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“Forty-one plus twenty-four is…”: investigating on arithmetic processing in late bilinguals at low and high proficiency

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ABSTRACT

The field of numerical cognition has tried to understand the underlying mechanisms of how humans understand and process numerical information. Numerical information varies from seemingly simple actions such as choosing the cookie with the most chocolate chips, in which we try to recognize numerosity, to more complex actions such as multiplying or dividing, in which we need to manipulate precise numbers. Having in mind that most people need to deal with numerical information on a daily basis and that this mathematical processing is closely linked to the language that it has been taught, the current study tries to better understand how bilingual people deal with manipulating precise numerical information. The aim of this study, more specifically, is to investigate if more proficient speakers of an L2 are better at dealing with precise numerical information in their L2 and/or their L1 than less proficient speakers. In order to explore that, an online experiment was run with 36 Brazilian Portuguese-English (BP-EN) late bilingual participants of different proficiency levels in which they solved arithmetic problems of different complexities (one or two-digit problems), types (addition, subtraction, multiplication, or division), and language (English or Portuguese). Results show that proficiency plays a small role in arithmetic processing in the L2. In too-simple problems, proficiency did not yield a strong interaction with reaction times, whereas, in too-complex problems, a language overload surpassed L2 proficiency as an aid to solving the arithmetic operation. Hence, results demonstrate that proficiency has an effect on arithmetic processing and that this effect interacts with the complexity of the problems presented.

Keywords: numerical cognition; bilingualism; late bilinguals; L2 proficiency; psycholinguistics.

RESUMO

A área da cognição numérica tem tentado entender os mecanismos subjacentes de como os seres humanos entendem e processam informações numéricas. Informações numéricas variam entre ações aparentemente simples como escolher o biscoito com mais gotas de chocolate, em que tentamos reconhecer numerosidade, ou ações mais complexas como multiplicar ou dividir, em que precisamos manipular números exatos. Tendo em mente que a maior parte das pessoas precisam lidar com informações numéricas diariamente, e que esse processamento matemático possui estreita ligação com a linguagem em que foi ensinado, o presente estudo tenta entender melhor como indivíduos bilíngues lidam com a manipulação de informações numéricas precisas. O propósito deste estudo, mais especificamente, é investigar se falantes de L2 mais proficientes lidam melhor com informações numéricas precisas em sua L2 e/ou sua L1, quando comparados à falantes menos proficientes de L2. A fim de explorar esta hipótese, foi realizado um experimento *online* com 36 falantes bilíngues tardios de Português Brasileiro-Inglês (PB-IN) com diferentes níveis de proficiência em que eles resolveram problemas aritméticos de diferentes complexidade (problemas de um ou dois dígitos), tipos (adição, subtração, multiplicação ou divisão) e língua (Português ou Inglês). Os resultados demonstram que a proficiência desempenha um papel limitado no processamento aritmético na L2. Em problemas demasiadamente simples, a proficiência não gerou uma interação significativa com os tempos de reação, ao mesmo tempo que em problemas demasiadamente complexos, uma sobrecarga linguística excedeu a proficiência na L2 em auxiliar a resolver o problema aritmético. Portanto, os resultados demonstram que a proficiência possui um efeito no processamento aritmético, e que esse efeito interage com a complexidade dos problemas apresentados.

Palavras-chave: cognição numérica; bilinguismo; bilinguismo tardio; proficiência na L2; psicolinguística.

SUMÁRIO

1 INTRODUCTION

Solving arithmetic problems is a task that people perform every day. These tasks can be as trivial as counting the hours for an event, or complex as solving integrals in calculus and organizing finances for a company. Understanding the underlying mechanisms needed to process arithmetic is important to advance educational approaches for the development of numerical cognition. Some examples of different arithmetic problems are known to influence its processing: exact (sums, subtractions, and multiplication) vs. approximate (such as distinguishing which two groups of objects are larger in number); simple (1+2) vs. complex (41+24) problems; and sum and subtraction vs. multiplication and division (DEHAENE, 1999; LEE, 2000). The ability to solve arithmetic problems, however, is known to interact heavily with language processing (DEHAENE, 1995; DEHAENE et al., 2004; SAALBACH et al., 2013; HAGOORT, 2019). Dehaene et al. (1999) found that exact arithmetic processes are highly dependent on language processing while approximate arithmetic processing relies on visuospatial processing. Additionally, because language is processed by a complex and comprehensive cognitive system, one that allows for multiple languages to be understood and produced, bilingualism might also have an effect on how arithmetic is processed.

An example of the interface between bilingualism and arithmetic processing is when speakers are traveling or living in an L2 environment and have to deal with more than just conveying meanings in their second language. For instance, they also have to account for other tasks, such as calculating the tip amount after eating in a restaurant. But how do L2 speakers deal with these arithmetic problems? Do they rely on their L1 or L2 for such mathematical computations? Probably, as Grosjean (2010) states, most people that come across situations in which they have to perform simple mathematical problems while in an L2 environment would prefer to switch to their L1 to do so.

Bilinguals have a strong preference for one specific language when they have to solve arithmetic problems. Spelke and Tsivkin (2001) demonstrated that when participants need to solve an arithmetic problem in a language other than the one in which they were taught mathematics, performance is worse for exact than for approximate problems. That is, for the problems that require language processing, as demonstrated by Dehaene et al. (1999), solving problems is more efficient in the language in which arithmetic was trained.

Understanding that different languages have different effects on arithmetic processing, factors that influence these languages might have a role as well, such as L2 proficiency. In a study with children in a bilingual setting, Rinsveld et al. (2015) showed that proficiency in the

L2 was demonstrated to be related to children's ability to solve arithmetic problems in the L2. The transversal developmental study was employed with children and young adults in a bilingual context where they were learning German and French simultaneously and were used to solving arithmetic problems in both languages. Subjects had to answer simple and complex arithmetic problems in German and French in two different modalities: written and spoken addition problems. For all of them, participants had to answer in the same language that the problem was presented. The results suggest that L2 proficiency significantly impacts arithmetic processing, especially for exact problems. Having in mind that we rely on language to process arithmetic problems, that speed and accuracy for these processes are affected by additional languages, and that proficiency has a role in how well bilinguals deal with arithmetic problems, the current study tries to better understand how bilingual people deal with manipulating precise numerical information. The aim of this study, more specifically, is to investigate if more proficient speakers of an L2 are better at dealing with precise numerical information in their L2 and/or their L1 than less proficient speakers.

1.1 ORGANIZATION OF THE THESIS

The present thesis is organized to guide the reader in the topics, concepts, and discussions. In order to do that, Chapter 1 introduces the topic of bilingualism and arithmetic processing, addressing how these two processes might interact on the day to day life.

The second chapter, Review of Literature, presents the theoretical background of the study. In section 2.1, the association between language and numerical cognition is discussed. In subsection 2.1.1, the debate that considers either an association or a dissociation between these two concepts is presented. The second subsection, 2.1.2, analyzes some models of numerical processing but focuses on Dehaene's Triple Code Model. In section 2.2, the definition and main concepts surrounding bilingualism are discussed. In section 2.3, the discussion is narrowed down to numerical cognition and its relation to bilingualism.

The third chapter, Method, describes the techniques and procedures used to conduct the study. Section 3.1 addresses the objectives of the study and presents the research questions and hypotheses. Section 3.2 covers the profile of participants chosen to take place in the study and their main characteristics from the data collected. Section 3.3 introduces the instruments used for the data collection, such as the learning background questionnaire, the L2 proficiency test, and the bilingual arithmetic task. Section 3.4 describes in detail the procedures employed in the data collection, and section 3.5 presents some considerations on open science and open data, in order to discuss data management in online studies.

Chapter four, Results and Discussion, reports on the data collected for this study. Section 4.1 presents a descriptive analysis, mainly on accuracy and RT means, for each of the arithmetic problems used in the experiment (Simple sum in section 4.1.1, Simple Subtraction in section 4.1.2, Simple multiplication in section 4.1.3, Simple division in section 4.1.4, Complex sum on section 4.1.5, Complex subtraction on section 4.1.6, Complex multiplication on section 4.1.7, and Complex division on section 4.1.8). Section 4.2, on the other hand, presents an inferential analysis, in which the statistical models applied to interpret the data are explained, and what strategy was used to encompass the number of variables being analyzed, which was to separate the data into four different groups and analyze them separately. Section 4.3 reflects on the data that was reported and analyzed in order to associate the findings with the review of the literature

Chapter 5, Conclusion and Final Remarks, reiterates the main findings of the study by presenting insights on numerical cognition through the bilingual lens (Section 5.1), the limitations of the study, and suggestions for future research (Section 5.2).

2 REVIEW OF LITERATURE

The review of literature will first discuss the relationship between language and numerical cognition, with a subsection regarding the association vs. dissociation debate between language and numerical processing and another subsection concerning models of numerical processing, with a focus on Dehaene's Triple Code Model and the rationale as to why take this model into consideration when conducting this study. The section is followed by a discussion on bilingualism to then discuss the interface existing on bilingualism and numerical cognition.

2.1 LANGUAGE AND NUMERICAL COGNITION

Humans and non-human animals share the ability to perceive quantities. You can think of a chimpanzee discerning which tree branch has more fruit, so less physical effort is required to fulfill nutritional needs, or of a human choosing the cookie with more chocolate chips. According to Beran and Parrish (2016), researchers have focused on how we perceive and manipulate quantities and/or numbers for more than 100 years and there is a consensus in the area that the capacity of discerning quantities and choosing between small and large quantities are "likely as evolutionarily old and phylogenetically broad as almost any other perceptual or cognitive capacities" (BERAN; PARRISH, 2016, p. 176). This area of research is known as Numerical Cognition, which studies the underlying mechanisms that allow humans to perceive, process, and memorize numerical information (KNOPS, 2020). For humans, evolution helped create a more complex system to communicate these quantities and manipulate them in abstract forms, not necessarily relating to real things. Humans have created a complex system of symbols and meanings that can represent quantities, so they are able to share information between them.

A useful ability that this complex system allows is to manipulate quantities, such as adding, subtracting, multiplying, or dividing two numbers. To put it simply, this manipulation can be done in two ways (MACLELLAN, 2001). First, with the aid of external devices, such as pen and paper, in which algorithms that were formally learned at school are applied. For example, writing down the problem in its Arabic number form such as 29 + 32, putting one on top of the other, starting with the units 9 + 2 = 11, and carrying over the 1 to the decimals sum, which is 2 + 3 + 1 = 6, so the answer is 61. According to Plunkett (1979), arithmetic is taught using standardized algorithms for ten different reasons. The two most important are that standardized algorithms are written (and therefore, correctible) and that these algorithms work for any set of numbers. However, there is another form in which these calculations can occur: mental calculation. Mental calculation can be defined as the conscious computation of a numerical result without the use of any external devices such as pen and paper, or even a calculator (REYS, 1984; MACLELLAN, 2001). Many strategies can be used to get to a result through mental calculations, such as direct recall (e.g. remembering the result of 2 + 2), the separation of tens and ones (e.g. 41 + 26 is first seen as 40 + 20 = 60, and then 1 + 6 = 7, so the result is 67), and many others (CHESNEY et al., 2014).

Having that in mind, it seems intuitive to think that language and mental calculations somehow share some thought mechanisms. For example, storing partial results of a sum must be stored in working memory until the end result is reached. Would this be stored in the Arabic form (40 + 20 = 60) or verbal form (forty plus twenty equals sixty)? There is not yet a consensus in neuropsychological and neuroimaging studies about whether these two systems concurrently activate specific brain areas (BRYSBAERT, 2018; LIN, IMADA, KUHL, 2019). Both research areas contain studies that point to an association or a dissociation between language and arithmetic (or non-linguistic) processing. Association and dissociation studies in these two areas will be explored in the next subsection.

2.1.1 The association vs. dissociation debate

Neuropsychological studies aim to understand the workings of the mind through behavioral observation (such as reaction times and accuracy) and through clinical observations of brain damage in specific areas that lead to a change in behavior. Varley et al. (2005) investigated aphasic patients that presented severe grammatical impairments and difficulties in processing phonological and orthographic number words but were able to use syntactic principles in addition and subtraction problems. These neuropsychological results point to independence between mathematical and language processing. On the other hand, other neuropsychological studies point to an association (DEHAENE; COHEN, 1995; DEHAENE et al., 1999). Dehaene and Cohen (1995) found that bilinguals present an acute difference while processing exact and approximate arithmetic problems when solving them in their L2. This could point to a linguistic dependence on exact arithmetic specifically.

Neuroimaging studies aim to observe which areas of the brain are recruited (or activated) while participants are engaged in a task. Morita, Asada, and Naito (2016) state that neuroimaging techniques can be classified into two different categories: the first category of techniques allow us to make observations on electrical activity in a group of cells in the brain (such as electroencephalography (EEG) and magnetoencephalography (MEG). The second category allows measuring the change in blood flow in the brain (such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET), which, in turn, allows for a higher spatial resolution than the first category.

Some studies in the neuroimaging area point out that there is an overlap in activation in areas that support both linguistic and non-linguistic functions (DEHAENE et al., 1999; SIMON et al., 2002; LIN; IMADA; KUHL, 2019). Dehaene, Molko, Cohen, and Wilson (2004) state that addition and subtraction problems show increased angular gyrus activation, and so do naming and phoneme detection tasks. Similarly, Simon, Mangin, Cohen, Bihan, and Dehaene (2002) conducted an experiment in which participants had to perform six different tasks: grasping, pointing, saccades, attention, calculation, and phoneme detection. They found two neighboring regions within the intraparietal sulcus (IPS) that were jointly activated by the subtraction task. One was activated only for the calculation, and another was activated both for the subtraction and the phoneme detection task. Hence, the authors argue that their results indicate an association between language and arithmetic processing.

Fedorenko, Behr, and Kanwisher (2011) state that the neuroimaging studies that found an association between these two cognitions may be mistaken by a methodological flaw. The authors say that some mathematical and linguistic brain areas are neighboring regions, and since the location of these regions varies slightly between subjects' brains, a group analysis would erroneously indicate an overlap. Hence, the researchers conducted a study in which participants performed language, arithmetic, working memory, cognitive control, and music tasks. They used fMRI to individually analyze the participants' brain activation for each task and found a clear distinction between language, arithmetic, cognitive control, and music tasks. The only exception was between language and working memory, which was demonstrated to activate a brain region located in the left middle frontal gyrus. The study concluded that there is a dissociation between linguistic and non-linguistic processing (FEDORENKO; BEHR; KANWISHER, 2011). However, studies that point to an association between language and arithmetic are not only neuroimaging ones but also behavioral ones, which are cited and explained above. So, while there may not be an overlap in neuroimaging, there can still be an association present.

Several other studies defend the existence of interactions between the two cognitions. Hagoort (2019) proposes a multiple-network view for the neurobiological basis of language based on Elementary Linguistic Units (ELUs) and Elementary Linguistic Operations (ELOs).

The author makes an analogy to explain such concepts: ELUs are like the building blocks of language (the sound patterns, lexical items, syntactic features) while ELOs are the basic operations that we do with these building blocks in order to form complex meanings. From his research what is most important for the present research proposal is that while ELUs are domain-specific in the brain, ELOs probably have shared domains with music and arithmetics. That is, even though they are seen as different cognitions, some interactions may likely occur (HAGOORT, 2019, p. 3).

On that note, Dehaene et al. (1999) demonstrated through behavioral and neuroimaging experiments that language plays an important role in exact arithmetic knowledge. Moreover, such knowledge contrasts with approximate arithmetic. While exact arithmetic is used for precise information and calculations, such as 2x4=8 and the whole multiplication table, approximate arithmetic is used to perceive and express quantities and approximate results, such as the number which is exactly in the middle (midsection) of 2 and 6, which is 4. Dehaene and colleagues tried to understand the relationship between arithmetic, language, and visuospatial processing. In a series of behavioral and neuroimaging experiments, bilingual participants had to train simple and complex addition problems (e.g. 24 + 41), approximation problems (e.g. estimating the result of a problem), and more complex operations (e.g. base 6 and 8 addition) in their L1 and L2. There was a phase of pre-testing (before training) and post-testing (after the training of the problems). They interpreted their results as an indication that approximate arithmetic relies on visuospatial networks on the left and right parietal lobes, while exact arithmetic strongly relies on language-specific representations (such as using rote memory to store the multiplication table) on the left inferior frontal circuit, which, according to the authors, is also responsible for generating associations between words. They concluded that exact arithmetic relies more on language-dependent representations and that solving approximate arithmetic problems is processed by a quantity representation implemented in visuospatial networks.

Simon et al. (2002) corroborated Dehaene and colleagues' results by conducting an experiment to identify areas in the parietal cortex related to grasping, pointing, saccades, attention, calculation, and phoneme detection since all of these tasks are known to activate the human parietal cortex. Their main goal was to identify which areas of the cortex are activated while participants calculated mathematical problems, detected phonemes, and performed other tasks known to also activate the parietal cortex. Their results indicate that two neighboring regions in the left intraparietal sulcus are activated during mental calculation, but only one is shared with phonological processing. According to the authors, their results are in line with

Dehaene and colleagues' hypothesis that there is a nonverbal processing to compute approximate arithmetic and another verbal processing to compute exact arithmetic.

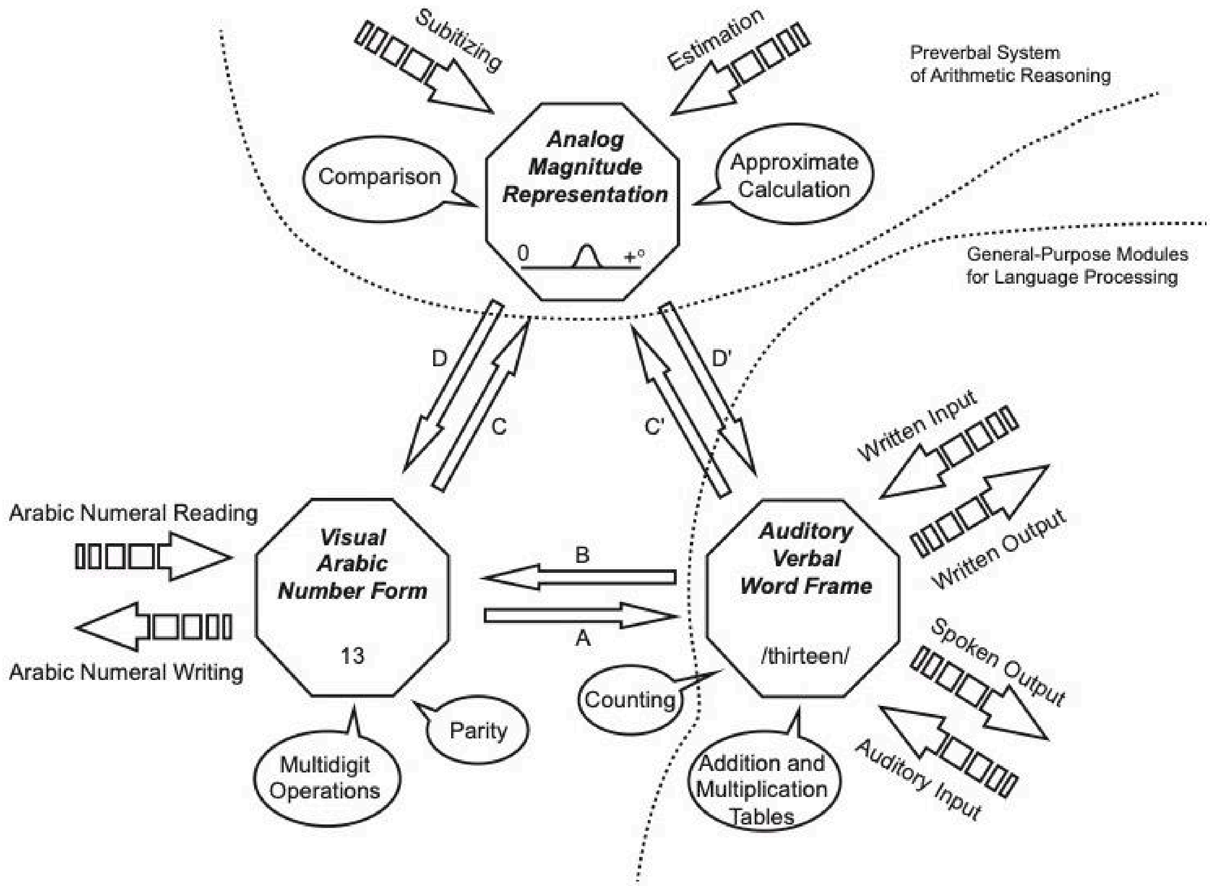
More recent studies, reported below, also investigated the relationship between language and mental arithmetic, but they went even further: Dehaene et al. (2004) tried to understand the difference between macaques and homo sapiens since both can process quantity but only humans can process language. Their neuroimaging study was able to identify areas in the monkey brain that are analog to the number processing areas in the human brain. Grabner et al. (2007) proposed that individuals with higher mathematical competence depend more on language-mediated processes to compute arithmetic problems when compared with people who performed relatively lower on standardized tests of intelligence.

2.1.2 Models of numerical processing

Research in the area of Numerical Cognition gained traction from the late 1980s to the early 1990s. One body of work that should be highlighted for its influence on the field is volume 44 of the journal Cognition, in which Dehaene (1992) proposes the Triple Code Model (TCM). This number processing model disputed a previous prominent model (while borrowing many concepts) which hypothesized that all numerical stimulus (e.g. the number word “eight”) was first converted by a central system that associated any numerical input to an amodal abstract representation (MCCLOSKEY et al., 1986). For example, when seeing or hearing the number eight in its number word (eight), spoken form (/eight/), or Arabic number form (8), a person would need to invariably and automatically translate it to an amodal abstract representation before being able to perform an arithmetic calculation or even accessing the spoken form through the number word (reading “8” as /eight/).

However, the Triple Code Model (TCM) proposed by Dehaene (1992), as the name suggests, does not include a central singular system of representation. Instead, Dehaene (1992) hypothesizes that humans process numerical information through three main codes: An auditory-verbal code, a visual-Arabic code, and an analog-magnitude code (shown in Fig. 1). These three systems will be explained below.

Figure 1 – Dehaene’s triple-code model of number processing



Source: Brysbaert (2018) exact copy vectorization of the original in Dehaene (1992) for better visualization

The three codes proposed for number processing are independent but interact with each other, as illustrated in the image above. The verbal number code, or auditory verbal word frame, allows the recognition and production of linguistically related number forms, such as the written number form “eight”, the spoken number form /eight/, counting, and retrieving arithmetic facts (addition and multiplication tables) from long-term memory. This code is “created and manipulated using general-purpose modules for language processing” (DEHAENE, 1992, p. 30), which is associated with the left perisylvian language areas and the left angular gyrus (KNOPS, 2020, p. 14). The visual-Arabic code, or visual Arabic number form, is able to recognize numerals in the Arabic form, allowing for reading and writing of the number “8”, for example. Finally, in the analog magnitude code, or analog magnitude representation, numerical information is represented in a pre-linguistic and abstract form, distributed over an analogical number line. This code allows for approximate recognition of numerosity, such as quickly deciding which line on a market has fewer people – it is not needed to count how many people are in each line, as that would take too long. We rely on the analog magnitude code to quickly and approximately decide which line has fewer people and is, hence, faster. According to Dehaene (1992), this code interprets numerosity according to a mental number line. Just like we read and write from left to right, an approximate representation of the numbers one to ten would be organized in the same manner in this analog code. This, however, is dependent on the language of instruction, as the authors found evidence that people whose languages are written from right to left organize the mental line in the same direction as they read (for a study on the mental number line with Iranians, see Experiment 7 on Dehaene, Bossini, and Giraux (1993)).

Another important characteristic of the triple-code model is that all three codes are independent but there are translation routes that allow information to be exchanged between them, represented by the arrows A, B, C, D, C', and D'. Routes A and B translate numbers from Arabic to verbal or verbal to Arabic forms and these processes probably involve syntactic composition and lexical retrieval (DEHAENE, 1992, p. 31). The other translation pathways - C for Arabic to quantity, D for quantity to Arabic, C' for verbal to quantity, and D' for quantity to verbal – can be more complex because they translate exact quantity to approximate. Dehaene explains that for pathways C and C', the number is translated into an approximate by its highest power of ten (e.g. 23 would be approximated to 20). On the other hand, paths D and D' retrieve approximate quantity information from the analog code and translates it to a round exact number (e.g. 200).

According to Brysbaert (2020), the triple-code model is still the most accepted model of number processing by researchers in the area. This is due to all the thorough work in neuropsychology (MCCLOSKEY; SOKOL; GOODMAN, 1986; DEHAENE, 1992) and subsequent neuroimaging studies that demonstrate results in line with the TCM (DEHAENE; MOLKO; COHEN; WILSON, 2004; see Moeller, Willmes, and Klein (2015), for a review). However, other studies dispute the TCM. They will be discussed below.

Fayol and Thevenot (2012) argue that finding the results of simple arithmetic problems is not necessarily related to fact retrieval, as the TCM proposes. They conducted a priming arithmetic experiment with adult participants (from ages 20 to 40) in which they had to solve arithmetic problems on a screen. Two sets of stimuli (two different conditions) were presented. The first condition, with a negative stimulus onset asynchrony (SOA), consisted of problems in which the operation symbol (+, -, or ×) appeared 150ms before the operands (e.g. + appearing before 2+2). In the second condition, with null SOA, the whole problem appeared on the screen. Results pointed to faster problem-solving in the negative SOA condition, but only for addition and subtraction, not for multiplication. That is, participants were faster to provide a result when shown the operation symbol beforehand. The authors interpret that the operation symbol would pre-activate something to solve the problems quicker. According to the TCM, this something would be the pre-activation of an arithmetic facts network to retrieve these facts quicker. However, since this effect was not seen with multiplication problems, this hypothesis cannot be held. Fayol and Thevenot (2012) argue that simple arithmetic problems are solved by fast and efficient procedures. So fast that participants might interpret it as memory retrieval, even though it might not be. The authors propose that simple arithmetic problems are processed through procedural memory, and that is why it is so fast.

Similarly, Prado, Mutreja, and Booth (2014) conducted a cross-sectional fMRI study with native English-speaking children from the 2nd to the 7th grade, in which they had to solve a set of arithmetic problems, a set of language trials (decide if words rhyme or not), and a set of localizer trials (decide which group of dots is larger). The two latter trials were there for better control of children's abilities and to test their neural activation areas for processing language and numerical related tasks. Their results point to a developmental change in the way children process and solve arithmetic problems. Two main results were found: (a) over time, there was more activation in a language-related region of the left temporal cortex for multiplication problems; and (b) over time, there was more activation in a numerical quantity processing region of the parietal cortex for subtraction problems. The authors interpret this as corroboration of Fayol and Thevenot (2012), proposing that the development of subtraction and addition problems are more dependent on procedures instead of fact retrieval over time, which is the opposite of what the TCM presents. However, fact retrieval still seems to be the strategy used for multiplication problems, which is in line with the TCM.

These two studies shed new light on a section of the Triple-Code Model that theorizes on simple arithmetic problems, which needs revision. Yet, the TCM is the most accepted model overall for encompassing the differences between analog magnitude code for approximate numerical processing and the verbal and Arabic code for exact numerical processing (BRYSBAERT, 2018). Hence, this study will consider the TCM when talking about number processing, while still having in mind its limitations.

Literature on numerical cognition per se is not abundant and there is even less research that aims at understanding the interface between numerical cognition and bilingualism, which is the aim of this study. To better understand this relationship, it is important to understand each construct separately. Therefore, bilingualism will be further discussed in the next section.

2.2 BILINGUALISM

Speaking more than one language is something more natural and common than it may seem. Even though there is no data available to analyze the proportion of bilinguals compared to the world's population, Grosjean (2013, p. 6) gathered some data to provide a better notion of the extent of bilingualism: i) more than half of Europe's population is at least bilingual; ii) in North America, 35% of Canadians and 18-20% of US Americans are bilingual; iii) in Africa and Asia, the proportion of bilinguals is much higher; iv) there are more than 7000 languages spread in only 193 countries. Wei (2000) states that societies that are monolingual and monocultural are the exception, not the norm, and estimates that one in every three people in the world is bilingual, a number that would be even higher if we count learners of foreign languages as bilinguals. These demographics serve as evidence for a significant proportion of bilinguals across the globe. However, one may notice that the way these estimations are postulated hints at how broad the concept of bilingualism can be. For example, should learners of English as a Foreign Language (EFL) be considered bilinguals? Should only early bilinguals (i.e. people who grew up speaking two languages) be considered bilinguals, which would consequently exclude late learners who are highly proficient? Questions like these can lead to endless (and important) discussions on the characteristics of a bilingual person.

Grosjean (2013) defines bilingualism as follows: "bilingualism is the use of two or more languages (or dialects) in everyday life" (GROSJEAN, 2013, p. 7). The author was meticulous in his choice of defining bilinguals according to language use instead of language proficiency. According to Grosjean (2013), it was common for studies on bilingualism to define bilinguals as people with high proficiency in two or more languages. However, the author states that including proficiency in the definition of bilingualism raises a methodological problem: how proficient one must be in their additional language(s) to be considered bilingual? One solution to this problem is to focus on language use, which is what will be considered in this study when defining a bilingual. Hence, for this study, the term bilingualism will be in line with Grosjean's definition.

Another key concept in Grosjean's view of bilingualism is the Complementarity Principle (GROSJEAN, 2008, p. 22). This means that each bilingual individual uses each language that they know for a specific purpose, and this will influence fluency in the language for each domain. For example, think of a native Brazilian Portuguese speaker living in an English-speaking country and using English for work and Portuguese to talk to family and friends. When talking about work, this individual will likely prefer to talk about it in English, as it is the language that s/he is used to. However, when talking about family and the country where s/he came from, the preferred language will likely be Portuguese. Fluency in each language will be affected due to the different uses that each language serves for every individual.

Grosjean states that the Complementarity Principle has at least three major consequences. First, there will be a variation in fluency that is domain-specific, according to the needs that every individual has for each language. This is also applied to all the four language skills, such as reading, writing, listening, and speaking. If the individual in the example above uses English to write for work every day, and that is not true for Portuguese, then their writing performance will probably be better in English than in Portuguese. Second, regular bilinguals are often not very good translators or interpreters, since these tasks are usually domain-general, and that requires specific training. And third, changes in needs for each language might restructure the linguistic configuration. That is, if one language is not needed and not used anymore, it can retract while the other expands. If we think of the example above, if that person stops using Portuguese over the course of many years, this might lead to English being the most dominant language and having more influence on Portuguese than before. S/he might have more difficulties in expressing themselves in Portuguese over time.

Having chosen a definition for bilingualism, we now have a clear picture of who bilinguals are. However, the age at which these people learned each language is important. According to Li (2013), studies that tried to identify the relationship between age and L2 acquisition gained traction after the popularization of the critical period hypothesis. This hypothesis suggests that there is a period from birth to puberty in which the human brain is apt to automatically learn languages by exposure (LENNEBERG, 1967). After puberty, learning would take more time and lead to less successful outcomes. However, Li (2013) explains that this hypothesis is too simplistic and that it is unrealistic to expect a clear and universal age cutoff in which languages for every human being will be learned with more difficulty.

Li (2013) states that more recent research has been using the term Age of Acquisition (AoA) to account for the differences observed in language learning regarding the age at which learning or acquisition started. As an example, two important studies in the area found a negative correlation between age of learning and L2 attainment both for people who started learning an L2 before and after the critical period (see Johnson and Newport (1989) for a study with Korean and Chinese people learning English, and Birdsong and Molis (2001) for a replication study with Spanish speakers learning English). Since then, it is common to find researchers separating bilinguals as early and late learners, as the former population has a higher chance of attaining high proficiency levels in the L2 and the latter has a lower chance.

Accordingly, since performance in the L2 varies so much, it has been made necessary in the research context to distinguish this variation. According to Souza (2019), the identification of a participant's ability in the use of their L2 (being it a direct measurement or not) is a common methodological approach for research. The author adds that proficiency is a variable that is frequently used by researchers in the area of second language acquisition and language processing to control the participants' knowledge of the language.

In his discussion on proficiency in the L2 as a methodological object in psycholinguistics, Souza (2019) defines proficiency in the L2 as follows:

> A global factor derivative of significant correlations obtained in factorial analysis of a set of measurable components. These components include abilities that reflect access in real-time to mental representations associated with formal, discursive, and pragmatic aspects related to the L2. (SOUZA, 2019, p. 201)[1].

In addition, he states that proficiency can be seen as a cognitive dimension that can shape i) language processing architecture in bilinguals; ii) working memory capacity; iii) language acquisition aptitude; iv) maturational factors in the central nervous system. Assessing variation in proficiency is then a good and reliable approach to better understand bilingualism itself when using adequate methodology.

This section discussed the extent of bilingualism in the world, the definition of bilingualism based on language use, the importance of age of acquisition, and how proficiency measuring can be a reliable variable for psycholinguistic studies. These aspects are important for this study, as the objective is to analyze if proficiency is related to arithmetic processing in bilinguals. Having discussed language and numerical cognition, and bilingualism, the next section is dedicated to intersecting all of these different areas to narrow down this study's focus.

[1] Translation by the author. Original: "[...] trata-se de um fator geral derivável de correlações significativas obtidas em análises fatoriais de um conjunto de componentes mensuráveis, componentes estes que incluem habilidades que refletem o acesso em tempo real a representações mentais associadas a aspectos formais, discursivos e pragmáticos da segunda língua."

2.3 BILINGUALISM AND NUMERICAL COGNITION

In his book about bilingualism, Grosjean (2010) states that proficiency is not universal to all domains of a language. That is, a person may be able to communicate very well in his/her L2 on a daily basis, such as going to the supermarket and talking with friends. However, s/he might find it difficult to go to a mechanic for a car repair since there is a whole new vocabulary in use that s/he is unaware of simply because it was only previously learned in the L1 or neither language. Grosjean defines this as the Complementarity Principle, as already seen above, and his perspective on this matter is that our behavior influences the areas that are more trained, and for some of these behaviors one language completely dominates the other. For the author, mathematical computations fit into this perspective as one behavior to be trained in one language.

Interested in investigating the role of language in arithmetic learning, Spelke and Tsivkin (2001) conducted three experiments with Russian-English bilinguals. The participants were bilingual college students who had learned mathematics in Russian and were late learners of English. In Experiment 1, participants had to learn facts in Russian and English about exact (oversimplified example being $2 \times 2 = 4$) and approximate operations and equations (oversimplified example being $5 \div 4 \approx 1$) facts. Half of the facts were presented in only one language, and the other half was presented in both Russian and English. The participants trained these sets of facts for two days. After that, their speed and accuracy were tested for facts that were trained and untrained facts, in the two languages. Results demonstrated that participants had a similar performance for answering approximate operations in both languages, but strong dependency in the language of training for exact operations. Experiment 2 was a continuation of Experiment 1, with a greater focus on exact operations, and the results were similar.

Motivation for Experiment 3 was found in the first author's personal experience: she could readily provide French addresses in her L2 but not phone numbers. Hence, this experiment tested geographical and historical facts containing numbers (e.g. "On the stone, Mary discovered fifty-seven lines of Peaken text."). Participants had to learn a fictitious history lesson in one language and a fictitious geography lesson in another language. After the training sessions, they were tested if they remembered the numerical and non-numerical information. Languages were balanced between trials to check whether these pieces of information are language-dependent or not. The results of this experiment demonstrated that retrieval from memory of recently trained numerical facts was faster when they were presented and asked in the same language. When a numerical fact was presented in one language but asked in another, reaction times were significantly slower. Contrastingly, non-numerical facts were similarly remembered regardless of the language of presentation and testing. The main findings of the study as a whole are i) exact operations on numbers seem to be highly dependent on language, especially the language in which arithmetic was trained; ii) approximate operations on numbers don't present high dependency on language. Other experiments that tested language and arithmetic thinking also found similar results (MARIAN, FAUSEY, 2006; VENKATRAMAN et al., 2006; SAALBACH et al., 2013).

Also investigating bilingualism and mental mathematics, Lin, Imada, and Kuhl (2019) conducted an MEG brain imaging experiment in which participants had to answer mathematical problems either in their L1 or L2. The stimuli consisted of simple and complex addition and subtraction problems. They were presented auditorily so participants were forced to decode the information in the desired testing language. The participants had to answer arithmetic problems in a simple, one-digit sum (2+7= ?) or complex, two-digit form (22+9= ?). Two possible answers were presented to participants and the correct one should be selected on a keyboard. Their results indicated brain activation differences between languages before mathematical computation takes place, which could affect arithmetic processing. However, some of their participants reported that as soon as they heard the stimuli in their L2, they translated it to their L1 to calculate it. The authors argued that the lack of control over participants' translation of the stimuli could have affected the results.

Marian and Fausey (2006) conducted an experiment to understand the relationship between language and memory with similar findings to Spelke and Tsivkin (2001). However, an unexpected finding in this study is that balanced bilinguals showed more consistent language and memory dependency than unbalanced bilinguals (with lower proficiency in their L2). The authors suggest further studies to investigate the relationship between proficiency, language, and memory. That being said, the way we learn things is deeply embedded in the language in which we are taught and, likely, mathematics is not different.

Understanding that the language of arithmetic instruction plays an important role, Rinsveld, Brunner, Landerl, Schiltz, and Ugen (2015) conducted an experiment with subjects that were learning mathematics in a bilingual context. The transversal developmental study was employed with children and young adults in a bilingual context where they were learning German and French simultaneously and were used to solving arithmetic problems in both languages. Subjects had to answer simple and complex arithmetic problems in German and French in two different modalities: written and spoken addition problems. For all of them, participants had to speak the answer in the same language that the problem was presented. The results suggest that language proficiency significantly impacts arithmetic performance, especially for complex addition. For simple additions, subjects reached similar performance for both languages when proficiency was high, which was interpreted that either arithmetic thought was automatized enough for both languages or that it became independent from the verbal code. However, the authors argue that other studies are needed to generalize the findings, especially with other arithmetic operations and number-processing tasks.

Having that in mind, the present research aims at addressing the relationship between bilingualism, proficiency, and mental arithmetic in the Brazilian context. More specifically, the study aims at investigating the impact that proficiency in the L2 has in the processing of arithmetic problems. In the next chapter, the research questions and methodological choices adopted in this study will be discussed.

3 METHOD

This chapter presents details on the methods that were used to conduct this research. There are five subsections. The first subsection describes the intended participants of the study. The second subsection lists and explains the instruments that were used for data collection. The third subsection presents the procedures for data collection. Then, a brief consideration on open science, pre-registering, and open data is presented. The last subsection talks about data analysis procedures.

3.1 OBJECTIVES AND RESEARCH QUESTIONS

The current study tries to better understand how bilingual people deal with manipulating precise numerical information. The aim of this study, more specifically, is to investigate if more proficient speakers of an L2 are better at dealing with precise numerical information in their L2 and/or their L1 than less proficient speakers.

3.1.1 Research questions

The present study addresses these four questions:

Research Question 1: Are more proficient speakers of L2 better at solving simple addition and subtraction problems in the L2 than less proficient speakers?

Research Question 2: Are more proficient speakers of L2 better at solving simple multiplication and division problems in the L2 than less proficient speakers?

Research Question 3: Are more proficient speakers of L2 better at solving complex addition and subtraction problems in the L1 than less proficient speakers of L2?

Research Question 4: Are more proficient speakers of L2 better at solving complex multiplication and division problems in the L1 than less proficient speakers of L2?

3.1.2 Hypotheses

Having the research questions in mind, below are the hypotheses and their rationales.

Hypothesis 1: Participants with high proficiency in the L2 will be faster and more accurate in exact addition and subtraction problems in the L2 than participants with low proficiency.

For this hypothesis, it is assumed that language and exact arithmetic processing are interdependent (DEHAENE, COHEN, 1995). It is expected that highly proficient speakers will deal better with mental arithmetic in the L2 for two reasons. First, Lin, Imada, and Kuhl (2019) found that accuracy is reduced when participants have to answer arithmetic problems in the L2. If this is true, it can be expected that arithmetic processing will be sensitive to participants' proficiency. Additionally, Rinsveld *et al.* (2015) found that language proficiency significantly impacts arithmetic performance, in which higher proficiency results in faster and more accurate processing.

Hypothesis 2: Participants with high proficiency in the L2 will be faster and more accurate in exact multiplication and division problems in the L2 than participants with low proficiency.

This study assumes that exact arithmetic solving is dependent on language processing (DEHAENE, COHEN, 1995). It is expected that highly proficient speakers will deal better both with multiplication and division problems in the L2 for three reasons. First, Lin, Imada, and Kuhl (2019) found that accuracy is reduced when participants have to answer arithmetic problems in the L2. Secondly, Rinsveld *et al.* (2015) found that language proficiency significantly impacts arithmetic performance in the L2, in which higher proficiency results in faster and more accurate processing of arithmetic problems in their second language. Additionally, Stazyk *et al.* (1982) found that addition and multiplication are highly similar cognitive processes.

Hypothesis 3: Participants with high proficiency in the L2 will be faster and more accurate in exact addition and subtraction problems in the L1 than participants with low proficiency.

For this hypothesis, it is assumed that language and numerical cognitions are interdependent (DEHAENE, COHEN, 1995). It is expected that highly proficient L2 speakers will have faster and more accurate arithmetic processing in the L1 for two reasons. First, Dehaene *et al.* (1999) state that there are areas in the brain that overlap for language and arithmetic processing. Secondly, Rinsveld *et al.* (2015) found that language proficiency significantly impacts arithmetic performance in the L2, in which higher proficiency results in faster and more accurate processing in their second language. If arithmetic processing is language-dependent and higher proficiency in another language affects how arithmetic is processed, it can be expected that this change could expand to the L1 as well.

Hypothesis 4: Participants with high proficiency in the L2 will have faster and more accurate in exact multiplication and division problems in the L1 than participants with low proficiency.

For this hypothesis, it is assumed that language and numerical cognitions are interdependent (DEHAENE, COHEN, 1995). It is expected that highly proficient L2 speakers will have faster and more accurate arithmetic processing in the L1 for two reasons. First, - Dehaene *et al.* (1999) state that there are areas in the brain that overlap for language and arithmetic processing. Secondly, Rinsveld *et al.* (2015) found that language proficiency significantly impacts arithmetic performance in the L2, in which higher proficiency results in faster and more accurate processing in their second language. If arithmetic processing is language-dependent and higher proficiency in another language affects how arithmetic is processed, it can be expected that this change could expand to the L1 as well. Additionally, Stazyk *et al.* (1982) found that addition and multiplication are highly similar cognitive processes. Hence, faster processing of multiplication and division problems in the L1 can be expected.

3.2 THE PARTICIPANTS

The volunteers that took part in this study were a group of 37 bilingual adults with Brazilian Portuguese as their L1 and English as their L2. One participant was discarded due to not informing their proficiency level. They all had a similar education level, and their levels of proficiency were measured through the DIALANG software (more details about the proficiency test in subsection 3.3.1.2). Participants were invited to participate in the study by alerts through social media and *Divulga UFSC*, the institutional bulletin of the Federal University of Santa Catarina (UFSC).

All volunteers were Brazilians who were at least 18 years old (M = 30.1 years old, 17 females). Regarding whether they consider themselves fluent in English, 69.4% of participants answered positively. On average, the volunteers reported that their onset age of learning English was 12.5 years old (SD = 5.0). 13.9% reported having lived in a country where English is the official language, with duration ranging from three to 36 months (M = 11,8 months). Regarding formal language instruction, 83.3% of them reported having taken English classes and 8.3% are still having classes.

The participants were also asked to self-assess their English skills for speaking, listening, reading, and writing through a 5-point Likert scale (bad = 1, regular = 2, good = 3, very good = 4, and excellent = 5). The average of their self-assessments is reported below, in table 1.

Table 1 – Description of participants' self-assessed English skills

Skill	**Average (M)**	**Standard Deviation (SD)**
Speaking	3.44	1.21
Listening	4.08	0.97
Reading	4.31	0.86
Writing	3.53	1.18
Total	3.84	1.11

Proficiency was measured through the DIALANG software and results were given according to the Common European Framework of Reference for Languages (CEFR scale). Thirteen participants were considered to have below-average proficiency (B1 or less) and 23 had an above-average proficiency (B2 or more; see Table 2 for more details). The majority of the participants reported speaking only one additional language (44.4%), but comprehending two additional languages (47.2%).

Table 2 – Participants' proficiency results from DIALANG

Proficiency score	**Number of participants**	**Percentage**
A1	3	8.3%
A2	4	11.1%
B1	6	16.6%
B2	9	25%
C1	11	30.5%
C2	3	8.3%

3.3 INSTRUMENTS FOR DATA COLLECTION

This subsection presents the instruments that were used to collect data. They are the language background and mathematical learning questionnaire, proficiency test, and the bilingual oral production arithmetic task. The last task is an adaptation of Lin, Imada, and Kuhl's (2019) study.

3.3.1 L2 Assessment of proficiency

One of the central variables in this study is proficiency in the L2. To better assess participants' proficiency, two tools were used: a language background and mathematical learning questionnaire and a proficiency test. Each one of them has unique characteristics to determine each speaker's ability to use the L2. Subsection 3.3.1.1 explains in detail the language background and mathematical learning questionnaire and an implementation of a set of questions regarding mathematical learning background, which is also important for this study. Subsection 3.3.1.2 is concerned with the proficiency test DIALANG, its particularities, and its details.

3.3.1.1 Language background and mathematical learning questionnaire

Questionnaires of language background and self-reported proficiency are widely used by researchers as a methodological tool for proficiency estimation (LEMHÖFER; BROERSMA, 2012). Having this in mind, the participants recruited for this study answered a language background questionnaire that has been used in previous studies (TOASSI, 2012; WISINTAINER, 2016; FELICIO, 2018; SANTOS, 2019) at Laboratório da Linguagem e Processos Cognitivos (LabLing).

However, since the focus of this study is on arithmetic processing in bilinguals, questions regarding participant's mathematical learning background and their daily use of arithmetic were also asked. Hence, a set of questions concerning these issues were added at the end of the language background questionnaire, turning it into just one questionnaire to save participants' time and effort. In this bundled questionnaire (see appendix A), volunteers answered questions about biographical information (date of birth, sex, profession, etc.), their language learning trajectory, age of L2 acquisition, the frequency of L2 use, exposure to L2, estimates of their proficiency, which language were they instructed in mathematics, the frequency of arithmetic thinking in their daily lives, whether they frequently perform simple calculations by thinking or using a calculator, and if they consider themselves good at mathematics.

3.3.1.2 L2Proficiency test

To assess the measurement of one of the independent variables of the study, proficiency in the L2, participants were asked to take a proficiency test. For the purpose of time allocation and financial suitability, the instrument chosen for this study was a free online platform for language assessment, DIALANG (https://dialangweb.lancaster.ac.uk/). The reliability of this assessment tool was tested by Kektsidou and Tsagari (2019), in which the development of university students was tested using DIALANG over a period of time. The study yielded rich and complete results from the students' scores, demonstrating their language learning evolution and, hence, making evident the test's reliability. Other studies have also used DIALANG as a methodological tool for proficiency measure (WHITE; MELHORN; MATTYS, 2010; GHORBANI; EBADI, 2020).

The system is divided into three main sections: placement test, self-assessment, and language testing (ZHANG; THOMPSON, 2004). To start the assessment, the participant must first choose which test to take. There are five different ones: listening, writing, reading, grammar structures, and vocabulary. Only one test can be done at a time, but more than one test can be done in sequence for a more complete assessment. After choosing the first test, the participant is asked to take the placement test, which is a vocabulary size estimation task that consists of 75 words (real or novel). The participant must choose if each word exists in the English language or not. In the second part, self-assessment, the participant is asked to read some statements and decide if they reflect their abilities in the English language or not. The self-assessment is unique to each skill (listening, writing, or reading). By estimating the speaker's vocabulary size and comparing it with the answers to the self-assessment, the program selects the most adequate level of language testing in the third section.

In the language testing section, participants were asked to take the structures test, which is comprised of 30 questions. In the end, DIALANG presents the results for each question as well as the level of proficiency according to the Common European Framework of Reference for Languages (CEFR). Proficiency is labeled as A1 or A2 for basic users, B1 or B2 for independent users, and C1 or C2 for proficient users of the language.

3.3.2 Bilingual arithmetic task

The last instrument used for this study is an experiment created to assess the participants' ability to calculate arithmetic problems in their L1 and L2. For each stimulus, they heard a simple (one-digit) or complex (two digits) addition, subtraction, multiplication, or division problem. The stimuli were recorded by native speakers of English and Brazilian Portuguese (one female and one male for each language). To answer each problem, two alternatives appeared in the written form (e.g. "seven / six") on the screen and they chose the correct one by pressing the respective keys on the keyboard ("Q" for the answer on the left and "P" for the one on the right). In this task, Reaction Times (RT) and accuracy were measured for each answer for every participant. The experiment was programmed using the JsPsych framework and hosted on LabLing's website.

The following criteria were used to create the stimuli. First, all operands and results were integers, as the processing of decimals falls out of the scope of the present study. Additionally, no arithmetic problem had repeated operands (e.g. 8 x 8). These problems are known to be solved more quickly than comparable non-ties (e.g. 8 x 7), which is known as the ties effect (LEFEVRE *et al.*, 1996; MILLER *et al.*, 1984). Another criterion applied was that no numbers in the range from 12 to 19 will be used to avoid perception errors from the participants that could mistake it for the round decimals 20, 30, …, 90 in English. Also, no problem contained the operand zero, as this is also known to yield faster response times because a rule is always applied (for addition, the result of the equation will always be the same as the other operand, e.g. 2 + 0 = 0, and for multiplication, the result will always be zero, 2 x 0 = 0) (PARKMAN, 1972). The preponderance of operand-related errors, or operand-intrusion errors, was also taken into account (CAMPBELL, 1994; LEFEVRE; LIU, 1997). According to Campbell (1994), the presence of an operand on the suggested result can lead to more errors (e.g. **6** x 9 = 3**6** or 6 x **8** = 4**8**), so the results suggested to participants will not have the same digit as the operands. These criteria led to a methodological limitation when creating simple division problems because there are only six problems of this type that exist and fit into the criteria of being only one digit, having an integer result, and not having repeated operands, even when not taking into account the preponderance of operand-related errors. This limitation will be taken into account when reporting and interpreting the results in the next chapters.

For each problem, the participant was presented with two result options to choose from. One was the correct option, and the other was a distractor. All distractors were designed according to Ischebeck et al. (2006). For simple sum, subtraction, and division problems, distractors were either +/-1 or +/-2 from the correct answer. For simple multiplication, complex division, sum, and subtraction, distractors were either +/-10, +/-1, or +/-2 from the correct answer. For complex multiplication, distractors were either +/-10 from the correct answer, or an answer to a problem where one of the operands is increased or decreased by one (e.g. the problem 12 x 5 will display 60 (12 x **5**) or 66 (12 x **6**)). All criteria for every problem type were counterbalanced.

Campbell (1994) also states that participants are more prone to errors when arithmetic problems are presented in the word when compared to the Arabic form. However, since the present study is focusing on bilingual arithmetic processing, stimuli were presented verbally, through audio recordings, to force participants to at least hear the word numbers in their L1 and L2.

To avoid any bias, the stimuli were recorded by a female and a male narrator, either native speakers of Brazilian Portuguese or English (US). Hence, only one of four versions of the experiment was presented to each participant. Each version presented the same problem but with different narrators and/or language. In order to do that, four lists of the experiment were created, to counterbalance the versions each participant was presented (see more details of the stimuli presented in Appendix C). Each participant saw only one of the four lists. List 1 was done by 7 participants, List 2 was done by 10 participants, List 3 was done by 16 participants, and List 4 was done by 4 participants. Assigning participants to different lists in an online study is one of the challenges that is presented when conducting online experiments, and using an algorithm to randomly redirect each participant to one of the lists is the most efficient way to balance the number of participants in each list. However, this method is imperfect, as randomness rarely generates a perfect balance. There are ways to achieve perfect balance, but that requires advanced technical skills, so that was not adopted in this study (MATHÔT, MARCH, 2022).

Of course, it is expected that some participants might translate the problems into their L1 to solve them and translate the result back to the L2 to answer. This was controlled through a screening phase after the experimental session in which specific questions were asked regarding the strategies applied to perform arithmetic in the L2 and if there were translation processes involved or not.

3.4 PROCEDURES FOR DATA COLLECTION

The data collection procedure was carried out remotely. First, a call for data collection was announced through social media and the institutional platform *Divulga UFSC*. This announcement directed the potential participants to a webpage with the most important information about the experiment, e.g. the participant profile, the time it could take to finish, the purpose of the study, and the necessity of participating through a laptop. Interested volunteers clicked on the participate button and were redirected to the experiment page. They were first presented with the consent form (see Appendix B for more information). Once accepted, they received written instructions on how they should carry out the experiment. Then, they answered the language and mathematical background questionnaire and were given instructions on how to take the proficiency test and how to report its result.

After informing their proficiency, participants were presented with instructions for the bilingual arithmetic task. They had to take two practice trials beforehand: one in which they would hear the arithmetic problem and also see its Arabic form on the screen, along with the two possible answers in the written form; in the second practice trial, they would only hear the arithmetic problem and be presented with the two possible answers in the written form. A feedback image was presented after each practice trial to indicate if the answer was correct or not. An option to retake the practice trials was offered. After that, a screen with quick reminders was presented and, after pressing a button, they would finally start the task.

The whole procedure was carried out online and programmed in JavaScript using the JsPsych framework (DE LEEUW, 2015). This framework was chosen because of its ease of use, extended compatibility with most computers and browsers, reliability when running online and storing data, and due to the familiarity that the researcher had with this technology. All the procedures executed to ensure the safety of the data collected and participants' anonymity are explained in section 3.5.

3.5 CONSIDERATIONS ON OPEN SCIENCE AND OPEN DATA

Researchers from many areas of knowledge agree that there is a crisis in the reproducibility of published scientific studies due to the low reproducibility rate (BAKER, 2016; MUNAFÒ *et al*, 2017). Because of this, a movement in the scientific community has gained traction: open science. Open science is an umbrella term used to appoint measures that are being taken to shape the future of knowledge creation and dissemination (FECHER;

FRIESIKE, 2014). Fecher and Friesike (2014) propose five schools of thought for open science: i) *the infrastructure school*, responsible to propose solutions for technological infrastructure for data and study storage; ii) *the public school*, which is responsible to propose new solutions for more accessibility of new scientific knowledge; iii) *the measurement school*, that prioritizes creating new measures of performance and impact of new scientific studies; iv) *the democratic school*, which is responsible to think about new democratic models of study publications and scientific products, in order to make them available for free to everyone; and v) *the pragmatic school*, that has the objective of proposing new and optimized methods of conducting scientific research.

In order to make this study a little bit more fit into the idealized model of open science, one point needs to be addressed: open data. According to Fecher and Friesike (2014), the democratic school proposed by them must be practiced by two main agencies: open access and open data. The first agency is already a common practice in Brazil, which is to make scientific publications available to everyone for free. Something that is not as common in great scientific communities, such as North America and Europe, where readers must pay to read the majority of their published studies. The second agency is about a more recent practice, which is to make the data collected available in public databases. This is necessary mainly for two different reasons. First, to amplify transparency and facilitate the validity of studies beyond peer review, because that allows virtually anyone to analyze the same data and try to get the same results. Secondly, it is also important to facilitate the work of other researchers who are trying to replicate the study, as they can easily and quickly have access to the data to replicate the study as close as possible to the original and compare the results in the end. Thankfully, more and more scientific journals nowadays are requiring the practice of open data as a requirement for publications.

This study also rigorously follows the *Ofício Circular número 2 do Conselho Nacional de Ética em Pesquisa*, published in February 2021 which, by itself, follows the criteria established by the Brazilian law of data management and storage, *Lei Geral de Proteção de Dados* (LGPD). This letter (*ofício*), recommends that collected data should not be stored in virtual platforms, shared environments, or “clouds”, something that was not done in this study to avoid unwanted people having access to participants’ personal data. In order to do that, all personal data obtained will be transferred to a physical drive and stored in a locked cabinet, along with all collected data. Only anonymized data will be made public, as detailed below.

The practice of open data is safe and goes through rigorous evaluation and coding by the researcher. It is the researcher’s responsibility to make sure that it is not possible to identify the participants through the published data. In order to do that, the data will be organized in a spreadsheet, categorized by alphanumeric codes that refer back to each participant (e.g. P21041501). Data extracted from questionnaires will not be integrally published, but only the parts that are vital to statistical analysis. The present study intends to publish the following data: participants' reaction times for each stimulus (measured in milliseconds), accuracy in the solving of each arithmetic problem (coded in 0 or 1), score in the working memory capacity test (Arabic digits from 0 to 70), score in each language ability in the proficiency test (according to the Common European Framework of Reference for Languages – CEFR), age of L2 acquisition (in years, e.g. 14), and the average and standard deviation of participants' age (in years).

This study was approved by UFSC's Ethics Committee for Research on Human Participants under the registration number (CAAE) 48291521.5.0000.0121.

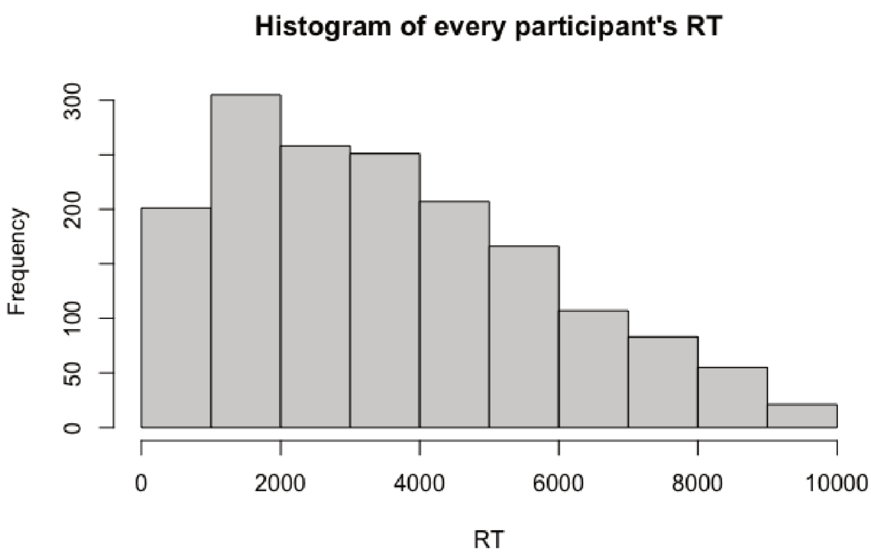
4 RESULTS AND DISCUSSION

The main goal of this study was to investigate the relationship between L2 proficiency in late bilinguals and arithmetic processing. More specifically, if late bilinguals with higher proficiency are faster and more accurate when processing simple and complex sum, subtraction, multiplication, and division problems when compared with those with lower proficiency. In addition, participants that took part in this study were tested in L1 and L2 arithmetic processing. That is, participants were tested if their L2 proficiency can influence their arithmetic processing in their L2 and/or their L1. In this chapter, an analysis of the data collected is presented. The first subsection consists of a descriptive analysis and the second, of an inferential analysis.

4.1 DESCRIPTIVE ANALYSIS

Thirty-seven volunteers participated in the experiment remotely. One participant was removed for not informing their L2 proficiency. The data was saved automatically in LabLing's server and was downloaded to be analyzed in R. The data cleaning process involved joining every participant's data into one data frame, removing excess rows and columns, treating null observations and NAs to be removed (56 NAs removed), and extracting the proficiency level from the questionnaire to organize it as observations for each participant. Figure 2 presents a histogram of all participants' reaction times (N = 37; M = 3574.2 ms; SD = 2250.3 ms) and demonstrates a parametric distribution positively skewed.

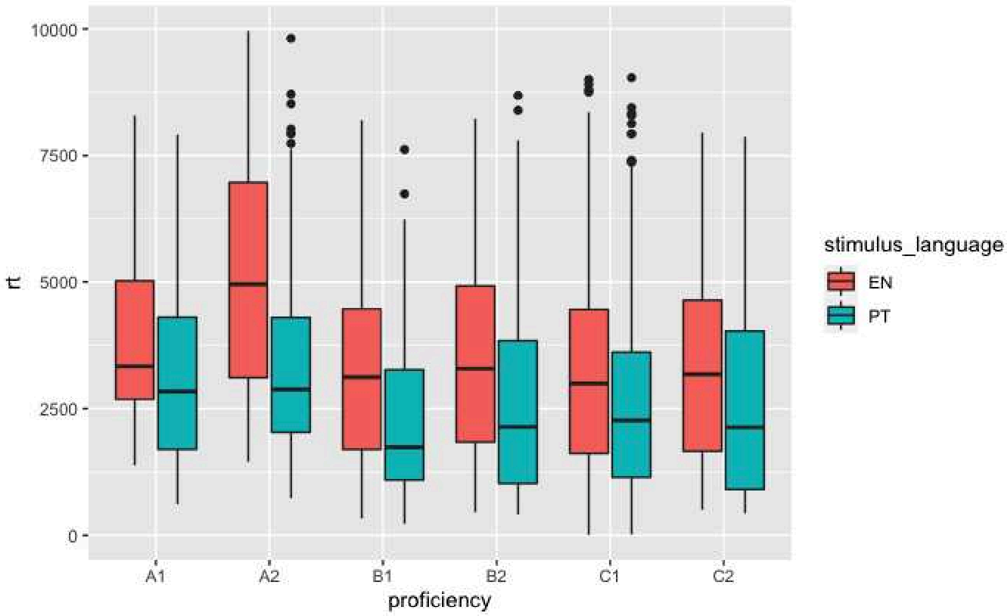
Figure 2: Histogram of the reaction times for every participant across all conditions



Source: the author.

Figure 3 presents the reaction times of all participants separated by proficiency level and the language in which each problem was presented (English or Portuguese). Participants with proficiency bands ranging from A1 to A2 demonstrated a slower reaction time when compared to other bands, but especially participants with A2 proficiency had slower reaction times. All other proficiency bands exhibit similar reaction times for each language. However, there is a visible difference in each proficiency band between Portuguese and English.

Figure 3 – Reaction times across all proficiency bands for each stimulus language



Source: the author.

Across all stimuli, there were four types of arithmetic problems (sum, subtraction, multiplication, and division) in two types of complexity (simple and complex). These different types of arithmetic problems are the conditions that are going to be used to answer the research questions in the present study. Table 3 presents means and standard deviations for all types of problems and complexities, and also how accurate the participants were in correctly answering them (timeouts/NAs were treated as wrong answers).

Table 3 – Means and standard deviations for all types of problems and complexities.

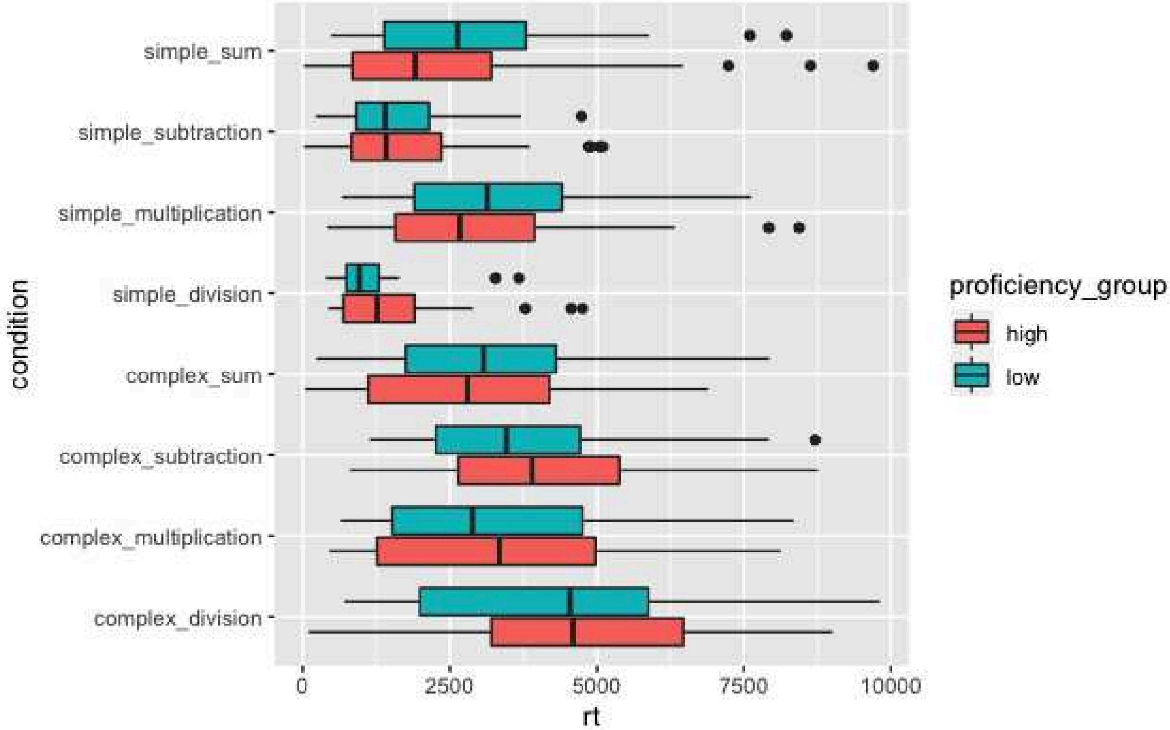
Condition	**Mean (ms)**	**SD (ms)**	**Accuracy (%)**
Simple sum	3202.5	2183.6	85.39%
Simple subtraction	2231.9	1679.6	92.47%
Simple multiplication	3590.2	2028.7	81.36%
Simple division	1883.9	1455.7	94.73%
Complex sum	3709.9	2146.8	82.74%
Complex subtraction	4342.7	2135.3	82.27%
Complex multiplication	4100.6	2254.4	76.19%
Complex division	4830.3	2317.4	63.67%

Source: the author.

As can be seen in Table 3, simple multiplication problems had longer reaction times when compared with other simple arithmetic problems. Simple division problems likely had such comparably short reaction times because of the methodological limitation of how many division problems are there with only one digit, so fewer observations were made and the problems were fairly simple (see section 3.3.2 in the methods chapter for more details). Simple multiplication had the lowest accuracy and simple division had the highest accuracy by a difference of 13.37 percentage points. While sum and multiplication had similar accuracy rates, simple subtraction resulted in a significantly higher accuracy rate than the aforementioned problems.

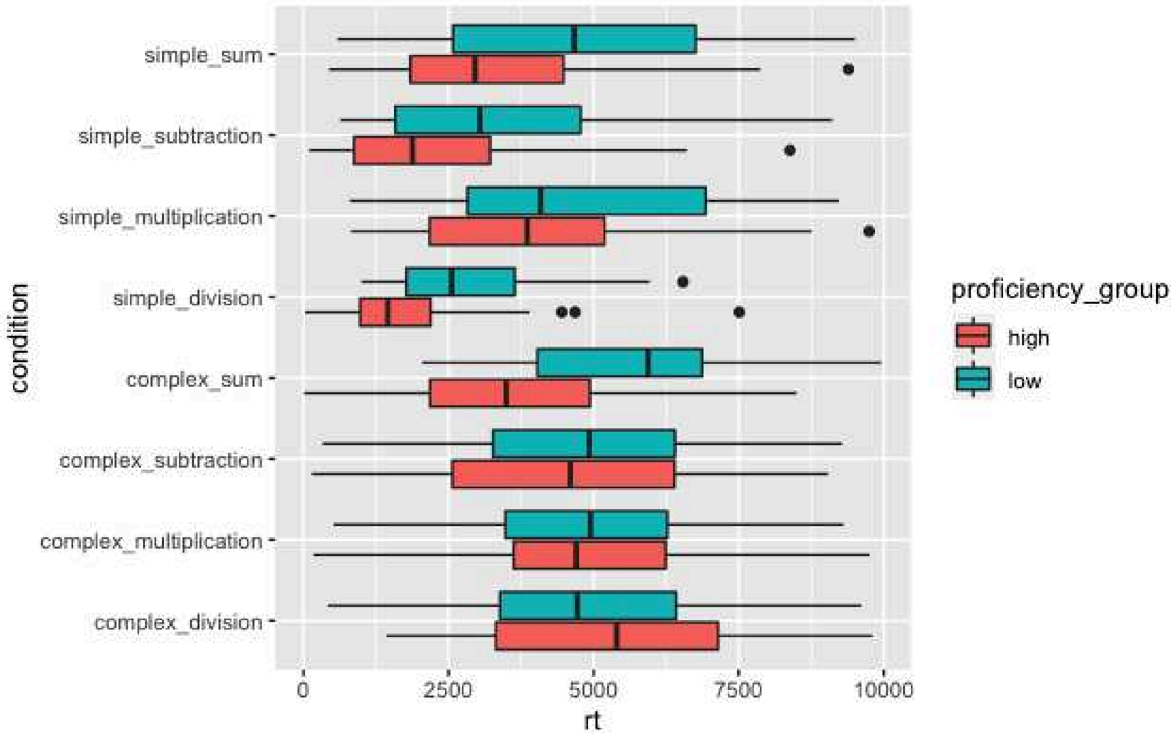
Regarding the complex problems, complex sum had the lowest mean and complex division the highest, resulting in a difference of 1120.4 ms between them. Accuracy was similar for sum and subtraction, while complex multiplication showed lower performance, and complex division was the lowest with 19,07 percentage points away from the complex sum. The graphs below demonstrate the reaction times across all conditions separated by proficiency groups (low proficiency = A1-B1; high proficiency = B2-C2). The graphs are organized by the language in which the stimuli were presented. Figure 4 illustrates the RTs for the Portuguese stimuli, while Figure 5 illustrates the RTs for English.

Figure 4 – Reaction times for Portuguese stimuli across all conditions separated by proficiency group



Source: the author.

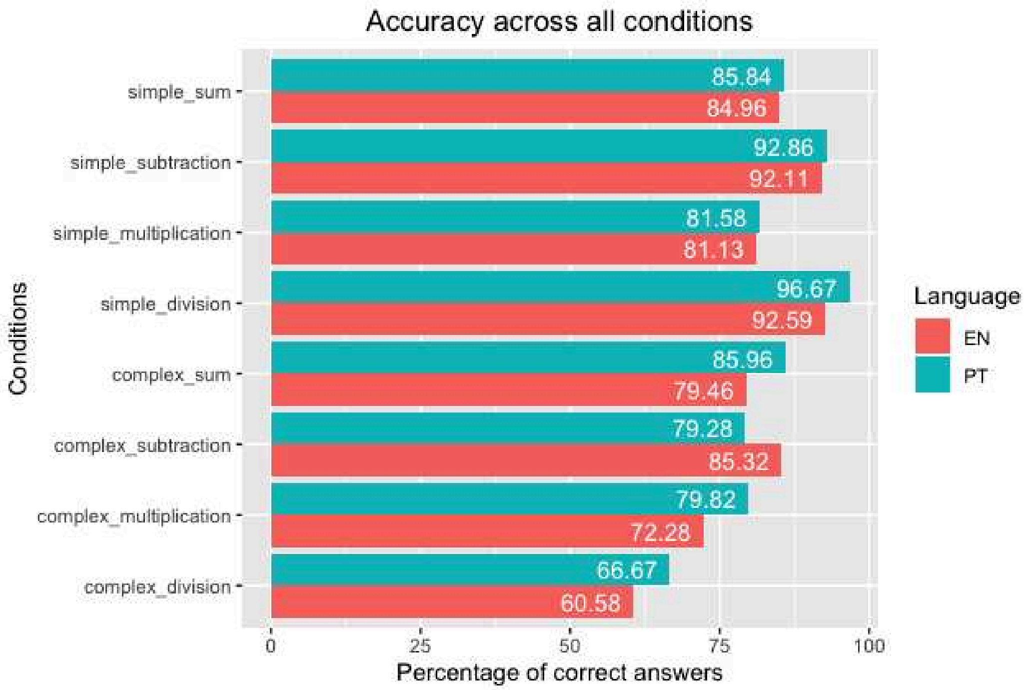
Figure 5 – Reaction times for English stimuli across all conditions separated by proficiency group



Source: the author.

When comparing the two graphs (Figures 4 and 5), a slower reaction time can be observed for all proficiency groups for the English stimuli, which is expected and is in line with what is shown in Figure 3. While no clear pattern can be observed in the Portuguese stimuli regarding which proficiency group was faster, in the English stimuli it is clear that the high proficiency group had faster reaction times for all conditions (except complex division, which is arguably the most cognitively challenging problem). However, the difference between the high and low proficiency groups is more noticeable in the simple problems, except for the complex sum, which exhibits the most perceptible difference in reaction times. Regarding accuracy, Figure 6 presents in more detail the accuracy of all conditions in comparison to the language presented.

Figure 6 – Accuracy for all of the conditions, in percentage, for each language



Source: The author

Concerning participants' accuracy in the resolution of problems presented in English, as can be seen in Figure 6, subtraction exhibits the highest accuracy rate, both in the simple and complex types of arithmetic problems. With the exception of simple division, which had simpler problems due to a methodological limitation[2], a pattern in the accuracy of English

[2] There were only 6 simple division problems (instead of 12 like all other problem types) because of how many number pairings are divisible with integer results under the criteria established for creating the stimuli. See more details in section 3.3.2 in the methods chapter.

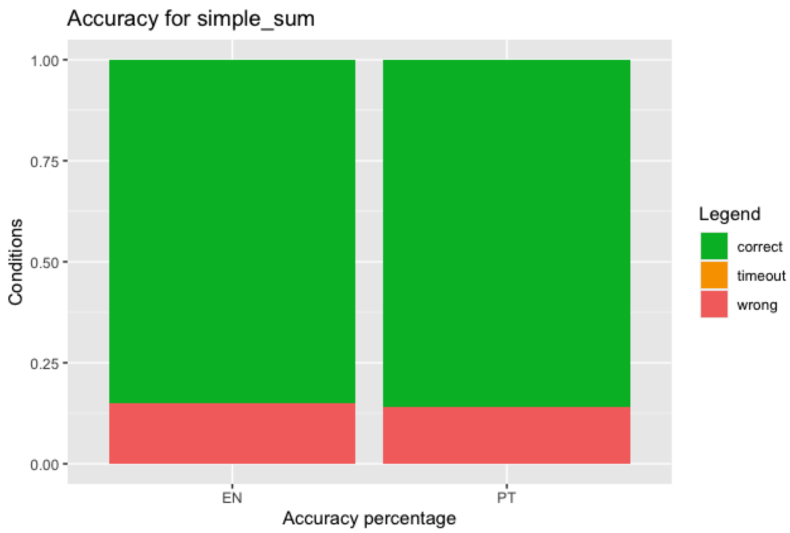
problems appears when comparing simple and complex problems, from highest to lowest accuracy: subtraction, sum, and multiplication.

This is also true for Portuguese when considering only simple problems. However, on Portuguese complex problems, sum takes a lead, and subtraction and multiplication present very similar accuracy rates. Complex division problems exhibit the lowest accuracy rate. These results could indicate that there is an order of complexity in the problems, sum is the easiest and division is the hardest. In the next subsections, each condition is analyzed in detail, so they can be compared between languages as well.

4.1.1 Simple Sum

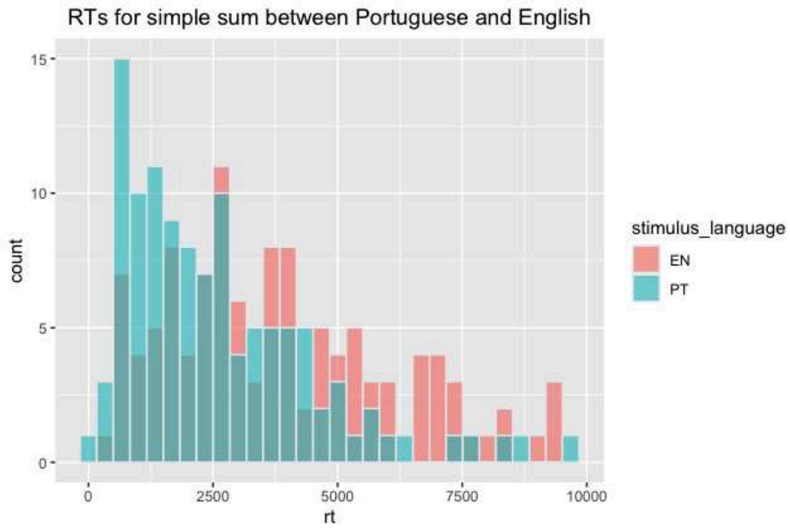
In the simple sum condition, participants were presented with sum problems with only one digit, either in English (e.g. eight plus nine) or in Portuguese (e.g. *oito mais nove*). As can be seen in Figure 7, accuracy was similar for both languages: 85.84% in Portuguese and 84.96% in English.

Figure 7 – Accuracy for the simple sum condition, in Portuguese and English



Source: The author

Figure 8 – Reaction times for the simple sum condition, in Portuguese and English



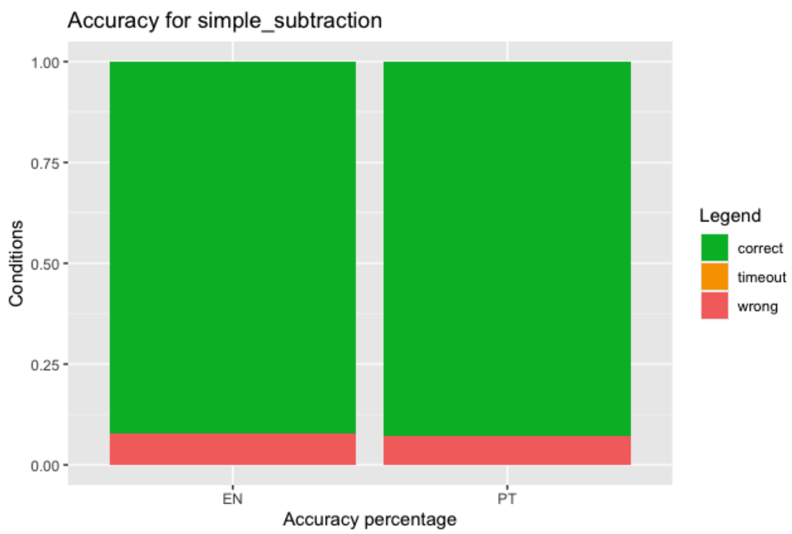
Source: The author

Figure 8 presents a histogram of the reaction times for the simple sum condition specifically. The reaction times show that participants were overall faster to solve problems in Portuguese than in English, which is expected. The mean RT for Portuguese is 2585 ms (SD = 1916 ms). For English, the mean RT is 3819 ms (SD = 2266 ms).

4.1.2 Simple subtraction

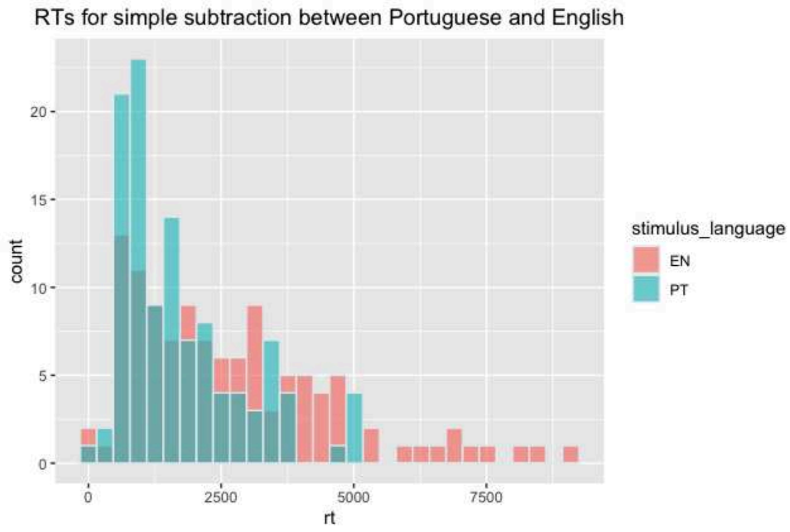
In the simple subtraction condition, participants were presented with subtraction problems with only one digit, either in English (e.g. nine minus four) or in Portuguese (e.g. *nove menos quatro*). As can be seen in Figure 9, accuracy was similar for both languages: 92.86% in Portuguese and 92.11% in English.

Figure 9 – Accuracy for the simple subtraction condition, in Portuguese and English



Source: The author

Figure 10 – Reaction times for the simple subtraction condition, in Portuguese and English



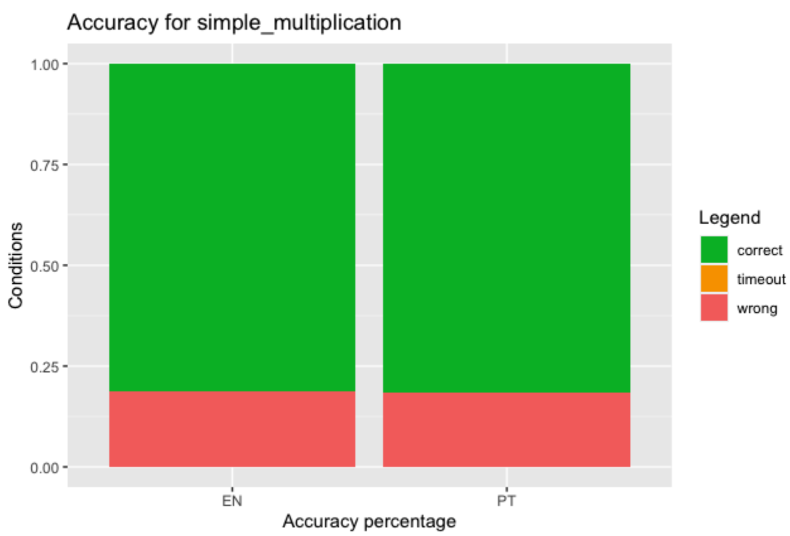
Source: The author

Figure 10 presents a histogram of the reaction times for the simple subtraction condition specifically. The reaction times show that participants were overall faster to solve problems in Portuguese than in English, which is expected. The mean RT for Portuguese is 1747 ms (SD = 1164 ms). For English, the mean RT is 2707 ms (SD = 1955 ms).

4.1.3 Simple multiplication

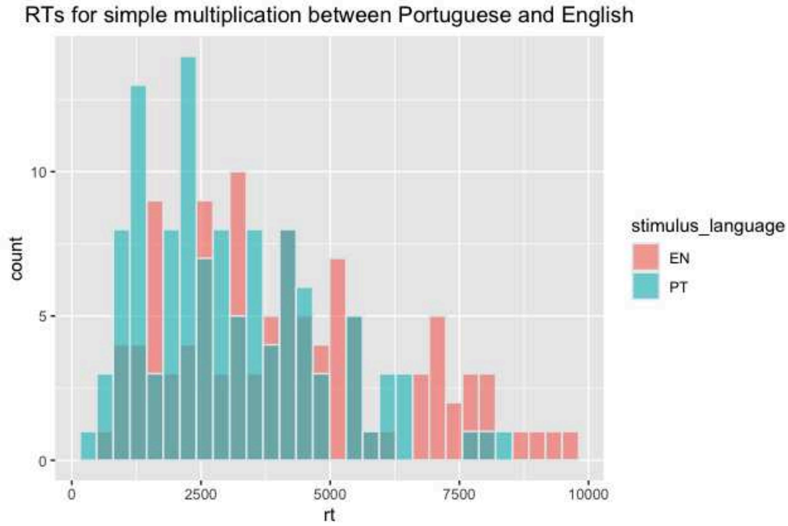
In the simple multiplication condition, participants were presented with multiplication problems with only one digit, either in English (e.g. seven times three) or in Portuguese (e.g. *sete vezes três*). As can be seen in Figure 11, accuracy was similar for both languages: 81.58% in Portuguese and 81.13% in English.

Figure 11 – Accuracy for the simple multiplication condition, in Portuguese and English



Source: The author

Figure 12 – Reaction times for the simple multiplication condition, in Portuguese and English



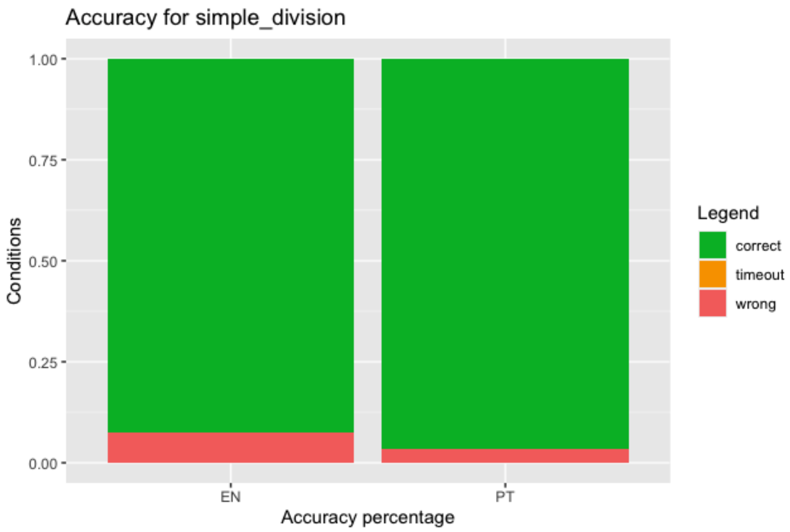
Source: The author

Figure 12 presents a histogram of the reaction times for the simple multiplication condition specifically. The reaction times show that participants were overall faster to solve problems in Portuguese than in English, which is expected. The mean RT for Portuguese is 3080 ms (SD = 1736 ms). For English, the mean RT is 4138 ms (SD = 2180 ms).

4.1.4 Simple division

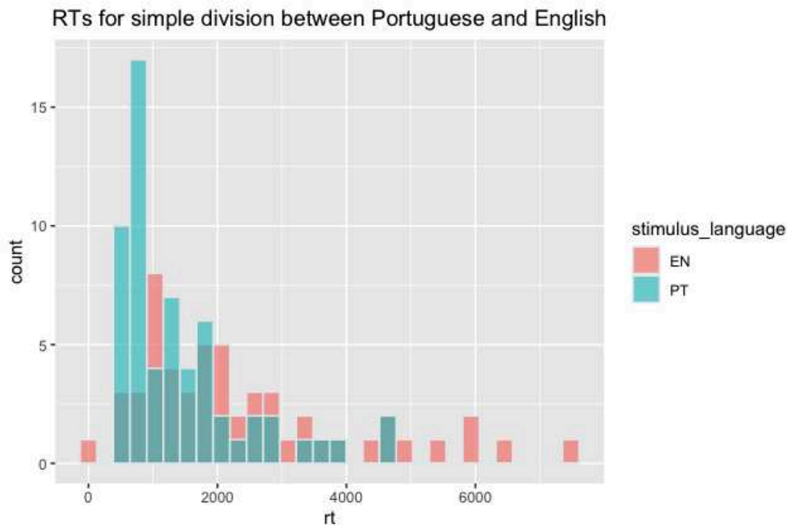
In the simple division condition, participants were presented with division problems with only one digit, either in English (e.g. six divided by three) or in Portuguese (e.g. *seis dividido por três*). As can be seen in Figure 13, accuracy was higher for Portuguese (96.67%) than for English (92.59%). This condition had fewer stimuli due to methodological limitations.

Figure 13 – Accuracy for the simple division condition, in Portuguese and English



Source: The author

Figure 14 – Reaction times for the simple division condition, in Portuguese and English



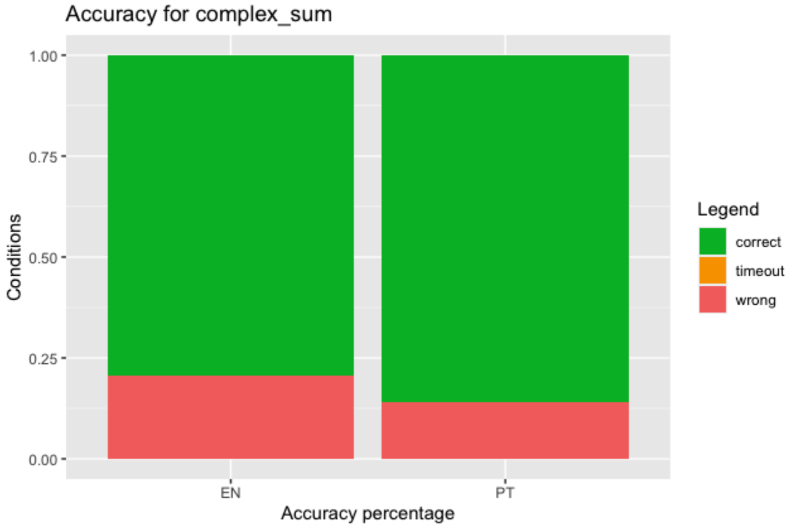
Source: The author

Figure 14 presents a histogram of the reaction times for the simple division condition specifically. The reaction times show that participants were overall faster to solve problems in Portuguese than in English, which is expected. The mean RT for Portuguese is 1436 ms (SD = 1019 ms). For English, the mean RT is 2381 ms (SD = 1697 ms).

4.1.5 Complex sum

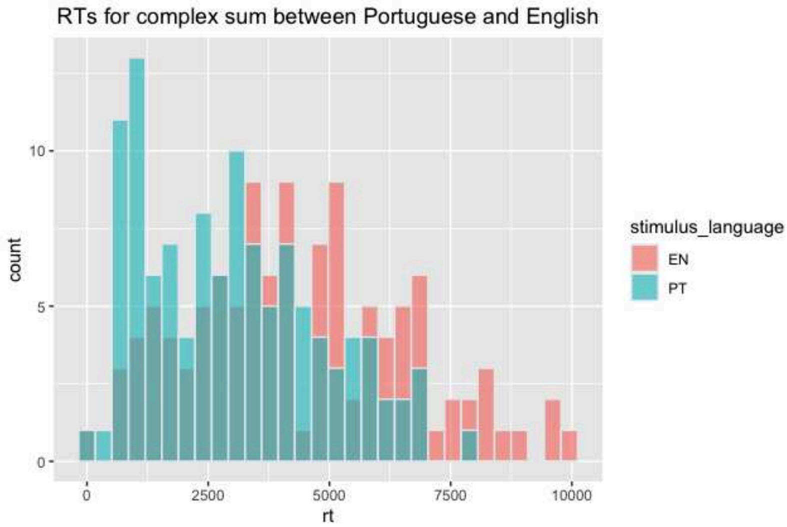
In the complex sum condition, participants were presented with sum problems with two digits, either in English (e.g. thirteen plus seven) or in Portuguese (e.g. *treze mais sete*). As can be seen in Figure 15, accuracy was higher for Portuguese (85.96%) than for English (79.46%).

Figure 15 – Accuracy for the complex sum condition, in Portuguese and English



Source: The author

Figure 16 – Reaction times for the complex sum condition, in Portuguese and English



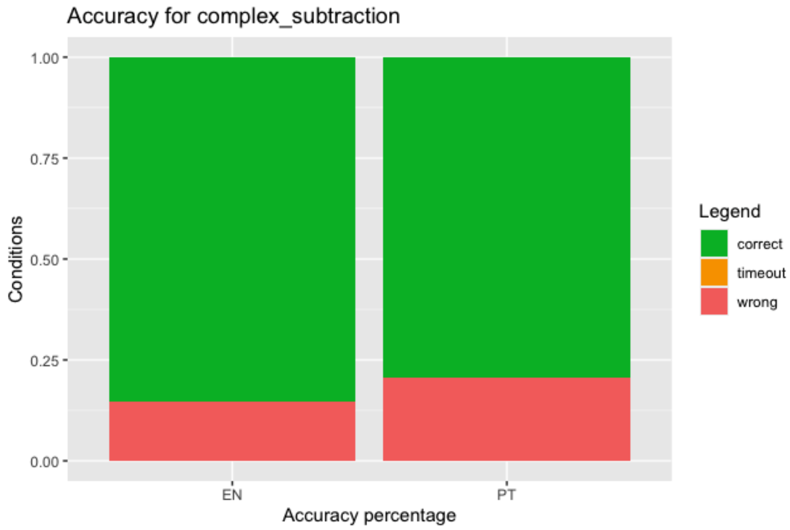
Source: The author

Figure 16 presents a histogram of the reaction times for the complex sum condition specifically. The reaction times show that participants were overall faster to solve problems in Portuguese than in English, which is expected. The mean RT for Portuguese is 3036 ms (SD = 1816 ms). For English, the mean RT is 4395 ms (SD = 2245 ms).

4.1.6 Complex subtraction

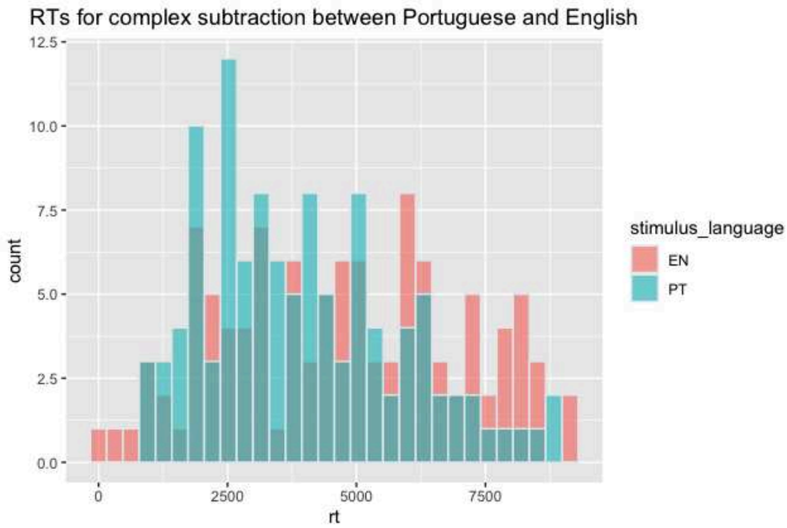
In the complex subtraction condition, participants were presented with sum problems with two digits, either in English (e.g. eighty-two minus nine) or in Portuguese (e.g. *oitenta e* *dois menos nove*). As can be seen in Figure 17, accuracy was higher for English (85.32%) than for Portuguese (79.28%).

Figure 17 – Accuracy for the complex subtraction condition, in Portuguese and English



Source: The author

Figure 18 – Reaction times for the complex subtraction condition, in Portuguese and English



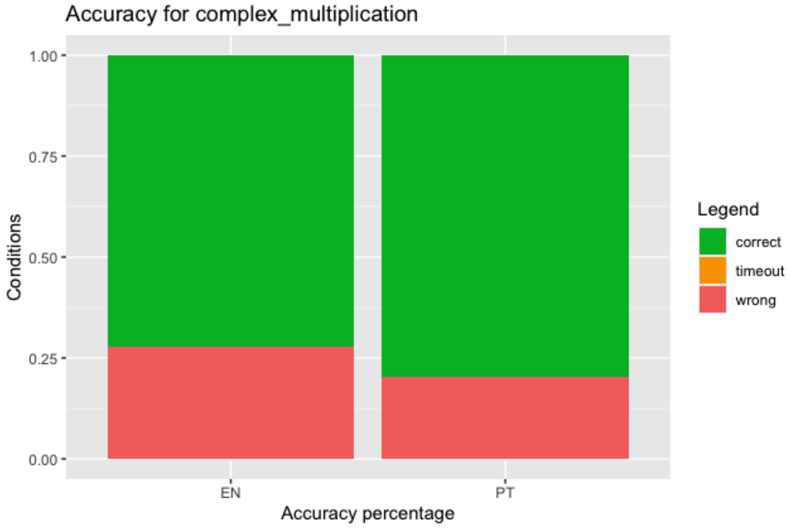
Source: The author

Figure 18 presents a histogram of the reaction times for the complex subtraction condition specifically. The reaction times show that participants were overall faster to solve problems in Portuguese than in English, which is expected, but divergent from the accuracy results for this same condition. The mean RT for Portuguese is 3962 ms (SD = 1917 ms). For English, the mean RT is 4730 ms (SD = 2280 ms).

4.1.7 Complex multiplication

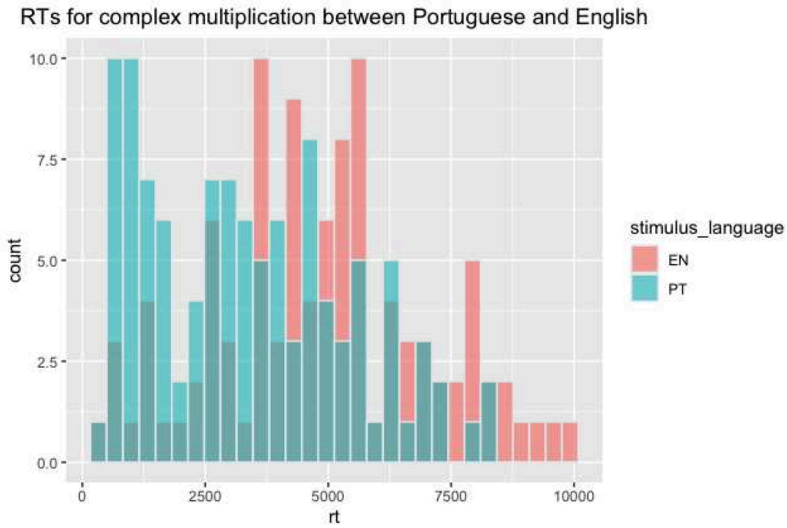
In the complex multiplication condition, participants were presented with multiplication problems with two digits, either in English (e.g. thirty-eight times two) or in Portuguese (e.g. *trinta e oito vezes dois*). As can be seen in Figure 19, accuracy was higher for Portuguese (79.82%) than for English (72.28%).

Figure 19 – Accuracy for the complex multiplication condition, in Portuguese and English



Source: The author

Figure 20 – Reaction times for the complex multiplication condition, in Portuguese and English



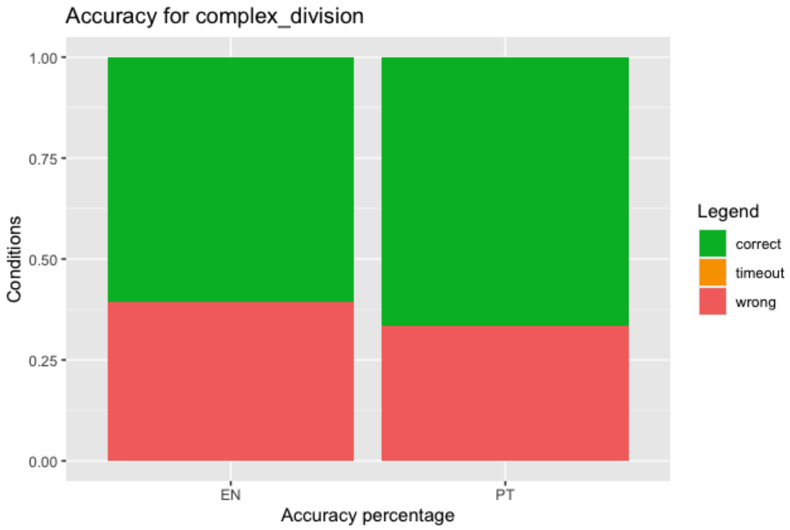
Source: The author

Figure 20 presents a histogram of the reaction times for the complex multiplication condition specifically. The reaction times show that participants were overall faster to solve problems in Portuguese than in English, which is expected. The mean RT for Portuguese is 3384 ms (SD = 2075 ms). For English, the mean RT is 4874 ms (SD = 2192 ms).

4.1.8 Complex division

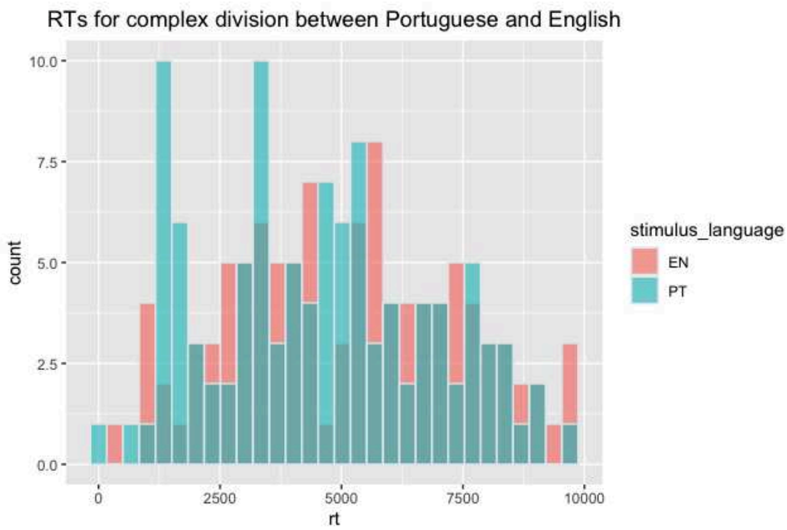
In the complex division condition, participants were presented with division problems with two digits, either in English (e.g. eighty-four divided by seven) or in Portuguese (e.g. *oitenta e quatro dividido por sete*). As can be seen in Figure 21, accuracy was higher for Portuguese (66.67%) than for English (60.58%).

Figure 21 – Accuracy for the complex division condition, in Portuguese and English



Source: The author

Figure 22 – Reaction times for the complex division condition, in Portuguese and English



Source: The author

Figure 22 presents a histogram of the reaction times for the complex division condition specifically. The reaction times show that participants were overall faster to solve problems in Portuguese than in English, which is expected. The mean RT for Portuguese is 4560 ms (SD = 2307 ms). For English, the mean RT is 5110 ms (SD = 2305 ms).

4.2 INFERENTIAL ANALYSIS

In order to answer the research questions properly, mixed-effects modeling was used to analyze whether the reaction times would be faster in the high-proficiency group when compared with the low-proficiency one. To accomplish that, four models were run to encompass all data, creating four subsets of data for each model categorized by language and arithmetic problems, as can be seen in Table 4. In all models, proficiency groups, conditions, and an interaction between these two were included as fixed factors. Participants were included as random factors. The results for each model are presented in the next subsections.

Table 4 – Subsets of the data created to run the mixed-effect models

Subset	Language	Arithmetic problems
Subset 1	EN	Sum/subtraction
Subset 2	EN	Multiplication/division
Subset 3	PT	Sum/subtraction
Subset 4	PT	Multiplication/division

Source: the author.

4.2.1 Model 1 – English sum and subtraction

This model included data from either sum or subtraction problems that were presented in English only. In Table 5, below, the first item demonstrates the results of the interaction between proficiency and reaction times. Proficiency itself, without taking into account the conditions of this experiment, did not yield a significant result ($p = 0.433$). The three items below (*conditioncomplex_sum, conditionsimple_subtraction,* and *conditionsimple_sum*) demonstrate the results of the interaction between each condition's reaction times against the baseline, which was randomly chosen to be *conditioncomplex_subtraction*. Hence, all arithmetic problems yielded significantly different reaction times when compared to complex subtraction (*conditioncomplex_sum* $p = 0.0013$, *conditionsimple_subtraction* $p < 0.001$, and *condition_simplesum* $p < 0.001$).

Table 5 – Results for the English sum and subtraction model

	Dependent variable:
	rt
proficiency_grouplow	515.901
	t = 0.795
conditioncomplex_sum	-970.069
	t = -3.222***
conditionsimple_subtraction	-2398.847
	t = -7.967***
conditionsimple_sum	-1245.444
	t = -4.136***
proficiency_grouplow:conditioncomplex_sum	1670.099
	t = 3.293***
proficiency_grouplow:conditionsimple_subtraction	818.708
	t = 1.625
proficiency_grouplow:conditionsimple_sum	678.851
	t = 1.342
Constant	4614.833
	t = 11.825***
Observations	448
Log Likelihood	-3958.139
Akaike Inf. Crit.	7936.278
Bayesian Inf. Crit.	7977.326
Note:	*p<0.1; **p<0.05; ***p<0.01

Source: the author.

Having in mind that the focus of this study is to evaluate if there is a relationship between language proficiency and arithmetic problem solving, the last three results (above Constant) are the ones with the most relevance here. All interactions mentioned below are compared against the baseline, which was randomly chosen to be the interaction between the highly proficient group and the complex subtraction condition. The first interaction of these fixed effects is between proficiency and the complex sum, which yielded a significant result ($p = 0.001$). The interaction with simple subtraction ($p = 0.104$) and simple sum ($p = 0.180$) did not demonstrate significant variance in reaction times.

4.2.2 Model 2 – English multiplication and division

This model included data from either division or multiplication problems that were presented in English only. Table 6 presents the results just like in Model 1. Once again, proficiency itself did not yield a significant result ($p = 0.4760$). Simple division ($p < 0.001$) and simple multiplication ($p < 0.001$) problems yielded a significantly different result, while complex multiplication did not yield a different result from the baseline (in this case, complex division).

Table 6 – Results for the English division and multiplication model

	Dependent variable:
	rt
proficiency_grouplow	-449.262
	t = -0.721
conditioncomplex_multiplication	-453.126
	t = -1.342
conditionsimple_division	-3334.365
	t = -7.800***
conditionsimple_multiplication	-1461.186
	t = -4.374***
proficiency_grouplow:conditioncomplex_multiplication	725.624
	t = 1.297
proficiency_grouplow:conditionsimple_division	1208.847
	t = 1.842*
proficiency_grouplow:conditionsimple_multiplication	1368.574
	t = 2.469**
Constant	5314.496
	t = 13.903***
Observations	365
Log Likelihood	-3236.208
Akaike Inf. Crit.	6492.415
Bayesian Inf. Crit.	6531.414
Note:	*p<0.1; **p<0.05; ***p<0.01

Source: the author.

Regarding the interaction between proficiency, condition, and reaction times, there was a significant result between proficiency and simple multiplication ($p = 0.0140$), as expected. The baseline considered here was the group with high proficiency and the complex division condition. However, contrary to expectations, the interactions between proficiency and simple division ($p = 0.0663$), and proficiency and complex multiplication ($p = 0.1955$) were not significant.

4.2.3 Model 3 – Portuguese sum and subtraction

Unlike the previously presented models, model 3 included stimuli presented in Portuguese that were either sum or subtraction problems. Table 7 presents the results just like on the previous models. Once again, proficiency itself did not yield a significant result ($p = 0.4567$). The three items below (*conditioncomplex_sum, conditionsimple_subtraction,* and *conditionsimple_sum*) demonstrate the results of the interaction between each condition's reaction times against the baseline, which was randomly chosen to be *conditioncomplex_subtraction*. All other problems yielded a significant difference from the baseline ($p < 0.001$ for all of them).

Table 7 – Results for the Portuguese sum and subtraction model

	Dependent variable:
	rt
proficiency_grouplow	-361.754
	t = -0.753
conditioncomplex_sum	-1205.338
	t = -4.587***
conditionsimple_subtraction	-2347.671
	t = -8.935***
conditionsimple_sum	-1697.699
	t = -6.461***
proficiency_grouplow:conditioncomplex_sum	743.119
	t = 1.718*
proficiency_grouplow:conditionsimple_subtraction	380.149
	t = 0.872
proficiency_grouplow:conditionsimple_sum	835.270
	t = 1.923*
Constant	4101.116
	t = 14.048***
Observations	450
Log Likelihood	-3910.653
Akaike Inf. Crit.	7841.306
Bayesian Inf. Crit.	7882.398
Note:	*p<0.1; **p<0.05; ***p<0.01

Source: the author.

When the stimuli were presented in Portuguese, the participants' L1, proficiency yielded no significant result, as expected ($p > 0.05$ for all of them). This result was expected since the proficiency measured was regarding participants' L2 and these results take into account their performance solving problems in their L1.

4.2.4 Model 4 – Portuguese multiplication and division

Similar to model 3, model 4 included stimuli presented in Portuguese, but those were either multiplication or division problems. Just like all other models, proficiency itself didn't yield any significant result ($p = 0.605$), while all other problems did ($p < 0.001$ for all of them).

Table 8 – Results for the Portuguese sum and subtraction model

	Dependent variable:
	rt
proficiency_grouplow	-280.044
	t = -0.522
conditioncomplex_multiplication	-1209.697
	t = -3.989***
conditionsimple_division	-3143.245
	t = -9.051***
conditionsimple_multiplication	-1719.671
	t = -5.752***
proficiency_grouplow:conditioncomplex_multiplication	10.203
	t = 0.021
proficiency_grouplow:conditionsimple_division	78.038
	t = 0.129
proficiency_grouplow:conditionsimple_multiplication	554.743
	t = 1.143
Constant	4699.116
	t = 14.265***
Observations	391
Log Likelihood	-3434.512
Akaike Inf. Crit.	6889.024
Bayesian Inf. Crit.	6928.711
Note:	*p<0.1; **p<0.05; ***p<0.01

Source: the author.

As expected, no interaction between L2 proficiency and multiplication or division problems, neither complex nor simple ($p > 0.05$ for all of them).

4.3 DISCUSSION

The primary goal of this study was to assess whether highly-proficient late speakers of English as an L2 were faster and more accurate at solving arithmetic problems presented in English when compared to low-proficient speakers. The secondary goal of this study was to assess if proficiency would have a similar, or any, effect when the arithmetic problems were presented in Portuguese.

In order to investigate the role of proficiency in arithmetic processing in L2 speakers, 37 participants took part in a remote experiment in which they had to complete some tasks. Firstly, participants answered a questionnaire with their personal information, L2 self-assessment, L2 learning background, daily experience with arithmetic, and the language in which they learned mathematics. Then, they undertook a remote English proficiency test, DIALANG, and informed the result. Finally, the volunteers carried out a bilingual arithmetic task, in which they were presented with audio recordings of arithmetic problems and had to choose one of two possible answers presented in writing. Reaction times and accuracy were collected for each trial (arithmetic problem) presented.

The results, presented in the previous section, revealed that participants were faster and more accurate to solve problems in Portuguese than in English, which was expected (there was one exception in the complex subtraction condition, to be discussed in detail later on). The reaction times and accuracy results were also run through a linear mixed effects analysis, where it is mostly relevant the interaction between proficiency and solving complex sum and simple division in the participants' L2. One possible interpretation for the significantly different results for these two types, when compared to the other types of arithmetic problems, may be due to their complexity in being solved. Figure 6 presents how accurate participants were in each problem type, and these complex sum and simple division seem to be right in the middle – neither too easy nor too hard.

Even though some level of complexity was methodologically considered in this study (one vs. two-digit operations), proficiency seemed to be even more sensitive to complexity than that. While two-digit operations are more complex than one-digit operations, there is an intrinsic complexity level for each arithmetic problem that should be taken into account in such an experiment.

The different complexity levels between these problems could have had an effect on this result. Being too easy would not yield a strong interaction with L2 proficiency, being considered not proficiency dependent. However, being too difficult would generate a language overload that surpasses L2 proficiency, and it would simply not be helpful if the complexity is too high. Hence, results demonstrate that proficiency has an effect on arithmetic processing, but depends on the complexity of the problems presented.

These results are in line with the study conducted by Rinsveld, Brunner, Landerl, Schiltz, and Ugen (2015), see discussion in section 2.3, in which the authors conducted an experiment with children and young adults who were learning mathematics in a bilingual context. The experiment tested the subjects' speed and accuracy in solving simple and complex (one vs two-digit) addition problems in French and German (the languages they were learning simultaneously). They found that language proficiency was more impactful on complex addition than on simple addition, and hypothesized that either the participants had automatized simple addition problems enough for both languages or that this type of operation had become independent from the TCM's verbal code.

These findings are only partially in line with the Triple Code Model proposed by Dehaene (1992). Since there was an interaction between language proficiency and arithmetic processing, this can be seen as evidence for the model's interpretation of the relationship between language and number processing. However, the results in this study are in accordance with Fayol and Thevenot (2012), work that challenges part of the TCM by proposing that simple addition and subtraction are solved by fast and efficient procedures in procedural memory instead of relying on fact-retrieval, which is suggested by the TCM. The present study is in line with Fayol and Thevenot (2012) because simple addition and subtraction did not yield significantly different results between high and low-proficiency groups.

Another interesting result from this study was that accuracy in complex subtraction was higher for the problems presented in English than those presented in Portuguese. The expectation was that participants would perform better (faster and more accurately) in Portuguese, as this was the language in which they were instructed mathematics. This pattern was not observed in participants' reaction times, as they were faster to solve the problems in Portuguese than in English, which was expected. This was an outstanding result that should be investigated in future studies.

4.3.1 READRESSING THE RESEARCH QUESTIONS AND HYPOTHESES

RQ1: Are more proficient speakers of L2 better at solving simple and complex addition and subtraction problems in the L2 than less proficient speakers?

H1: Participants with high proficiency in the L2 will be faster and more accurate in exact addition and subtraction problems in the L2 than participants with low proficiency.

Participants with higher proficiency in their L2 were significantly faster and more accurate to solve complex addition problems, but not simple addition or simple subtraction. Regarding complex subtraction, participants were more accurate to solve problems in their L2 (not expected, according to Lin, Imada, and Kuhl (2019)), but faster to solve problems in their L1 (expected). Although this result was not statistically significant, it is not in line with the hypothesis. Hence, the hypothesis is only partially confirmed, in which only the processing of complex addition problems is observed to be influenced by proficiency, partially in line with Rinsveld *et al.* (2015). This partial result is probably due to the intrinsic level of processing difficulty for each problem, where simple addition and subtraction would be easier than complex sum and, hence, proficiency would not have a significant impact.

RQ2: Are more proficient speakers of L2 better at solving simple and complex multiplication and division problems in the L2 than less proficient speakers?

H2: Participants with high proficiency in the L2 will be faster and more accurate in exact multiplication and division problems in the L2 than participants with low proficiency.

Participants with higher proficiency in their L2 were significantly faster and more accurate to solve simple multiplication problems, but not simple division or complex multiplication. Just like in RQ1, this hypothesis was only partially confirmed, since simple arithmetic problems did not yield a significantly different result. This may be due to the same intrinsic level of processing difficulty for each problem, but because complex multiplication would be more difficult than the other problems and, hence, proficiency would not have a significant impact.

RQ3: Are more proficient speakers of L2 better at solving simple and complex addition and subtraction problems in the L1 than less proficient speakers of L2?

H3: Participants with high proficiency in the L2 will be faster and more accurate in exact addition and subtraction problems in the L1 than participants with low proficiency.

The interaction between L2 proficiency and L1 arithmetic processing did not yield statistically significant results. Hence, this hypothesis was not confirmed.

RQ4: Are more proficient speakers of L2 better at solving simple and complex multiplication and division problems in the L1 than less proficient speakers of L2?

H4: Participants with high proficiency in the L2 will have faster and more accurate in exact multiplication and division problems in the L1 than participants with low proficiency.

The interaction between L2 proficiency and L1 arithmetic processing did not yield statistically significant results. Hence, this hypothesis was not confirmed.

5 CONCLUSION AND FINAL REMARKS

The aim of this chapter, in its first section, is to present a consideration of the questions that guided this study by trying to answer them having in mind the results and discussion presented in the previous chapter. The second section of this chapter aims at analyzing and discussing the limitations of this study and also gives suggestions for future research.

5.1 INSIGHTS ON NUMERICAL COGNITION THROUGH THE BILINGUAL LENS

As discussed in the review of the literature, there are many studies already in the area of numerical cognition debating whether language and numerical cognition are associated or dissociated. The main idea is to find out if humans use language as a means to store, organize, and manipulate numerical information. This debate is intriguingly reminiscent of the centuries-old question: do we think because we speak or do we speak because we think? That is, do we have the ability to process numerical information because of language or the other way around? Bilingualism can provide a plethora of new insights due to the varied nature of its population. And from the findings of this study, it is safe to argue that the answer is not a mere yes or no.

Language plays a role in the processing of exact numerical information to some extent, being dependent on other factors, such as problem complexity and language proficiency. The evidence for this claim derives from the results of this study, in which L2 proficiency had an impact on only some of the arithmetic problems. When the problems were too complex or too simple, language proficiency did not demonstrate an impact. There seems to be an optimum level of complexity in which language proficiency can have an impact on the processing of exact numerical information.

Hence, this indicates that exact numerical information could be processed independently from language at the same time that language could facilitate its processing, and, as it is known, the teaching and learning of arithmetic.

5.2 LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

While conducting the study, there were some methodological limitations encountered that should be taken into consideration. Firstly, this study was conducted during the COVID-19 pandemic, and that forced the experiment to be carried out remotely in its entirety. If conditions permitted, this would have been a lab-based experiment to better control for distracting variables such as outside noise, computer hardware and software variability, and controlled breaks. This would also generate in-person contact with the researcher and volunteer, and the questionnaires (especially the post-task questionnaire) could have generated more insightful comments from the volunteers. This is important because the participants could be tired after performing all the tasks and would not want to type any more information regarding the strategies applied to undertake the experiment. However, talking could have been a more pleasurable activity, so participants would feel more at ease at sharing that information.

By being a lengthy online experiment, with participants taking an average of 65 minutes to complete it, some other tasks were left out so participants would not be discouraged to finish the experiment. Even though the dropout rate of this study is unknown because each participant's data was only saved after they were done completing every task, if more tasks were added to the experiment, the dropout rate would be even higher, and finding volunteers to complete the experiment would be even harder. Hence, if possible, future studies should also measure participants' executive functions (such as working memory) and measure their proficiency in more depth as well, by testing more linguistic competencies.

Future studies should also measure mathematical or arithmetical aptitude. This variable was not measured in this study for the same reason as the working memory test – it would be impractical for participants and this would generate more dropout rates. This measure is important to understand the impact that mathematical aptitude might have on reaction times, and have a clearer picture of the role that proficiency might have in arithmetic processing.

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APPENDIX A – LANGUAGE AND MATHEMATICAL BACKGROUND QUESTIONNAIRE

Informe o seu e-mail:

Qual a sua idade (anos completos)?

Qual a sua nacionalidade?

Qual a sua ocupação?

Você é: ( ) canhoto ( ) destro

Sexo: ( ) masculino ( ) feminino ( ) outro

Qual o seu nível de escolaridade?
( ) Ensino Médio completo
( ) Ensino Médio incompleto
( ) Superior completo
( ) Superior incompleto
( ) Pós-graduação/Especialização (completo ou incompleto)
( ) Pós-graduaçã/Mestrado (completo ou incompleto)
( ) Pós-graduação/Doutorado (completo ou incompleto)

Além do português, quantos idiomas você fala?
( )1 ( ) 2 ( ) 3 ( ) 4+

Além do português, quais idiomas você fala?
( ) Nenhum ( ) Alemão ( ) Árabe ( ) Espanhol ( ) Francês ( ) Hindi ( ) Inglês
( ) Italiano ( ) Japonês ( ) Mandarim ( ) Polonês ( ) Russo ( ) Outro

Além do português, quantos idiomas você entende?
( )1 ( ) 2 ( ) 3 ( ) 4+

Além do português, quais idiomas você compreende?
( ) Nenhum ( ) Alemão ( ) Árabe ( ) Espanhol ( ) Francês ( ) Hindi ( ) Inglês
( ) Italiano ( ) Japonês ( ) Mandarim ( ) Polonês ( ) Russo ( ) Outro

Você se considera fluente em inglês? (É considerado fluente aquele que consegue se comunicar na segunda língua sem precisar recorrer à língua materna)
( ) sim ( ) não

Com que idade você começou a aprender inglês?

Você se sente à vontade para conversar em inglês com alguém que você não conheça?
( ) sim ( ) não

Em que contexto(s) você aprendeu inglês? (Ex.: curso no Brasil, morou no exterior)

Faça uma avaliação do seu desempenho na L2:

	Excelente	Muito bom	Bom	Regular	Ruim
Fala					
Compreensão					
Leitura					
Escrita					

Você já morou num país no qual a sua L2 seja o idioma oficial?
( ) sim ( ) não

Sobre o(s) país(es) que você já morou em que Inglês era o idioma oficial:

Onde você morou?

Quanto tempo morou lá?

Durante o tempo em que você morou no exterior, em que contexto(s) você utilizou a língua inglesa? (Ex.: em casa, na escola)

Você já teve algum tipo de instrução formal em inglês? (Ex. curso de inglês, professor particular, etc.)
( ) sim ( ) não

Sobre as aulas de Inglês que você relatou ter feito:

Por quanto tempo você frequentou as aulas?

Você continua tendo aulas de inglês?

Assinale a alternativa que mais combina com você atualmente:
( ) Comunico-me somente em português;
( ) Comunico-me essencialmente em português, e em inglês raramente;
( ) Comunico-me essencialmente em português, e em inglês ocasionalmente (Ex.: em sala de aula apenas).
( ) Comunico-me tanto em português quanto em inglês, com a mesma regularidade nas duas línguas.

Com que frequência você se encontra num ambiente onde o português e o inglês podem ser utilizados alternadamente? Assinale abaixo.
( ) O tempo todo;
( ) Quase o tempo todo;
( ) Em certas ocasiões;
( ) Raramente;
( ) Nunca.

Quantas horas por dia/semana você tem contato com o inglês? (Ex.: assistir TV – 2 horas por dia)

Em que língua você aprendeu matemática?

Com que frequência você usa a matemática (contas simples, como 20 ÷ 4) no seu dia a dia?
a) O tempo todo;
b) Quase o tempo todo;
c) Em certas ocasiões;
d) Raramente;
e) Nunca.

Você costuma fazer contas matemáticas simples de cabeça? ( ) Sim ( ) Não

Quando deparado com contas matemáticas simples, qual o seu hábito de fazê-las de cabeça ou usar o auxílio de uma calculadora?
( ) Sempre tento fazer contas de cabeça
( ) Na maioria das vezes faço contas de cabeça, mas às vezes uso a calculadora
( ) Tento fazer contas de cabeça, mas uso a calculadora na metade das vezes
( ) Uso a calculadora na maioria das vezes
( ) Sempre uso a calculadora

A sua ocupação exige que você faça contas frequentemente? ( ) Sim ( ) Não

Você se considera bom em fazer cálculos de cabeça? ( ) Sim ( ) Não

Com que frequência você faz cálculos de cabeça <u>em inglês</u>?
a) O tempo todo;
b) Quase o tempo todo;
c) Em certas ocasiões;
d) Raramente;
e) Nunca.

Faça uma avaliação do seu desempenho em fazer contas de cabeça em inglês:
( ) Excelente;
( ) Muito bom;
( ) Bom;
( ) Regular;
( ) Ruim.

APPENDIX B – TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO (TCLE)

Completion Progress

Participação em Experimento de Processamento Aritmético Bilíngue
Termo de Consentimento Livre e Esclarecido (TCLE) baseado na resolução 510/2016
de acordo com o CNS (Conselho Nacional de Saúde)

UNIVERSIDADE FEDERAL DE SANTA CATARINA
CENTRO DE COMUNICAÇÃO E EXPRESSÃO
PROGRAMA DE PÓS-GRADUAÇÃO EM INGLÊS
LABLING – LABORATÓRIO DA LINGUAGEM E PROCESSOS COGNITIVOS

Se desejar, use a função "imprimir" do seu navegador
para gerar uma cópia desse documento.

Caro (a) participante,

Eu, João Luiz Coelho, aluno de mestrado no Programa de Pós-Graduação em Inglês: Estudos Linguísticos e Literários da Universidade Federal de Santa Catarina, orientado pela Professora Dra. Mailce Borges Mota, gostaria de convidá-lo(a) a participar da minha pesquisa, intitulada "Forty-one mais vinte e quatro: Uma Investigação sobre o Processamento Aritmético em Bilíngues tardios com Proficiência alta e baixa".

O objetivo da pesquisa é investigar o impacto da proficiência na segunda língua (inglês) quando adultos resolvem problemas aritméticos simples e complexos. Peço que você leia este formulário de consentimento e que, antes de concordar em participar do estudo, tire todas as dúvidas que possam surgir.

A coleta de dados se dará de maneira remota, em algum computador que você tiver a seu dispor. Se você concordar em participar deste estudo, você será solicitado(a) a responder um questionário de contexto de aprendizagem de línguas e de matemática, realizar um teste de proficiência e uma tarefa de processamento aritmético bilíngue. Todas as tarefas serão feitas por você de maneira assíncrona, quando houver disponibilidade de tempo. No questionário, você será convidado a responder perguntas sobre alguns dados pessoais, de aprendizagem de línguas e de aprendizagem de matemática (por exemplo, idade, sexo, escolaridade, hábitos com a segunda língua e em que contexto aprendeu matemática). Nenhuma pergunta do questionário é obrigatória, reservando o seu direito de não responder qualquer questão, sem necessidade de explicação ou justificativa para tal. No teste de proficiência, você realizará atividades de leitura, escuta e escrita, que durará aproximadamente 30 minutos. Na tarefa de processamento aritmético bilíngue, você ouvirá problemas aritméticos simples (2 + 2) e complexos (21 - 3) de adição, subtração, multiplicação e divisão, e deverá escolher a alternativa correta entre duas que aparecerão na tela, ao pressionar suas respectivas teclas no teclado. Seu tempo de resposta será registrado automaticamente. Esta tarefa terá duração aproximada de 30 minutos.

Em decorrência da participação nesta pesquisa, você pode estar exposto(a) a eventuais riscos, mesmo que baixos, tais como nervosismo, constrangimento, cansaço ou aborrecimento inerentes a qualquer situação de avaliação. Para minimizar esses riscos sessões de prática serão feitas antes da realização da tarefa de processamento aritmético bilíngue para que você possa se familiarizar com os procedimentos. O experimento será dividido em blocos e você pode descansar um pouco entre eles. Outro risco existente é de outras pessoas terem acesso aos seus dados (quebra de sigilo) contra a vontade dos pesquisadores responsáveis. Para evitar que isso aconteça, quatro medidas serão tomadas. Primeiramente, a coleta de dados será conduzida de maneira individual, somente um participante por vez. Todos os dados, incluindo os que contém informações pessoais, serão armazenados em uma mídia física no Laboratório da Linguagem e Processos Cognitivos (LabLing). Os dados que contém os resultados dos testes conduzidos e experimentos feitos serão categorizados com códigos alfanuméricos (como P21041501), de maneira que não será possível identificar os participantes. É importante ressaltar que esses dados codificados, e somente eles, serão publicados em um repositório online para aferição de outros pesquisadores e transparência na prática científica. Nenhum dado pessoal seu será publicado.

Como consequência inevitável da participação neste estudo, você receberá o resultado de seu teste de proficiência em língua inglesa, o que pode ajudá-lo a conhecer mais sobre suas habilidades na língua. O estudo também trará benefícios para a área da psicolinguística, adicionando evidências sobre a associação ou dissociação entre bilinguismo e cognição numérica.

Você não pode receber nenhum valor financeiro por participar desta pesquisa, mas, se você tiver alguma despesa por participar da pesquisa, terá direito a ressarcimento do valor gasto. Se você tiver qualquer custo extra com internet enquanto estiver fazendo as atividades da pesquisa, vamos nos responsabilizar pela despesa com internet. Caso venha sofrer qualquer prejuízo, material ou imaterial, comprovadamente decorrente de sua participação nesta pesquisa, você será indenizado de acordo com a legislação vigente. Os pesquisadores estarão à disposição para esclarecimentos antes, durante e depois da pesquisa. Você tem assegurada a liberdade de desistir de participar a qualquer momento do estudo, sem nenhuma penalização.

Somente os pesquisadores responsáveis terão acesso aos seus dados pessoais e tomaremos todas as medidas cabíveis para não revelar a sua identidade. Utilizaremos códigos para identificar seus dados, ao invés do seu nome (por exemplo, P21041501). Os dados armazenados digitalmente serão acessados apenas pelos pesquisadores responsáveis pelo estudo. Dados físicos (como registros de acompanhamento de coleta de dados) serão guardados em armário chaveado no LabLing. Somente os pesquisadores responsáveis terão acesso às chaves dos armários. Os resultados desta pesquisa serão divulgados em eventos ou publicações científicas sem qualquer identificação dos participantes. Seus dados serão codificados e serão analisados em conjunto com os dados de outros participantes, sem qualquer identificação pessoal. Você pode ter acesso aos resultados da pesquisa a qualquer momento entrando em contato com os pesquisadores.

Para assegurar rigor metodológico e garantir transparência na ciência, este estudo está pré-registrado na plataforma Open Science Framework (OSF). Isso significa que alguns detalhes do estudo, como o seu objetivo, as perguntas de pesquisa e hipóteses, a natureza e desenho do estudo, os procedimentos de coleta de dados, as variáveis a serem medidas e analisadas e o plano de análise estatística estão disponíveis de maneira pública na internet. Além disso, os dados coletados, após serem anonimizados e codificados para garantir que os participantes não sejam identificados, serão disponibilizados na mesma plataforma, OSF, para garantir uma prática transparente e reprodutível. O presente estudo pretende publicar os seguintes dados obtidos: tempos de reação dos participantes para cada estímulo em milissegundos, acurácia na resolução de cada problema aritmético codificado em 0 ou 1, escore de cada habilidade no teste de proficiência de acordo com o Quadro Comum Europeu de Referência para Línguas (CEFR), a idade de aquisição da L2, em anos (por exemplo, 14 anos), e a média e desvio padrão da idade dos participantes, em anos. Caso alguma outra variável analisada demonstre capacidade de explicar estatisticamente os resultados (por exemplo, a frequência com que o participante faz cálculos mentais no dia a dia), esses dados serão também incluídos na publicação. Porém, caso a variável permita de alguma maneira identificar os participantes, esses dados não serão incluídos na publicação de dados. Nenhum dado pessoal seu será publicado.

Os procedimentos metodológicos adotados obedecem aos preceitos éticos implicados em pesquisas envolvendo seres humanos, conforme normatizado pela Resolução do Conselho Nacional de Saúde nº 510 de 07 de abril de 2016, que dispõe sobre as normas aplicáveis a pesquisas em Ciências Humanas e Sociais. Os pesquisadores também aderem a esse documento e comprometem-se a conduzir a pesquisa de acordo com o que preconiza a referida Resolução. Além disso, garantimos o cumprimento da Lei Geral de Proteção de Dados ((13.709/2018) com relação à proteção de seus dados pessoais, bem como do Ofício Circular Nº 2/2021/CONEP/SECNS/MS, que trata de pesquisas com etapas em ambientes virtuais, como é o caso de nosso estudo.

Você tem o direito de revogar a utilização e publicação dos seus dados em qualquer momento, mesmo após concordar com este termo. Para revogar a utilização dos seus dados ou sanar quaisquer dúvidas, você pode entrar em contato com João Luiz Coelho, pelo e-mail joaocoelho.tdm@gmail.com ou pelo telefone (48) 999859498, ou com a professora Dra. Mailce Borges Mota através do e-mail mailce.mota@ufsc.br, telefone (48) 3721-3792, ou no prédio do Centro de Comunicação e Expressão – CCE, bloco B, sala 513, Universidade Federal de Santa Catarina, UFSC.

Esta pesquisa foi avaliada e aprovada pelo Comitê de Ética em Pesquisa com Seres Humanos (CEPSH) da UFSC. O CEPSH é um órgão colegiado interdisciplinar, deliberativo, consultivo e educativo, vinculado à Universidade Federal de Santa Catarina, mas independente na tomada de decisões, criado para defender os interesses dos participantes da pesquisa em sua integridade e dignidade e para contribuir no desenvolvimento da pesquisa dentro de padrões éticos. Caso você tenha alguma dúvida ou reclamação quanto à condução ética dessa pesquisa, você pode entrar em contato com o CEPSH – UFSC. Endereço: Prédio da Reitoria II, 4º andar, sala 401, Rua Desembargador Vitor Lima, nº222, Trindade, CEP 88040-400, Florianópolis-SC. Telefone: (48) 3721-6094. E-mail: cep.propesq@contato.ufsc.br.

Após a leitura do presente termo e de sua concordância em participar do estudo, solicitamos que informe seu consentimento na próxima pergunta deste questionário online. Sua participação somente ocorrerá se você concordar com este termo. Uma via desse termo será enviada para o e-mail informado nesse questionário para que você também tenha acesso futuro a esse documento. Este é um documento importante que traz informações de contato e garante os seus direitos como participante da pesquisa, por isso solicitamos que o guarde. Você terá acesso ao registro do seu consentimento sempre que solicitado.

- ○ Concordo em participar de maneira voluntária na pesquisa 'Forty-one mais vinte e quatro: Uma Investigação sobre o Processamento Aritmético em Bilíngues tardios com Proficiência alta e baixa', de autoria de João Luiz Coelho.
- ○ Eu não concordo em participar da pesquisa.

próximo

APPENDIX C – STIMULI LIST

first argumen t	operation	second argument	condition	correct answer	distractor	criterion to distractor	list 1	list 2	list 3	list 4
6	+	9	simple_sum	15	13	-2 in correct answer	EN_F	EN_M	PT_F	PT_M
3	+	7	simple_sum	10	9	-1 in correct answer	EN_F	EN_M	PT_F	PT_M
8	+	9	simple_sum	17	18	+1 in correct answer	EN_F	EN_M	PT_F	PT_M
4	+	9	simple_sum	13	11	-2 in correct answer	EN_M	PT_F	PT_M	EN_F
5	+	8	simple_sum	13	12	-1 in correct answer	EN_M	PT_F	PT_M	EN_F
4	+	8	simple_sum	12	11	-1 in correct answer	EN_M	PT_F	PT_M	EN_F
2	+	7	simple_sum	9	11	+2 in correct answer	PT_F	PT_M	EN_F	EN_M
7	+	9	simple_sum	16	18	+2 in correct answer	PT_F	PT_M	EN_F	EN_M
3	+	9	simple_sum	12	13	+1 in correct answer	PT_F	PT_M	EN_F	EN_M
5	+	9	simple_sum	14	15	+1 in correct answer	PT_M	EN_F	EN_M	PT_F
7	+	8	simple_sum	15	17	+2 in correct answer	PT_M	EN_F	EN_M	PT_F
6	+	8	simple_sum	14	12	-2 in correct answer	PT_M	EN_F	EN_M	PT_F
8	-	5	simple_subtraction	3	4	+1 in correct answer	EN_F	EN_M	PT_F	PT_M
9	-	4	simple_subtraction	5	4	-1 in correct answer	EN_F	EN_M	PT_F	PT_M
9	-	2	simple_subtraction	7	9	+2 in correct answer	EN_F	EN_M	PT_F	PT_M
8	-	6	simple_subtraction	2	1	-1 in correct answer	EN_M	PT_F	PT_M	EN_F
7	-	4	simple_subtraction	3	4	+1 in correct answer	EN_M	PT_F	PT_M	EN_F
9	-	3	simple_subtraction	6	8	+2 in correct answer	EN_M	PT_F	PT_M	EN_F
8	-	3	simple_subtraction	5	7	-2 in correct answer	PT_F	PT_M	EN_F	EN_M
9	-	7	simple_subtraction	2	1	-1 in correct answer	PT_F	PT_M	EN_F	EN_M
9	-	5	simple_subtraction	4	2	-2 in correct answer	PT_F	PT_M	EN_F	EN_M
8	-	2	simple_subtraction	6	7	+1 in correct answer	PT_M	EN_F	EN_M	PT_F
9	-	6	simple_subtraction	3	1	-2 in correct answer	PT_M	EN_F	EN_M	PT_F

8	-	7	simple_subtraction	1	3	+2 in correct answer	PT_M	EN_F	EN_M	PT_F
8	x	2	simple_multiplication	16	15	-1 in correct answer	EN_F	EN_M	PT_F	PT_M
9	x	2	simple_multiplication	18	19	-1 in correct answer	EN_F	EN_M	PT_F	PT_M
7	x	3	simple_multiplication	21	22	+1 in correct answer	EN_F	EN_M	PT_F	PT_M
8	x	3	simple_multiplication	24	26	+2 in correct answer	EN_M	PT_F	PT_M	EN_F
8	x	4	simple_multiplication	32	22	-10 in correct answer	EN_M	PT_F	PT_M	EN_F
9	x	4	simple_multiplication	36	32	-2 in correct answer	EN_M	PT_F	PT_M	EN_F
7	x	4	simple_multiplication	28	29	+1 in correct answer	PT_F	PT_M	EN_F	EN_M
8	x	5	simple_multiplication	40	42	+2 in correct answer	PT_F	PT_M	EN_F	EN_M
7	x	6	simple_multiplication	42	52	+10 in correct answer	PT_F	PT_M	EN_F	EN_M
9	x	6	simple_multiplication	54	64	+10 in correct answer	PT_M	EN_F	EN_M	PT_F
8	x	7	simple_multiplication	56	54	-2 in correct answer	PT_M	EN_F	EN_M	PT_F
9	x	7	simple_multiplication	63	53	-10 in correct answer	PT_M	EN_F	EN_M	PT_F
6	db	2	simple_division	3	1	-2 in correct answer	EN_F	PT_M	PT_F	EN_M
8	db	2	simple_division	4	6	+2 in correct answer	EN_M	EN_F	PT_M	PT_F
6	db	3	simple_division	2	1	-1 in correct answer	PT_F	EN_M	EN_F	PT_M
8	db	4	simple_division	2	3	+1 in correct answer	PT_M	PT_F	EN_M	EN_F
9	db	3	simple_division	3	5	+2 in correct answer	EN_F	PT_M	PT_F	EN_M
4	db	2	simple_division	2	1	-1 in correct answer	EN_F	PT_M	PT_F	EN_M
12	x	7	complex_multiplication	84	96	+1 in second operand	EN_F	EN_M	PT_F	PT_M
38	x	2	complex_multiplication	76	86	+10 in correct answer	EN_F	EN_M	PT_F	PT_M
29	x	3	complex_multiplication	87	58	-1 in second operand	EN_F	EN_M	PT_F	PT_M
27	x	3	complex_multiplication	81	84	+1 in first operand	EN_M	PT_F	PT_M	EN_F
35	x	2	complex_multiplication	70	68	-1 in first operand	EN_M	PT_F	PT_M	EN_F

12	x	8	complex_multiplication	96	86	-10 in correct answer	EN_M	PT_F	PT_M	EN_F
34	x	2	complex_multiplication	68	78	+10 in correct answer	PT_F	PT_M	EN_F	EN_M
45	x	2	complex_multiplication	90	88	-1 in first operand	PT_F	PT_M	EN_F	EN_M
12	x	5	complex_multiplication	60	72	+1 in second operand	PT_F	PT_M	EN_F	EN_M
43	x	2	complex_multiplication	86	76	-10 in correct answer	PT_M	EN_F	EN_M	PT_F
26	x	3	complex_multiplication	78	52	-1 in second operand	PT_M	EN_F	EN_M	PT_F
39	x	2	complex_multiplication	78	80	+1 in first operand	PT_M	EN_F	EN_M	PT_F
96	db	8	complex_division	12	13	+1 in correct answer	EN_F	EN_M	PT_F	PT_M
98	db	7	complex_division	14	24	+10 in correct answer	EN_F	EN_M	PT_F	PT_M
78	db	6	complex_division	13	12	-1 in correct answer	EN_F	EN_M	PT_F	PT_M
80	db	5	complex_division	16	26	+10 in correct answer	EN_M	PT_F	PT_M	EN_F
60	db	4	complex_division	15	14	-1 in correct answer	EN_M	PT_F	PT_M	EN_F
54	db	3	complex_division	18	19	+1 in correct answer	EN_M	PT_F	PT_M	EN_F
78	db	2	complex_division	39	29	-10 in correct answer	PT_F	PT_M	EN_F	EN_M
84	db	7	complex_division	12	14	+2 in correct answer	PT_F	PT_M	EN_F	EN_M
90	db	6	complex_division	15	5	-10 in correct answer	PT_F	PT_M	EN_F	EN_M
76	db	4	complex_division	19	17	-2 in correct answer	PT_M	EN_F	EN_M	PT_F
78	db	3	complex_division	26	24	+2 in correct answer	PT_M	EN_F	EN_M	PT_F
96	db	2	complex_division	48	46	-2 in correct answer	PT_M	EN_F	EN_M	PT_F
13	+	7	complex_sum	20	10	-10 in correct answer	EN_F	EN_M	PT_F	PT_M
29	+	5	complex_sum	34	33	-1 in correct answer	EN_F	EN_M	PT_F	PT_M
32	+	9	complex_sum	41	40	-1 in correct answer	EN_F	EN_M	PT_F	PT_M
37	+	5	complex_sum	42	44	+2 in correct answer	EN_M	PT_F	PT_M	EN_F

42	+	9	complex_sum	51	52	+1 in correct answer	EN_M	PT_F	PT_M	EN_F
24	+	7	complex_sum	31	41	+10 in correct answer	EN_M	PT_F	PT_M	EN_F
59	+	2	complex_sum	61	62	+1 in correct answer	PT_F	PT_M	EN_F	EN_M
68	+	5	complex_sum	73	63	-10 in correct answer	PT_F	PT_M	EN_F	EN_M
72	+	9	complex_sum	81	79	-2 in correct answer	PT_F	PT_M	EN_F	EN_M
79	+	3	complex_sum	82	92	+10 in correct answer	PT_M	EN_F	EN_M	PT_F
85	+	7	complex_sum	92	94	+2 in correct answer	PT_M	EN_F	EN_M	PT_F
25	+	9	complex_sum	34	32	-2 in correct answer	PT_M	EN_F	EN_M	PT_F
93	-	7	complex_subtraction	86	87	+1 in correct answer	EN_F	EN_M	PT_F	PT_M
82	-	9	complex_subtraction	73	75	+2 in correct answer	EN_F	EN_M	PT_F	PT_M
74	-	5	complex_subtraction	69	68	-1 in correct answer	EN_F	EN_M	PT_F	PT_M
62	-	4	complex_subtraction	58	68	+10 in correct answer	EN_M	PT_F	PT_M	EN_F
51	-	8	complex_subtraction	43	42	-1 in correct answer	EN_M	PT_F	PT_M	EN_F
47	-	9	complex_subtraction	38	48	+10 in correct answer	EN_M	PT_F	PT_M	EN_F
35	-	6	complex_subtraction	29	19	-10 in correct answer	PT_F	PT_M	EN_F	EN_M
37	-	9	complex_subtraction	28	26	-2 in correct answer	PT_F	PT_M	EN_F	EN_M
91	-	7	complex_subtraction	84	74	-10 in correct answer	PT_F	PT_M	EN_F	EN_M
85	-	6	complex_subtraction	79	81	+2 in correct answer	PT_M	EN_F	EN_M	PT_F
71	-	9	complex_subtraction	62	60	-2 in correct answer	PT_M	EN_F	EN_M	PT_F
63	-	9	complex_subtraction	54	55	+1 in correct answer	PT_M	EN_F	EN_M	PT_F