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Second language acquisition influences the processing of number words

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Abstract

We evaluated whether learning a second language (L2) influences the processing of numerical information. A group of German/English bilinguals with high/low L2 fluency performed two-digit number comparison tasks while the unit-decade compatibility was evaluated. All participants presented compatibility effect with Arabic digits regardless of their L2 learning stage. However, low fluency bilinguals performed verbal number comparison as monolinguals (regular compatibility effect in German, reverse compatibility effect in English) while fluent bilinguals with intensive experience in L2 learning did not show compatibility effects in either German or English. These results suggest that L2 learning determines the processing of two-digit number words.

Keywords: Second language acquisition; Number cognition; Bilingualism; Two-digit number processing; Number comparison task

1. Introduction

Previous studies in the field of second language acquisition have demonstrated that learning a second language (L2) determines the cognitive functioning of people. The consequences of L2 learning have a broad impact in different mental processes such us cognitive control, memory processes, language processes, etc. For example, research on control processes has shown that bilinguals have superior ability to focus on relevant information and to ignore irrelevant information (Bialystok, 1992). Also, bilinguals are better than monolinguals at inhibiting nonverbal information and performing switching tasks (Bialystok & Martin, 2004). In addition, studies on working memory (WM) have shown an advantage for bilinguals in tests of spatial WM (Feng, 2008). Finally, learning a second language changes the way in which bilinguals process linguistic information. Bilinguals with reduced experience in a second language are more sensitive to lexical properties of their two languages while language processing is more semantic and less influenced by lexical properties in bilinguals with an extensive training in L2. Sunderman and Kroll (2006) compared a group of low fluency English/Spanish bilinguals (L1/L2, respectively) and a group of highly proficient bilinguals on a translation recognition task in which they decided whether two words, one in each language, were translation equivalents. The results showed that low fluency bilinguals committed more form-related

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errors such us responding that “cara”/”card” were correct translations (“cara” means “face” in English). On the contrary, bilinguals with high L2 fluency produced more semantic errors such us responding that “cara”/”head” were correct translations. These results indicate that the pattern of cross-linguisitic influence changes with increasing L2 fluency so that, L2 learners are more vulnerable to lexical influences from their languages while the processing of high fluency bilinguals is more semantically driven.

Although there is abundant evidence on the consequences of acquiring a second language, to our knowledge, there is no research about the possible effect of L2 fluency on numerical cognition. The current study was aimed to explore whether second language acquisition determines the processing of two-digit numbers. To this end, we made use of the unit-decade compatibility effect (compatibility effect for short) (Nuerk, Weger, & Willmes, 2001). In studies exploring the compatibility effect the participants are presented two-digit number pairs and they have to decide which number is larger. There are two types of trials: in compatible trials the decade digit and the unit digit of one number are larger than those of the other (e.g., 67-24, both 6 > 2 and 7 > 4) while in incompatible trials the decade digit of one number is larger than that of the other number but the unit digit of this number is smaller than that of the other (e.g., 64-27, 6 > 2 but 4 < 7). The results obtained in recent studies have shown no compatibility effect, regular compatibility effect (slower response time in incompatible trials as compared with compatible trials) and reverse compatibility effect (faster response time in incompatible trials as compared with compatible trials) (Macizo & Herrera, 2008, 2010; Macizo, Herrera, Paolieri, & Román, 2010; Nuerk, Weger, & Willmes, 2005) . The variability of this effect mainly depends on the format of two-digit numbers (Arabic numbers and verbal number words), and its direction has been taken as evidence of different ways of processing two-digit numbers (see Macizo et al., 2010, Nuerk & Willmes, 2005, for an extensive explanation). The absence of compatibility effect suggests that participants process two-digit numbers as a whole (Ganor-Stern, Pinhas, & Tzelgov, 2009). The regular compatibility effect with number words suggests that participants process the decade and unit digits separately. This effect is obtained with Arabic numbers and verbal numbers in languages where numbers follow the inversion property, for example, in German language, where the unit-decade order in Arabic digits (e.g., 27) is inverted in verbal notation (e.g., 27 = “siebenundzwanzig”, literally, “seven and twenty”) (Macizo et al., 2010; Nuerk & Willmes, 2005). Finally, the reverse compatibility effect indicates that participants decompose two-digit numbers but that they mainly focus on the decade digit (Macizo & Herrera, 2010). The reverse compatibility effect is observed with verbal numbers in languages with no inversion property in which verbal numbers follow the decade-unit order (e.g., Spanish, English, Italian).

Recent studies exploring number cognition in bilinguals have shown that they process verbal numbers as monolinguals of each of their languages (Macizo et al., 2010). Thus, Italian/German bilinguals show reverse compatibility effect in Italian (L1) but regular compatibility effect in German (L2). These findings indicate that bilinguals are very strongly determined by lexical properties of the language in which numbers are presented. However, in these studies the stage of second language acquisition of bilinguals is neither controlled nor evaluated so the conclusions should be considered carefully since they might be modulated by L2 fluency.

In the present study we directly addressed the consequences of learning a second language on the processing of two-digit numbers. A group of German/English bilinguals (L1/L2, respectively) with reduced experience in L2 and a group of bilinguals with extensive knowledge of L2 performed two-digit number comparison tasks while the compatibility effect was examined. According with previous research demonstrating that low fluency bilinguals are more influenced by lexical properties of their language (Sunderman & Kroll, 2006, see above), we expected regular compatibility effect in German and reverse compatibility effect in English in this group of participants. In addition, if high fluency bilinguals are less influenced by superficial properties of the languages (unit-decade order in German and decade-unit order in English for two-digit number words), they might show the same type of compatibility effect in each of their languages.

2. Method

2.1. Participants

Two groups of German/English bilinguals (L1/L2, respectively) (32 women, 8 men), from the University of Potsdam (Germany) participated in the study. The first group was composed of twenty bilinguals with low experience in L2. Their mean age was 25.05 (*SD* = 5.64). One participant was left-handed and 19 were right-handed. The second group was composed of twenty bilinguals with high experience in L2. Their mean age was 22.60 (*SD* = 4.38). Three participants were left-handed and 17 were right-handed. The participants reported no history of language and numerical disabilities and all had normal or corrected-to-normal visual acuity. All participants learnt numbers and arithmetic operations in German. After performing the current experiment, the bilinguals were asked to complete a language proficiency questionnaire on reading, writing, listening, and speaking in their two languages (see Table 1). The participants were equated in their knowledge of German, however, participants with high experience in L2 learning scored higher in the L2 proficiency questionnaire than participants with low experience in L2 (*p*s < .05).

Table 1. *Characteristics of participants in the study*

	Low fluency bilinguals		High fluency bilinguals	
	German (L1)	English (L2)	German (L1)	English (L2)
Speech fluency	8.7 (2.7)	5.4 (1.6)	9.8 (0.6)	8.3 (1.1)
Speech comprehension	9.0 (2.6)	6.5 (2.2)	10.0 (0.0)	8.6 (0.9)
Writing proficiency	8.6 (2.5)	5.0 (2.0)	9.8 (0.4)	7.7 (1.3)
Reading proficiency	8.8 (2.7)	6.1 (2.2)	9.7 (0.9)	8.7 (0.9)
Number of hours per week writing	14.3 (11.0)	0.9 (2.3)	17.4 (23.7)	7.9 (7.8)
Number of hours per week reading	16.7 (12.0)	2.8 (4.6)	17.1 (26.6)	13.1 (25.9)
Number of hours per week watching TV	22.0 (22.3)	2.6 (3.8)	22.6 (42.1)	12.0 (25.2)

Note. Mean scores and standard deviation (in bracket) of German/English bilinguals in their first language (L1) and their second language (L2). The ratings range from less to more in a ten-point scale for each dimension.

2.2. Design and materials

The experimental stimuli included 240 between-decade two-digit number pairs between 21 and 98 previously used in our laboratory (Macizo & Herrera, 2008, 2010; Macizo et al., 2010). The group of participants (low fluency bilinguals and high fluency bilinguals) was a between-subject variable while the unit-decade compatibility (compatible and incompatible) and the number format (Arabic numbers, L1 number words and L2 number words) were manipulated within-subjects. One-hundred twenty trials were assigned to the compatible condition and 120 were assigned to the incompatible condition. The stimuli groups in compatible and incompatible trials were equated in numerical variables. Decade and tie numbers were not included. In addition, we included 60 filler trials. These trials were within-decade two-digit number pairs randomly selected from decades 20 to 90.

2.3. Procedure

The experiment was controlled by a Genuine-Intel compatible 2993 MHz PC using E-prime experimental software, 1.2 version (Schneider, Eschman, & Zuccolotto, 2002). Participants were tested individually. They were seated approximately 60 cm from the computer screen. Stimuli were presented in lower-case black letters (Courier New font, 48 point size) on a white background. At this viewing distance, one character subtended a vertical visual angle of 1.91 degrees and a horizontal visual angle of 1.67 degrees. Each number pair was presented until the subject's response. The interval between the response and the next number pair was fixed to 500 ms. In each trial, two numbers were presented in the middle of the screen above each other and participants had to indicate as quickly and accurately as possible the larger of two numbers with the top key if the top number was larger and with the bottom key if the bottom number was larger. In half of the trials the top number was the larger and in the rest of trials the bottom number was the larger. The participants performed three number comparison tasks (Arabic number comparison, L1 number comparison and L2 number comparison). All participants began with the Arabic number comparison task and they continued with the verbal comparison tasks. The order of the two verbal comparison tasks (L1 and L2) was counterbalanced across participants. For each task, four stimuli lists were created in order to counterbalance the spatial presentation of the two numbers (top/bottom) and the response hand (right/left). So, across lists a given larger number was assigned to: (1) top presentation/right-hand response ("u" key), (2) top presentation/left-hand response ("y" key), (3) bottom presentation/right-hand response ("n" key) and (4) bottom-presentation/left-hand response ("b" key). The lists were counterbalanced across participants so they were presented an equal number of times in the experiment. Each number comparison task was divided in two blocks of 150 trials each (120 experimental trials and 30 filler trials randomly selected). There was a 5 min. break between blocks and between tasks. Within each number comparison task, the block order was counterbalanced across participants and number pairs were randomized within blocks for each participant.

3. Results

The incorrect responses (4.13% in the Arabic number task, 5.34% in the L1 number task and 6.80% in the L2 number task) and the reaction times (RTs) exceeding a criterion of 3 *SD* for an individual participant's mean (1.57% in the Arabic number task, 1.79% in the L1 number task and 1.63% in the L2 number task) were excluded from analysis.

An analysis of variance (ANOVA) was carried out on RT data with Fluency (low fluency bilinguals and high fluency bilinguals), Compatibility (compatible vs. incompatible trials) and Number format (Arabic numbers, L1 numbers and L2 numbers). The interaction among the three factors was significant, $F(2, 76) = 3.70, p < .05$. In order to qualify this interaction, we performed separate analyses for Arabic number pairs and verbal number pairs (L1 and L2).

3.1. Bilinguals processing Arabic numbers

An ANOVA was carried out with Fluency (low fluency bilinguals and high fluency bilinguals) and Compatibility (compatible, incompatible). The main effect of Fluency was not significant ($F < 1$). The main effect of Compatibility was significant, $F(1, 38) = 32.48, p < .001$. Responses to compatible trials were 22 ms faster than responses to incompatible trials. The Fluency x Compatibility interaction was not significant ($F < 1$). Therefore, all the bilinguals processed Arabic digits in a similar way regardless of their experience with L2 learning (see Figure 1).

3.2. Bilinguals processing verbal numbers

The Fluency (low fluency bilinguals and high fluency bilinguals), the Language (L1 and L2) and the Compatibility (compatible, incompatible) were submitted to an ANOVA. The main effect of Language was significant, $F(1, 38) = 4.97, p < .05$. In addition, the Fluency x Language x Compatibility second-order interaction was significant, $F(1, 38) = 5.22, p < .05$. None other main effects or interactions were significant ($p > .05$).

When we considered participants with low experience in L2, the Language x Compatibility interaction was significant, $F(1, 19) = 9.77, p < .01$. When low fluency bilinguals performed the task in L1 (German), they were 19 ms faster in compatible trials as compared to incompatible trials, $F(1, 38) = 4.62, p < .05$. When they performed the task in L2 (English), there was a marginal effect of compatibility, $F(1, 38) = 3.20, p < .08$, which indicated that bilinguals were 18 ms slower in compatible trials as compared to incompatible trials (see Figure 1).When high fluency bilinguals performed the verbal number comparison tasks, none main effects or interactions were significant (all Fs < 1). In fact, the difference between incompatible and compatible trials was not significant in L1 (German) (-5 ms difference) and it was not significant in L2 (English) (2 ms difference) (Fs < 1).

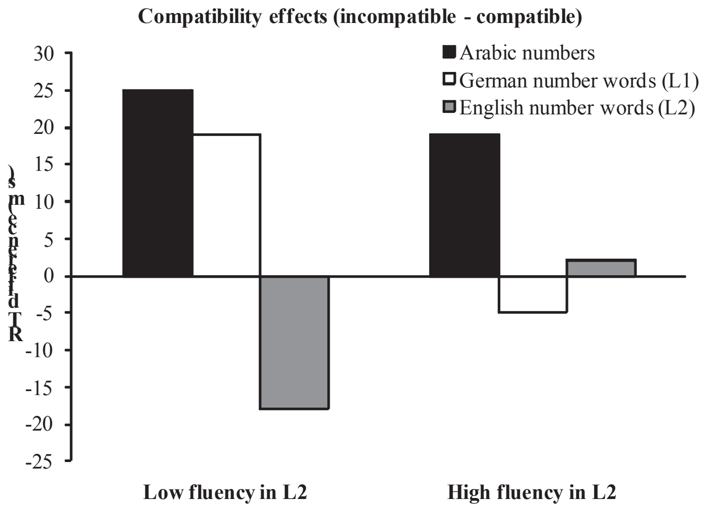

Figure 1. Compatibility effects (incompatible trials minus compatible trials) on the mean reaction times (RT, in milliseconds) as a function of number format (Arabic numbers, L1 numbers and L2 numbers) for German/English (L1/L2) bilinguals with Low and High fluency in their L2.

3.3. Bilinguals vs. monolinguals processing two-digit numbers

The results obtained in the experiment indicate that bilinguals with low experience in L2 learning behave as monolinguals of their languages (regular compatibility effect in German and reverse compatibility effect in English). In contrast, bilinguals with large experience in L2 did not show either regular or reverse compatibility effect which suggests that they differed from the way monolinguals process number words. In order to confirm these differences between monolinguals and low/high fluency bilinguals, we performed additional analyses. The bilinguals were compared with a group of 16 English monolinguals from the University of Penn State (USA) and 16 German monolinguals from the University of Potsdam (Germany).

In the Arabic number comparison task, the ANOVA performed with Group (low fluency bilinguals, high fluency bilinguals, German monolinguals and English monolinguals), and Compatibility (compatible, incompatible) showed a main effect of compatibility, $F(1, 68) = 54.78$, $p < .001$. Responses to compatible trials were 21 ms faster than responses to incompatible trials. The Compatibility x Group interaction was not significant ($F = 1$).

In the verbal number comparison task, when bilinguals with low L2 experience were compared with monolinguals, all the participants presented the same compatibility effect: There were no differences between bilinguals performing the comparison task in L1 (German) and German monolinguals in the regular compatibility effect, $F < 1$. Similarly, bilinguals performed the comparison tasks in L2 (English) as English monolinguals and they presented the same reverse compatibility effect ($F < 1$).

When bilinguals with high experience in L2 were compared with monolinguals, they presented a different pattern of compatibility effect. There were differences between bilinguals performing the comparison task in L1 (German) and German monolinguals in the compatibility effect, $F(1, 34) = 5.96$, $p < .05$; indicating that only the monolinguals showed regular compatibility effect (36 ms faster in compatible trials), $F(1, 34) = 8.06$, $p < .01$. In addition, there were differences in the compatibility effect when bilinguals performing the task in L2 (English) were compared with English monolinguals, $F(1, 34) = 3.16$, $p < .08$, showing that only the monolingual group presented reverse compatibility effect (26 ms faster in incompatible trials), $F(1, 34) = 5.05$, $p < .05$.

4. Discussion

This study was aimed to evaluate whether the way of processing numerical information changes as a function of learning a second language. The response to this question is affirmative. Two groups of German/English bilinguals which varied in their L2 experience and fluency performed a number comparison task while the compatibility effect was taken as an index of the manner in which they processed number words. Regardless of their L2 acquisition stage, all bilinguals showed regular compatibility effect with Arabic digits. The same pattern of results was obtained in monolingual participants without knowledge of a second language. These results suggest that the processing of Arabic digits is not permeable to either linguistic influences or learning of a second language. However, the processing of verbal numbers was determined by the bilingual's fluency. Low fluency bilinguals presented the same compatibility effect as monolinguals in each of their languages, regular compatibility effect in German (L1) and reverse compatibility effect in English (L2). These findings suggest that participants with little experience in a second language are vulnerable to influences of the language in which numbers are presented. According to the interpretation of the compatibility effect, although low fluency bilinguals processed the unit and the decade separately irrespective of the language (German or English), they focused more on the unit digit when they processed in L1 than when they processed in L2 in which the mainly focused on the decade. Previous research in the field of bilingualism corroborates that participants with low experience with L2 process linguistic information more lexically (Sunderman & Kroll, 2006). The current study shows that lexical influences extend to the processing of numerals.

On the other hand, participants with extensive knowledge of L2 did not show compatibility effect in L1 or L2. Therefore, they presented a different pattern of results from monolinguals of German and English. These findings clearly suggest that participants with high L2 fluency were not affected by lexical properties of their languages (German with inversion property and English with no inversion property). Otherwise, they might be shown differences in the compatibility effect across their languages. Moreover, the absence of linguistic influences on number processing was observed not only in L2 but also in the way of processing numbers in their first language. This observation is surprising: Language modulations are easy to observe in the bilinguals' L2, but they are difficult to find in the bilinguals' L1 (Kroll & Stewart, 1994).

Moreover the results obtained in this study indicate that bilinguals with low experience in L2 decompose the processing of two-digit verbal numbers (compatibility effect) while high fluency bilinguals process two-digit numbers holistically (no compatibility effect). Although speculative at the present time, it might be possible that the holistic processing of verbal numbers in experienced bilinguals might be the result of their increased WM capacity which let them to process numbers as a whole. First, it has been observed that bilinguals have superior WM capacities as compared to monolinguals (Macizo & Bajo, 2006). Second, when the processing of numerical information requires the participation of WM (e.g., sequential presentation of the two numbers to be compared) the compatibility effect disappears suggesting that participants maintain the numbers as a whole during the comparison process (Ganor-Stern et al., 2009). Third, large compatibility effects are associated with reduced WM capacity while small compatibility effects are linked to large WM capacity (Macizo, Herrera & Pestelli, submitted).

5. Conclusion

The present study demonstrates that learning a second language has consequences for cognitive abilities beyond linguistic domain. Second language acquisition determines the processing of numerical information. Bilinguals with low knowledge of L2 process number words as monolinguals, indicating that they are sensitive to lexical information of verbal numbers in German and English. Bilinguals with large experience in L2 are unaffected by number format. In addition, they seem to process holistically two-digit number words probably because of their increased working memory capacities.

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