

Bilingualism and numerical cognition

Bilinguismo e cognição numérica

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ABSTRACT

The present study aimed to investigate the relationship between bilingualism and numerical cognition, more specifically, the way English-Portuguese bilinguals solve simple mathematical problems when these are presented in different formats (digits, English, and Portuguese) and whether their language history background has any effect on such behavior. The main results suggest that bilinguals are faster and more accurate in solving mathematical problems presented in digit format and in solving those problems presented in the written format when the language of the stimuli was the one in which they learned basic arithmetic. Also, the participants' language background experience did not have any significance in their task performance.

KEYWORDS:

Bilingualism 1. Numerical Cognition 2. Arithmetic 3. Language History Background 4.

RESUMO

O presente estudo visou investigar a relação entre bilinguismo e cognição numérica, mais especificamente, a maneira como pessoas bilíngues (português-inglês) resolvem problemas matemáticos simples quando eles são apresentados de diferentes maneiras (dígitos, inglês e português) e se o histórico de linguagem exerce algum efeito nesse comportamento. Os principais resultados deste estudo sugerem que os bilíngues são mais rápidos na resolução de problemas matemáticos apresentados em dígito, e mais precisos ao resolver problemas apresentados em forma escrita na língua em que aprenderam aritmética básica. Por fim, a experiência de língua dos participantes não teve significância quanto à acurácia e o tempo de resposta dos mesmos.

PALAVRAS-CHAVE:

Bilinguismo 1. Cognição numérica 2. Aritmética 3. Histórico de linguagem 4.

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1. Introduction

Learning a second language means learning how to interpret the world in a different way. As the old saying “learn a new language and get a new soul” points out, bilingual individuals have distinct ways of perceiving the same world, since bilingualism is not only about language, but also about culture. According to Grosjean & Li (2013), bilinguals are not necessarily fluent in their both languages, but they use them for different purposes and in different situations, in order to achieve different goals.

According to Crystal (1997), about two-thirds of the world’s children are raised in bilingual homes or environments. Along the same lines, Wei (2000) posits that at least one person in every three of the world’s population uses two or more languages for family life, work, and leisure activities. It is now common sense to assume that there are more bilinguals than monolinguals in the world; those people have different backgrounds, social status, gender, and nationalities, to name a few factors. In that sense, what truly allows the world to connect is, in fact, bilingualism and what demonstrates the importance of speaking more than one language is the fact that we can successfully communicate with people all over the world.

Considering the fact that we live in a world full of bilinguals and multilinguals, it becomes important to investigate the aspects that make bilinguals’ minds and brains distinct from monolinguals’. Bialystok (2008:1) argues that learning a new language is an experience that may change “behavioral, neuropsychological, and structural aspects of cognitive performance”. The same author also claims that no other cognitive experience is as intense as bilingualism (Bialystok, 2017). Regardless of age and context in which it happens, what we now know is that a person’s brain is profoundly affected by the experience of learning and using more than one language (Kroll & Bialystok, 2013).

Research shows that there are many positive outcomes that arise from a bilingual experience. Apart from the social advantages that are normally pointed out, cognition, memory, and physical brain health are some of the aspects that can be positively influenced by bilingualism (Bialystok *et al.*, 2012; Kroll & Bialystok, 2013; Valian, 2014; Bialystok, 2017, among many others). After all, mastering more than one language allows us to have twice the access to opportunities to learn and interact in different types of situations and can significantly influence everything we do. And we are now aware that bilingualism affects our brain in a unique way, for it is an experience that recruits distinct mental resources in comparison to the cognitive apparatus that is activated in

a monolingual brain (Kroll & Bialystok, 2013; Bialystok, 2017).

It is also known that the bilingual brain does not separate languages in different chunks and storing compartments (Perani & Abutalebi, 2005); in fact, it uses them to complement each other when people interact in the world. When bilinguals speak one of the languages they know, they are making the choice and effort not to use the other language the brain masters. Our minds and brains find themselves in the constant practice of making decisions according to where, who, and what they are talking about, besides many other variables. Despite this, during each different daily situation, one of the languages is more activated than the other, but never exclusively activated. According to Kroll, Bobb & Wodniecka (2006), bilinguals cannot forget everything they know about language A when speaking language B, simply because our brains do not allow us to.

In that sense, one of the most important findings from bilingual research is that both languages of the bilingual are always active, even in contexts in which only one of the languages is being used (Colomé, 2001; Costa et al., 2000; Kroll et al., 2006). This phenomenon, known as ‘simultaneous activation’, has been demonstrated in several studies during listening, reading, speaking and writing tasks, in all levels of proficiency and several combinations of languages (for a summary, see Kroll & De Groot, 2005).

But what happens when we unconsciously and apparently for no reason choose one language instead of the other? Dealing with numerical concepts seems to be one of such cases. Reading numbers in one’s second language can be a challenging task. It requires special attention and quick reasoning in a way that differs from the reading of sentences that do not contain numbers. Previous studies have found that bilinguals tend to read and deal with numbers more efficiently in the language in which they first learned arithmetic (Marsh & Maki (1976), Salillas & Wicha (2012), Van Rinsveld, Brunner, Landerl, Schiltz, & Ugen (2015), or in the language of training (Spelke & Tsivkin, 2011). The interesting and complex relationship between bilingualism and numerical cognition is not necessarily about first language (L1) *versus* second language (L2), but about the language in which arithmetic was first learned *versus* an L2. According to Grosjean (2015)³: “The first language advantage, however, is limited to speakers whose early schooling was in their home language”.

Nevertheless, in the context of bilingualism, not all numbers seem to be equally complicated to read. According to Van Rinsveld et al. (2015), the smaller the number, the easier

³ Grosjean, F. What languages do bilinguals count in?. Available at: <https://www.psychologytoday.com/intl/blog/life-bilingual/201504/what-languages-do-bilinguals-count-in/> Accessed in: October 25, 2019.

the challenge. Level of proficiency in L2 is also an important variable. If we think about Brazilian bilinguals who speak Portuguese and English, for instance, those who have been exposed to English for a longer time may probably find it easier to read numbers in the L2 than the ones who have not. Those who are in contact with numbers in English on a daily basis, however, might probably find it easier to read numbers in that language than the ones who have a more occasional contact with the L2. In addition to that, research has shown that the language of training might affect the processing of numerical cognition in bilinguals (Spelke & Tsivkin, 2011), confirming the role of the language of instruction in the consolidation in memory of knowledge related to math, a finding that may carry out significant implications for contexts of bilingual education.

There have only been a few studies on the relationship between bilingualism and numerical cognition. They have all contributed with great success to the area of investigation, since they allow us to understand the complexity of the bilingual brain a little more. There is still, though, a good deal of aspects on the topic that deserve to be investigated. The complexity of the bilingual brain seems to demand special attention, especially when numerical cognition is involved.

A great part of previous studies centers on numerical operations and language behavior. Not many of them, however, focus on the way numbers are presented within calculations, an empirical gap that the present study intends to fill out. Within that context, the goal of this research was to investigate whether high proficiency bilingual speakers of Portuguese-English show any language preference in reading numbers when they solve simple mathematical problems involving addition, taking into consideration the participants bilingual background experience. This is a key angle to consider when researching the relationship between bilingualism and arithmetic, since different forms of presenting numbers (digit or written format) can influence the accuracy and response time in tasks evaluating language behavior. Besides that, from what it is known, this is the first study that takes into account the bilinguals' language background experience in order to better understand the individual's language preference when dealing with numbers, a novelty that deserves to be mentioned. For these reasons, we believe the present study contributes to further understanding of the intricacies of the bilingual mind.

2. Background

The present study explores the way bilinguals deal with numbers. According to Grosjean

(2015), there are people who prefer to think of mathematics in the language of math, separating it from words and vocalizations. It appears to be clear, however, that bilingualism and numerical cognition have an interesting and unitary relationship that involves a set of significant characteristics. In order to further explore the discussion, the following section presents some of the previous studies on the field of bilingualism and arithmetic and their main findings.

2.1. Language use and arithmetic

In the past decades, there have been many studies investigating language use and arithmetic. This topic, which has grown tremendously within scientific research, has been studied from several perspectives. When there was no technology for designing more sophisticated studies, reaction time was all that could be measured in studies investigating how bilinguals process numbers. With such a measure, researchers could better understand and explore the fact that there seems to be a language preference when bilinguals calculate. Nowadays, however, thanks to the advances of technology, most studies in the field are based on neuroimaging, which allows for a more specific and deep understanding of the bilingual brain.

In one of the first studies designed to investigate the complex relationship between language and arithmetic, Marsh & Maki (1976) developed an experiment with 20 English-Spanish and Spanish-English bilinguals: ten had learned arithmetic in English and had it as their preferred language, whereas the other ten learned to calculate in Spanish and had it as their preferred language. Participants saw addition problems made out of one, two, or three operations, typed on slides. Their job was to provide, as quickly and accurately as possible, in the language of instruction, the answers for the calculations. The recording of their responses allowed both a reaction time and an accuracy analysis. The results suggest that addition operations can be solved faster and more accurately in a bilingual's preferred language than in their non preferred language. Another interesting conclusion posited by the authors was that the participants may have performed arithmetic calculations without the use of language, since numbers may be not coded by a specific language in the brain. However, they claimed, when participants made use of language to solve the calculations, they took longer to do it in their non preferred language than in the language they would rather speak.

A few years later, McClain & Shih Huang (1982) developed two experiments with different types of bilinguals. In the first experiment, ten participants reported Mandarin as their preferred language and English as their non preferred language, and the other ten reported the opposite.

Arithmetic problems were recorded on tape by a Chinese-English bilingual with no detectable accent, and participants had to respond in the language in which the problems were presented. In the second experiment, the authors reproduced what was first done, this time with 20 Spanish-English and 20 English-Spanish bilinguals. The study also included participants who only solved problems in their preferred language, in order to make it possible to compare the behavior of bilinguals and monolinguals. The main results suggest, once more, that bilinguals perform arithmetic better in their preferred language, and also that monolinguals are faster in solving calculations in comparison to bilinguals.

In the year of 2000, Spelke & Tsivkin performed three experiments with Russian-English bilingual college students in order to investigate the role of a specific language in the representations of numbers in humans. In the first experiment, participants were taught new numerical operations; in the second study, they were taught new arithmetic equations; in the third experiment, they were taught new geographical or historical facts either containing numerical or non-numerical information. In all three experiments, participants learned the previously mentioned items and tested on those items and new items in both Russian and English. The main findings suggest that a specific language contributes to the representation of exact numbers, since participants performed better in the retrieval of the information of exact numbers when tested in the language of training. On the other hand, when the task involved retrieving information about approximate numbers and non-numerical facts, there was no effect of language of training.

Finally, in 2015, Van Rinsveld, Brunner, Landerl, Schiltz, & Ugen had bilinguals solve simple and complex addition problems. Participants, who were different types of bilinguals (7th, 8th, 9th 10th graders and young adults), spoke Luxembourgish⁴ or German as an L1 and French as an L2. The participants saw problems in digits and auditory form and had to provide the right answer for addition calculations as fast and accurately as possible. The results suggest that language proficiency is crucial to complex addition solving. For simple additions, however, language did not appear to be as crucial. The authors claimed that this happened because all participants had previously had significant contact and practice with their L2. In a nutshell, the authors claim that problems were solved faster and with fewer errors in German than in French, since German was the L1 of all participants and it was also the language in which they learned arithmetic.

⁴ An official language of Luxembourg which developed from a dialectal variant of German.

The previously mentioned studies have all reached the conclusion that bilinguals perform arithmetic calculations better in their preferred language, that is, they are faster and more accurate when dealing with numbers in the language in which they learned arithmetic or were exposed to training. However, none of the previous studies took into consideration different ways of presenting those numbers. The following subsection highlights some of the studies that dealt with the way numbers are presented within calculations.

2.2. Written words versus symbols

When we think of a number, the first thing that normally comes to our minds is its symbol representation. Imagining number five, for example, can mean picturing the symbol 5; if that is the case, we are not thinking about words, but about symbols. However, in our minds, we tend to separate symbols and words. What happens is that when our brains process numbers, its representation format is decisive. According to Frenck-Mestre & Waid (1993), within numerical cognition, numbers are not only language-sensitive, but format-sensitive too.

In their study, “Activation of number facts in bilinguals,” Frenck-Mestre & Waid (1993) examined the effect that numbers – digits *versus* word format – have on bilinguals when they need to solve mathematical problems. According to the authors, the way a number, in this case a calculation, is presented influences the way we solve them. Because of that, in their study the authors developed two experiments in which English-French bilingual participants had to solve calculations presented first in the digit format, and then in the participants’ first and second languages.

In the first experiment, participants had to decide whether the responses for addition calculations were correct or incorrect. The answers for the calculations were randomized between either the true sum of the pair or numerically different from it. In the second experiment, on the other hand, the participants’ job was to decide whether the responses for addition and multiplication problems were correct or incorrect. This time, three different types of answers were presented: they could be either true, associatively related, or neutral. In true trials, the responses for addition and multiplication calculations were correct. In associatively related trials, the responses for addition problems would have been true if they were multiplication tasks, and vice versa. Finally, in neutral trials, the answers for addition and multiplication calculations were mathematically unrelated to it.

The results of experiment 1 showed that bilinguals were slower to answer problems

presented in their L2 in comparison to their L1. Besides, in the comparison of all three formats of item presentation, participants proved to be significantly faster when answering problems presented in digit format. The authors also found interference effects in all three formats of presentation. In other words, the participants made mistakes in digits and in both first and second languages. With respect to experiment 2, the results confirmed the previous findings and showed that bilinguals were not only faster but also more accurate in answering calculations presented in a digit format, regardless of whether they were addition or multiplication problems.

Almost 20 years later, Salillas & Wicha (2012) tested multiplication in adult bilinguals, this time by measuring electrophysiological and behavioral responses. Their study explored the relationship between math-language connection and language dominance in adulthood. According to the authors, when we are children, language and math seem to have a closer relationship than it does as we grow older, since language is needed to mediate the entire process of first learning arithmetic. Once we get older, however, language and math tend to be seen as two separated, non-related things.

In Salillas & Wicha's (2012) study, Spanish-English bilinguals that had learned arithmetic in Spanish had to decide whether the answers being shown for multiplication calculations were correct or not. Problems were presented in three formats, digit, written in Spanish, and written in English, and their solutions could be correct, incorrect but related to one of the operands, or incorrect but unrelated to one of the operands. Among the findings of the study, the main one suggests that memory networks for multiplication are defined at an early age and are linked to a specific language and are retrieved independent of language dominance in adulthood. In other words, even though an adult bilingual may be dominant in his/her L2, the language in which arithmetic was first learned is likely to be the one that prevails when he/she needs to deal with calculations. Also, problems presented in the participants' L1 had qualitatively different brain responses than problems presented in the participants' L2, indicating that a bilingual brain may respond differently when mathematical problems are presented in their preferred or in their non preferred language.

Finally, from the evidence found in the study, the authors concluded that, when talking about numbers, the language in which a person learned arithmetic in the past can strongly be the one that prevails, regardless of language dominance in adulthood. Such findings also have major pedagogical implications for bilingual education, reinforcing the importance of teaching school subjects in both the bilinguals' languages, such as in immersion or Content and Language

Integrated Learning (CLIL, Coyle *et al.* 2010) pedagogical contexts.

3. Methods

3.1. Goals

The main goal of this study was to investigate whether high proficiency bilingual speakers of Portuguese-English show any language preference in reading numbers when they solve simple mathematical problems involving addition, taking into consideration the participants' bilingual background experience. This investigation aims to contribute to the studies in the field of psycholinguistics of bilingualism by further exploring the complex relationship between bilingualism and numerical cognition. The following specific objectives guided the investigation:

- a) verify if Portuguese-English bilinguals show any language preference when reading numbers while solving addition mathematical problems (involving three conditions: in digit format, written in Portuguese, or written in English).
- b) analyze whether the participants' language background experience (age in which they started to study English; how long they have been speaking it; contexts in which they use the language; the period of time they have been working as English teachers; the experience of living abroad and the language in which they most practice reading and listening skills) affects their language preference for reading numbers when solving mathematical problems.

3.2. Hypotheses and experimental predictions

Two hypotheses were created in order to verify the specific objectives. They are detailed below, along with the specific predictions derived from them:

- a) The presentation format (digit, written in Portuguese, or written in English) of the items in the task would affect the efficacy with which participants performed the mathematical operations. It was, therefore, expected that participants would solve addition calculations faster and more accurately when they were presented in digit format, in comparison to Portuguese and English written formats, respectively. This prediction was based on previous studies, which indicate that people are faster and more accurate in answering
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calculations presented in digit format than in written format (Franck-Mestre & Waid (1993); Salillas & Wicha (2012)).

- b) The participants' language background experience would not affect their behavior in the task. That is, factors such as the age in which they started to study English; how long they have been speaking it; contexts in which they use the language; the period of time they have been working as English teachers; and the experience of living abroad and the language in which they most practice reading and listening skills were not expected to interfere with their overall responses. This specific prediction was based on the fact that, as stated above, previous studies indicate that the format or language in which problems are presented have the most important impact in the number of correct responses as well as in the time participants normally take to solve them. Therefore, in the case for all the participants of the present study, for whom English was not the language in which arithmetic was first learned, it was expected that English would be the language that demanded more effort from them, incurring in longer response time scores and lower accuracy rates regardless of their English language experience.

The experiment contained two independent variables. The first was the presentation format of the items in the task (involving three conditions: digit, written in Portuguese, or written in English) and the related dependent variables were accuracy (expected target responses for the calculations) and response times (measured in milliseconds). With respect to the participants' language background experience, there were items in the questionnaire that assessed (a) age in which participants started to study English; (b) how long they have been speaking it; (c) contexts in which they use the language; (d) period of time they have been working as English teachers; (e) experience of living abroad; (f) and the language in which they practice reading and listening skills the most).

3.3. Participants

The sample was made out of 30 Brazilian proficient bilinguals who work as English teachers. Most participants were recruited in a private English language course located in Porto Alegre, whereas the rest of them were recruited at UFRGS. All the participants reported to either be currently working or have already worked in English schools and claimed to have a large experience with English teaching. The volunteer participants were recruited through verbal

invitation and were free to withdraw from the research at any time, if they decided to.

All of the participants reported to have Brazilian Portuguese as their mother tongue. They also informed to have first learned to read and write in Portuguese, and to have learned basic arithmetic concepts, such as addition and subtraction calculations, at a regular school in Brazil, therefore, in Portuguese. They all reported that they make use of their mother tongue in multiple contexts, such as in college, at work, for leisure, and at home.

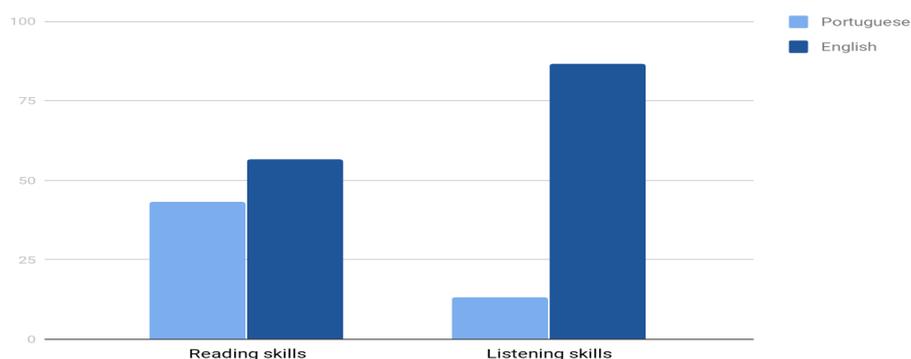
Initially, 31 individuals were recruited to participate in the research. One of them, however, got confused when solving problems and accidentally inverted the designated keys on the keyboard, providing the opposite result. Instead of clicking “L” for correct answers and “A” for incorrect ones, he did the other way around. Because of that, he had to be excluded from the analysis, leaving the final sample with 30 participants.

The group was made out of individuals with ages between 18 and 54 years old, with a mean age of 28.20 (SD: 9.70). A total of 17 reported themselves as female and 13 as male, resulting in 56.7% women and 43.3% men. Also, eight of them (26.7%) had already lived abroad, while 22 of them (73.3%) had not.

The participants reported to have started studying English between the ages of 6 and 32 years old, with a mean age of 11.20 (SD: 4.66). The minimum amount of time that the participants have spoken English is 5 years, and the maximum was 46 years, with a mean of 16.16 (SD: 9.56). In addition, the minimum amount of time that they reported to have worked as English teachers was 3 months and the maximum was 29 years, with a mean amount of 5.58 (SD: 6.17).

The participants also reported the language in which they read and practice listening skills the most: 13 of them (43.3%) indicated that Portuguese is the language in which they read more, and 17 of them (56.7%) said it was English. Only four of them (13.3%) indicated Portuguese as the language in which they practice listening skills the most, while 26 (86.7%) of them said it was English. Figure 1 below shows these data.

Figure 1 – Language in which participants practice reading and listening skills the most



Source: created by the authors

As all of the participants were English teachers and a great part of them were undergraduate and graduate Letras students, they were asked about the multiple contexts in which they use English in their daily lives. Only three participants reported that they use English for work purposes only. The remaining 27 participants said that they use English in many different contexts, such as in college, at work, for leisure, and at home.

3.4. Materials

The present study involved the use of two instruments that were applied to participants. First, they answered a Language History Questionnaire; after that, they answered the Number Task. Both are described below.

3.4.1. Language History Questionnaire

The Language History Questionnaire used in this study was based and adapted from the Language Background Questionnaire for Research with Bilinguals developed by Scholl & Finger (2013). The present questionnaire contained questions about the participants' usage of Portuguese and English and aimed to better understand the relationship between the languages one knows and one's daily life. In order to assess the participants' language background experience, questions such as the following were included in the questionnaire: In which language did you learn to read and write? In what language did you learn basic arithmetic (addition/subtraction calculations, etc.)? In addition to Portuguese and English, how many other languages do you speak? Have you ever taken a proficiency exam? In any of your daily contexts do you count and/or perform calculations in English?

3.4.2. Number task

The experimental task used in the present study was adapted from Frenck-Mestre and Vaid (1993). In the original task, calculations consisted of addition and multiplication problems and the nature of the responses could be either true, associatively related, or neutral. Also, a microcomputer was used to record participants' answers. In this study, calculations consisted exclusively of addition problems presented in the format of $a+b$ and followed by a response, c . Besides being presented in the digit format ($3 + 4 = 7$), calculations were also provided in written format. In our case, two different languages, English and Portuguese, were used (four + two = six; um + oito = nove).

The nature of responses for all three formats was either true or neutral; associatively related answers were not included since there were only addition problems. In true trials, the results of calculations were correct (e.g., in all three formats: $3 + 4 = 7$, four + two = six, and um + oito = nove). In neutral trials, the results were mathematically unrelated to the calculations (e.g., in all three formats: $3 + 9 = 18$, five + eight = twenty, and sete + nove = vinte e um). As in the original task, the mathematical problems were displayed in white against a dark background in lowercase arial characters. The operation was divided into three main blocks (digit, English, and Portuguese); the nature of a response (true or neutral) was randomized within language/format blocks.

The task contained a total of 27 trials, divided into three blocks, being 20 experimental trials and 7 control trials, in all three formats, whose responses were not included in the analysis. Both experimental and control trials were necessary so that a comparison between time of responses for wrong and right calculations could be done. In the task, participants were told that they would see two numbers separated by a plus sign (+), presented horizontally, and an answer for the calculation. Their job was to indicate, as quickly as possible, whether the response was correct or not, by using designated "yes" or "no" keys on the keyboard. Subjects were informed of the language/format of instruction before each block.

In the experimental trials, operands varied from 1 to 9. Calculations containing the same operands and zero as one of the operands were excluded from trials, since tie problems (e.g.: $3 +$

3) and zero problems (e.g.: $0 + D = D$) operate in a distinct way⁵. This decision was based on Frenck-Mestre and Vaid's (1993) claim that they might cause confusion and interference. A total of 20 problems were chosen from the original study and all of them were presented in all three formats (digit, English, and Portuguese) and related to a type of trial (true or neutral). For example, a candidate saw the numbers "7 + 5" followed by "12" (digit, true), "nine + two" followed by "eleven" (English, also true), and "dois + três" followed by "quatro" (Portuguese, neutral).

Within the 20 problems for the addition task, there were 9 true trials and 11 neutral trials (see Table 1). A problem was always presented three times, in three different blocks (digit, English, and Portuguese) randomly. The participants had to decide whether the answer being shown for the calculation was correct or not. It is also important to point out that, in the original research, number "six" was excluded from calculations because it is written the same way in both English and French. In the present study, there was no need for such an exception, since number "six" is written differently in English and Portuguese. Also, the following exception was proposed: there were less calculations to solve than in the original research since multiplication problems were not covered in trials.

Table 1 – Experimental trials in the Number Task

	DIGIT	ENGLISH	PORTUGUESE
TRUE	2+8=10	two+eight=ten	dois+oito=dez
	7+5=12	seven+five=twelve	sete+cinco=doze
	9+2=11	nine+two=eleven	nove+dois=onze
	4+2=6	four+two=six	quatro+dois=seis
	1+6=7	one+six=seven	um+seis=sete
	1+2=3	one+two=three	um+dois=três
	3+4=7	three+four=seven	três+quatro=sete
	6+7=13	six+seven=thirteen	seis+sete=treze
	1+8=9	one+eight=nine	um+oito=nove
NEUTRAL	3+1=5	three+one=five	três+um=cinco
	5+8=20	five+eight=twenty	cinco+oito=vinte
	2+3=4	two+three=four	dois+três=quatro
	9+5=12	nine+five=twelve	nove+cinco=doze
	5+3=9	five+three=nine	cinco+três=nove
	2+7=11	two+seven=eleven	dois+sete=onze
	3+9=17	three+nine=seventeen	três+nove=dezessete

⁵ Tie problems have been shown to behave differently from non-tie problems (Groen & Parkman, 1972). Zero problems have been shown to induce erratic performance (Sokol, McCloskey, Cohen, & Alirinos, 1991; Stazyk *et al.*, 1982).

7+9=21	seven+nine=twenty-one	sete+nove=vinte e um
8+6=13	eight+six=thirteen	oito+seis=treze
9+6=19	nine+six=nineteen	nove+seis=dezenove
9+8=22	nine+eight=twenty-two	nove+oito=vinte e dois

In order to provide evidence for further comparisons between right and wrong answers, the participants solved 7 additional true problems, which made up the control trials, presented in all 3 formats (digit, English, and Portuguese). Calculations in the set of control trials were once again divided into three blocks (digit, English and Portuguese), however this time operands were single digits from 0 to 9 (see Table 2).

Table 2 – Control trials in the Number Task

Table 2	DIGIT	ENGLISH	PORTUGUESE
TRUE	5+1=6	five+one=six	cinco+um=seis
	0+3=3	zero+three=three	zero+três=três
	1+4=5	one+four=five	um+quatro=cinco
	6+2=8	six+two=eight	seis+dois=oito
	9+4=13	nine+four=thirteen	nove+quatro=treze
	1+9=10	one+nine=ten	um+nove=dez
	8+7=15	eight+seven=fifteen	oito+sete=quinze

It is important to observe that no two problems shared the same sum in the Number Task. Consequently, true answers were never repeated. Table 3 below shows the structure of the task considering the experimental blocks, since the 27 different problems were divided into three blocks, 20 experimental and 7 control trials. Responses to control problems were also considered in the analyses.

Table 3 – Experimental blocks in the Number Task

Digit block	English block	Portuguese block
○ 9 true (experimental)	○ 9 true (experimental)	○ 9 true (experimental)
○ 11 neutral (experimental)	○ 11 neutral (experimental)	○ 11 neutral (experimental)
○ 7 true (control)	○ 7 true (control)	○ 7 true (control)

Finally, there was not a time limit set for each calculation in the Number Task. Therefore, participants could take their time to answer the problems. Even though they were asked to respond as fast as they could, they were the ones who established the time needed to answer

each calculation.

3.5. Procedures for data collection

The exhibition of stimuli and recording of responses were registered by *Psychopy* - an open source software, downloaded in a 14' Dell laptop. The participants answered the Language History Questionnaire first and then the Number Task, with the exception that one individual did the inverted order. The place where participants answered both tasks was either a quiet room at UFRGS or a classroom at the English language course where many of them were recruited. The participants normally took between 5 to 10 minutes to answer the task.

The first step when meeting a participant was always to explain the objective of having a Language History Questionnaire in the study since many of them had never answered one before. After they completed the questionnaire, they were told how the Number Task was going to work and their questions were addressed and clarified. Finally, after participants finished the Number Task, they were asked how they felt while answering it. All their reactions and opinions were registered and will be further explored in the qualitative analyses and final considerations sections.

4. Results

The first objective of this study was to verify if Portuguese-English bilinguals show any language preference when reading numbers while solving addition mathematical problems involving three conditions: in digit, written in Portuguese, or written in English. This preference was analyzed in terms of accuracy and response time. A Repeated Measures ANOVA conducted with the accuracy scores in the Number Task revealed a significant main effect of format blocks (digit, English, and Portuguese): $F(1.29)=31032.478, p=.000$.

Table 4 below shows the mean and standard deviation accuracy scores for all three format blocks. Within the three blocks, 27 problems each, the participants were more accurate in answering addition problems when the stimuli were presented in Portuguese. In second place came the digit block, followed by the English block.

Table 4 – Mean accuracy (and SD) by block in the Number Task (Total number of items: 27)

Table 4	Mean	Standard Deviation
Digit	26.30	1.02
English	25.83	1.20
Portuguese	26.46	.77

Further analysis of the data revealed a statistical difference between the digit and English conditions ($t(29)=115.07$, $p<0.001$), between the digit and Portuguese conditions ($t(29)=138.24$, $p<0.001$) and between the English and Portuguese conditions ($t(29)=183.26$, $p<0.001$).

Reaction time was a crucial aspect of the research as well. As predicted, the participants answered problems significantly faster when they were presented in digit format, followed by the Portuguese stimuli and then the English format. Table 5 below shows the mean, in milliseconds, and the standard deviation for all three format blocks. A Repeated Measures ANOVA conducted with the reaction time scores in the Number Task revealed a significant main effect of format blocks: $F(1.29)=269.111$, $p=.000$.

Table 5 – Mean Reaction Time (and SD) by block in the Number Task 9 (in milliseconds)

Table 5	Mean	Standard Deviation
Digit	2.3507	.8159
English	3.3986	1.2336
Portuguese	2.8942	.9437

Further analysis of the data revealed a statistical difference between digit and English trials ($t(29)=13.895$, $p<0.001$), between digit and Portuguese trials ($t(29)=12.424$, $p<0.001$) and between English and Portuguese stimuli ($t(29)=12.869$, $p<0.001$).

As predicted, the participants were faster in providing answers for those calculations that did not require any kind of translation, that is, the digit block. This prediction was based on Marsh & Maki's (1976:463) claim that numbers are processed faster when they appear the way they are expected to, "in the abstract without the aid of language." In the Portuguese block, calculations were presented in the language in which all participants learned arithmetic and it was not necessary for them to translate the stimuli into a different language, as it may have been the case in the English block. This block, in turn, was the one in which the participants took the longest.

One possible explanation could be that participants may have needed not only to translate the numbers into Portuguese but after that, to the abstract symbols as well. Another possible explanation could be the interference of cognitive control mechanisms, especially inhibitory control, in their performance in the task⁶. The cost of inhibiting the interference of Portuguese in responding to the calculations in English could also account for the longer time it took participants to accomplish the task in their L2.

The second objective of this study was to analyze whether the participants' language background experience affects their language preference for reading numbers when solving mathematical problems. This was analyzed by further investigating the correlation between accuracy/response time and some information gathered from the responses the participants gave in the Language History Questionnaire: (a) age in which participants started to study English; (b) how long they have been speaking it; (c) contexts in which they use the language; (d) the period of time they have been working as English teachers; (e) the experience of living abroad; (f) and the language in which they practice reading and listening skills the most.

Spearman correlation analyses did not reveal a statistical significance in any of the previously mentioned aspects considering both accuracy and response time. The participants' background was not a decisive point when dealing with addition calculations in digit format, English, and Portuguese, as expected. The most important issue regarding math problems was the way numbers were presented within the calculations in the Number Task. This was the main factor that led the participants to take either a shorter or longer time to answer the problems.

Similarly to what was found in previous investigations, the findings of the present study confirm that bilinguals perform arithmetic better in their preferred language, that is, in the language that they first learned arithmetic. Marsh & Maki (1976), and McClain & Shih Huang (1982) explored this point in their studies. When a comparison between different formats of presenting calculations is done, bilinguals are faster in solving those calculations that are presented in digit format. Frenck-Mestre & Vaid (1993) also proved this point in their research. Taking into consideration the results and conclusions reached in previous studies, what was found in this research is consistent with the previous literature, that is, accuracy and response time are directly related not only to the language of presentation, but also to the presentation format.

⁶ For the role of inhibitory control processes in bilingual language processing, see Bialystok (2008; 2017), Kroll & Bialystok (2013) and Valian (2014).

5. Final considerations

The goal of this study was to further explore the complexity existent in the relationship between bilingualism and numerical cognition. Previous studies have suggested that bilinguals prefer to deal with numerical aspects in the language they first learned arithmetic (Marsh & Maki (1976), Salillas & Wicha (2012), Van Rinsveld et al. (2015)). Within that context, the present research explored this relationship in terms of the way numbers are presented in addition calculations and in the relationship between language experience and numerical cognition. In order to do that, three different ways of presenting numbers within calculations were chosen; they appeared as digits, and written in the participants' both languages, English and Portuguese.

The participants' job was to decide whether the answers being shown for addition calculations were correct or incorrect. First, they saw problems presented in digit format, then in Portuguese, and finally in English. All problems were followed by a response and there was no time limit per calculation set. After the data analysis, it was concluded that participants were significantly faster in answering problems presented in digit format, in comparison to Portuguese and English formats. Also, they were more accurate in answering calculations presented in digits and Portuguese, in comparison to the ones presented in English.

The present research also took into consideration the participants' language background experience and analyzed its correlation with accuracy and response time. It is important to highlight the innovative aspect of such an analysis since none of the previously mentioned studies considered language background as a factor that might affect language and numerical cognition. The results show that an individual's language background experience did not have any effect on the participants' response when they performed simple addition calculations.

The main generalization that can be drawn from these results is the role of the language in which individuals learn basic math concepts when considering the retrieval of such information much later on in their lives. In other words, our findings emphasize the effects of the language of training in the efficacy of the processing of numerical information in bilinguals, a finding that carries out significant implications for contexts of bilingual education.

Finally, the evidence presented here suggests that further research on how the bilingual brain deals with numerical cognition can further enlighten our comprehension of the relationship between bilingualism and mathematical literacy. Such findings may bring important evidence regarding the role of the language of instruction in the acquisition and consolidation of basic

mathematical knowledge by children.

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