing: Exploring the cognate/non-cognate distinction. *European Journal of Cognitive Psychology, 4,* 293–310.

Santens, S., & Gevers, W. (2008). The SNARC effect does not imply a mental number line. *Cognition, 108,* 263–270.

Sasanguie, D., Defever, E., van den Bussche, E., & Reynvoet, B. (2011). The reability of and the relation between non-symbolic numerical distance effects in comparison, same-different judgments and priming. *Acta Psychologica, 136,* 73–80.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime user's guide* (Version 1.1). Pittsburgh, PA: Psychology Software Tools.

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

Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory, 6,* 174–215.

Talamas, A., Kroll, J. F., & Dufour, R. (1999). From form to meaning: Stages in the acquisition of second language vocabulary. *Bilingualism: Language and Cognition 2,* 45–58.

van Dijck, J. P., & Fias, W. (2011). A working memory account for spatial–numerical associations. *Cognition, 119,* 114–119.

van Dijck, J. P., Gevers, W., & Fias, W. (2009). Numbers are associated with different types of spatial information depending on the task. *Cognition, 113,* 248–253.

van Hell, J. G., & de Groot, A. M. B. (1998). Conceptual representation in bilingual memory: Effects of concreteness and cognate status in word association. *Bilingualism: Language and Cognition, 1,* 193–211.

van Hell, J. G., & de Groot, A. M. B. (2008). Sentence context modulates visual word recognition and translation in bilinguals. *Acta Psychologica, 128,* 431–451.

van Hell, J. G., & Kroll, J. F. (2013). Using electrophysiological measures to track the mapping of words to concepts in the bilingual brain. In J. Altarriba and L. Isurin (Eds.), *Memory, Language, and Bilingualism. Theoretical and Applied Approaches* (pp. 126–160). Cambridge: Cambridge University Press.

van Heuven, W. J. B., Mandera, P., Keuleers, E., & Brysbaert, M. (2014). SUBTLEX-UK: A new and improved word frequency database for British English. *Quarterly Journal of Experimental Psychology, 67,* 1176–1190.

van Opstal, F., & Verguts, T. (2011). The origins of the numerical distance effect: The same-different task. *Journal of Cognitive Psychology, 23,* 112–120.

van Opstal, F., Gevers, W., de Moor, W., & Verguts, T. (2008). Dissecting the symbolic distance effect: Comparison and priming effects in numerical and non-numerical orders. *Psychonomic Bulletin & Review, 15,* 419–425.

Verguts, T., Fias, W., & Stevens, M. (2005). A model of exact small-number representation. *Psychonomic Bulletin & Review, 12,* 66–80.

Vigliocco, G., Lauer, M., Damian, F. D., & Levelt, W. J. M. (2002). Semantic and syntactic forces in noun phrase production. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28,* 46–58.

Wynn, W. (1992). Children's acquisition of the number words and the counting system. *Cognitive Psychology, 24,* 220–251.