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Bimodal Bilingualism and Executive Functions: Possible Effects on Inhibition, Planning, and Working Memory

Bilingüismo bimodal y funciones ejecutivas: posibles efectos sobre la inhibición, la planificación y la memoria de trabajo

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Abstract

Scientific research has demonstrated that unimodal bilingualism (two spoken languages) has positive effects on executive control. However, few studies have explored the influence of bimodal bilingualism (spoken language and sign language) on executive functions. This study explores differences between monolinguals, unimodal bilinguals, and bimodal bilinguals in terms of inhibition, planning, and working memory. A total of 80 participants aged between 18 and 40 years were evaluated using executive function tasks designed to measure inhibition (verbal Stroop, nonverbal Stroop, verbal Simon, nonverbal Simon), planning (Tower of Hanoi), and working memory (Digits, Letters-Numbers, Visuospatial Span task, Letters-Figures). The results reveal that unimodal bilinguals have certain advantages over monolinguals in inhibition, planning, and working memory, although these advantages were not observed among bimodal bilinguals in relation to the executive functions explored.

Keywords: bilingualism, unimodal, bimodal, sign language, executive functions

Resumen

La evidencia científica muestra que el bilingüismo unimodal (dos lenguas orales) tiene efectos positivos sobre el control ejecutivo. Sin embargo, pocos estudios han investigado la influencia del bilingüismo bimodal (una lengua oral y una lengua de signos) sobre las funciones ejecutivas. Este estudio explora las diferencias entre monolingües, bilingües unimodales y bilingües bimodales en cuanto a inhibición, planificación y memoria de trabajo. Se evaluaron las funciones ejecutivas de un total de 80 participantes de entre 18 y 40 años, empleando tareas de inhibición (Stroop verbal, Stroop no verbal, Simon verbal y Simon no verbal), de planificación (Torre de Hanoi) y de memoria de trabajo (Dígitos, Letras-Números, Tarea de Span Visoespacial, Letras-Figuras). Los resultados muestran que los bilingües unimodales presentan ciertas ventajas sobre los monolingües en cuanto a inhibición, planificación y memoria de trabajo, que no se dan en los bilingües bimodales respecto a las funciones ejecutivas exploradas.

Palabras clave: bilingüismo, unimodal, bimodal, lengua de signos, funciones ejecutivas

INTRODUCTION

Research into the possible advantages of bilingualism has piqued the interest of researchers in recent years; however, most studies analyze unimodal bilingualism (two spoken languages) and focus less on bimodal bilingualism (spoken language and sign language). Current research has demonstrated that unimodal bilinguals (UBs) surpass monolinguals (MLs) in a series of executive function (EF) tasks (Quinteros Baumgart & Billick, 2018). In this paper, we will focus on analyzing the differences between bilinguals and monolinguals in inhibition, planning, and working memory (WM).

1. Theoretical background

Bilingualism can be defined as the ability to effectively use two languages for communication; however, since fluency in each language can vary, some researchers do not consider bilingualism to be a categorical variable (Luk & Bialystok, 2013). Consequently, Bialystok (2018) recommends that any interpretation of the results reported by studies on bilingualism take into account the criteria used for designating the bilingual and monolingual groups. In this study, the bilingual advantage is explored by dividing the sample into three groups, based on the information on linguistic competence provided by participants in a language use questionnaire. Only those with a self-rated linguistic competence of at least 7 out of 10 in both languages were considered bilinguals.

The bilingual advantage hypothesis states that bilingualism leads to enhanced executive function abilities motivated by the constant use of two languages (Antón et al., 2018). Consequently, UBs outperform MLs in those abilities (Van den Noort et al., 2019). Executive functions (EFs) encompass, among other abilities, inhibition (the ability to suppress a predominant, automatic response in favor of a subdominant response), planning (the ability to sequence multistep tasks, prioritize information, and execute an organized response), shifting (also called flexibility, the ability to shift between mental sets, tasks, and goals), sustained attention (the ability that allows the persistence of responses and continuous effort over long periods of time), and working memory (the ability to retain and manipulate information stored in memory for a short time while doing something with it) (Friedman & Miyake, 2017).

According to Bialystok (2011), bilingualism affects the brain through the constant activation of two languages, even in purely monolingual contexts (see Kroll et al., 2015, for a review). It has been observed that both languages spoken by a UB individual are activated even when only one of them is used in a particular moment (Linck et al., 2008), and this effect has been detected even when the languages belong to different modalities (e.g., deaf bilinguals activate signs while processing the written words of a spoken language) (Morford et al., 2011). The parallel activation of both languages generates a conflict in UBs' attention that does not occur among MLs. UBs have to exert efficient language control to update the demands of the context as well as the speakers and to switch between languages, inhibiting the nontarget language (Kroll et al., 2012). In this process, UBs must make use of EFs and this is the reason for the bilingual advantage (Anton et al., 2018).

A recent systematic review (Van den Noort et al., 2019) found that the majority of studies (54.3%) focusing on this question reported positive evidence of the bilingual advantage (even more so when participants were adults than when they were children): 28.3% found mixed results and only 17.4% found no evidence of this effect.

Consistently with the theory of the bilingual advantage, Bialystok et al. (2004) found that UB adults outperformed ML adults in controlled processing (smaller Simon task effect cost and faster response in conditions with greater demands on working memory). Bialystok (2006) and Bialystok and Depape (2009) also found that UB adults were faster than ML adults in attention control. Furthermore, in a study exploring the effect of age on the bilingual advantage, Bialystok et al. (2008) discovered that UB adults performed better than ML adults in EF tasks (Simon task, Stroop task, sustained attention to response task), and that this advantage was even greater in the older age group.

However, the bilingual advantage is an object of debate today since some researchers argue that it is nothing more than a mere consequence of uncontrolled external factors and small sample sizes (Antón et al., 2018; Morton & Harper, 2007; Hilchey & Klein, 2011; Paap et al., 2015, 2016). For example, it has been observed that participants' socioeconomic status (SES), immigrant status or ethnic background may play a role in the differences in EFs observed between UBs and MLs (Anton et al., 2018; Papageorgiou et al., 2018; Van den Noort, et al., 2019). Studies focusing on this topic should therefore control for all these variables, as we have done in this study.

Nonetheless, it is not only the characteristics of the participants that need to be considered when exploring the bilingual advantage; the characteristics of the tasks themselves must also be taken into account. The advantages of bilingualism are especially evident under certain conditions, such as in nonverbal tasks and those that demand greater use of EFs (Bialystok et al., 2008; Pelham & Abrams, 2014; Ye et al., 2017). For example, Ye et al. (2017) found that monitoring was more developed among UBs, but only in tasks requiring a lot of attention; they also observed that UBs outperformed MLs in nonverbal tasks. Conversely, the performance of UBs in verbal tasks was poorer than that of MLs (Bialystok et al., 2008; Pelham & Abrams, 2014).

Developmental stage may also have an impact on performance, mediated by the type of task in question. Most of the bilingual benefits observed among children and older adults are linked to simple tasks, whereas in young adults these benefits only appear in more complex tasks (Ye et al., 2017). Additionally, some studies argue that the age at which the second language was acquired is not particularly important; for example, Pelham and Abrams (2014) found UB advantages in attentional control in both native bilinguals and late bilinguals (i.e., those who learned their second language after the age of 13 years).

Regarding the tasks on which the present study focuses, some authors have found significant differences between MLs and UBs in inhibition when using tasks such as Stroop (Bialystok et al., 2008; Bialystok & Depape, 2009; Blumenfeld & Marian, 2011, 2013; Kousaie et al., 2014) and Simon (Bialystok, 2006; Bialystok et al., 2008; Bialystok & Depape, 2009; Bialystok et al., 2004; Woumans et al., 2015), which favor the latter group. For example, Blumenfeld and Marian (2011) evaluated MLs (*n* = 30; mean age 21.4) and UBs (*n* = 30; mean age 22; who had learned their second language before the age of 8 years) using nonverbal Stroop tasks. The results indicated that UBs performed better than MLs in terms of number of correct responses. In another study, Bialystok et al. (2004) conducted three experiments using nonverbal Simon tasks, comparing younger and older ML and UB adults (mean age 41.25 and 71.1, respectively). In general, UBs outperformed MLs in all three experiments, demonstrating lower response times (especially in incongruence), lower inhibition costs, and better WM.

However, not all studies have observed this difference between MLs and UBs in EFs using Stroop and Simon tasks (Antón et al., 2018; Kousaie et al., 2014; Papageorgiou et al., 2018). For example, Kousaie et al. (2014) failed to observe any advantage of UBs over MLs in inhibitory control when using nonverbal Simon and verbal Stroop tasks; likewise, Papageorgiou et al. (2018) reported similar results using nonverbal Simon tasks. Specifically, Kousaie et al. (2014) used a sample of young (70 MLs and 51 UBs; MLs mean age 21.64; UBs mean age 21.49) and older adults (61

MLs and 36 UBs; MLs mean age 72.43; UBs mean age 70.69) and, despite finding UBs to have a certain advantage over MLs in terms of the interference caused by the Stroop effect, this advantage did not transfer to nonverbal Simon tasks. The authors justify this finding by arguing that the ML samples were not as monolingual as they would have liked and, moreover, that other contextual variables (such as conducting the evaluation in different places and even with different laptops) or certain cultural aspects (such as the type of bilingualism to which their participants were exposed—both languages used in most situations, as opposed to other bilingual cultures in which the two languages are generally used in different contexts) may have had an influence. Another study, Papageorgiou et al. (2018) used nonverbal Simon tasks in a sample of 37 MLs and 37 UBs, both groups with a mean age of 70 years and similar distributions in terms of age, gender, and SES, finding no advantage of bilingualism. In this case, the authors attributed this null effect to the fact that the mean age at which the second language was learned in the UB group was high (15 years) and that participants used English most of the time, meaning that they were not forced to make an effort to switch between languages. This finding can also be attributed to the complexity of the task and participants' advanced age. Consistently with the aforementioned results reported by Ye et al. (2017), at an advanced age the bilingual advantage would only emerge in simple tasks.

In an analysis of 90 MLs (mean age 21.84) and 90 UBs (mean age 22.29), Antón et al. (2018) found no significant differences in performance in nonverbal Simon and verbal Stroop tasks. However, after systematic bootstrapping analyses, the authors found that bilingual advantages in EF tasks (nonverbal Simon task, verbal Stroop task, numerical Stroop task, and Flanker task) occurred more frequently in small samples and when the groups were significantly different in terms of memory and sociodemographic factors, especially SES (with higher scores among UBs).

The Tower of Hanoi is frequently used to measure planning and problem-solving skills; however, few studies have explored the effects of bilingualism on planning skills. One such study is the paper by Festman et al. (2010), which used a four-disk and five-disk Tower of Hanoi to compare the planning performance of two groups of UBs: bilinguals with strong language control abilities (*non-switchers*) (n = 13) and those with weaker language control abilities (*switchers*) (n = 16). Language control abilities were evaluated using a bilingual picture naming task. The participants spoke Russian and German and had learned their second language at an average age of 11.4 years. The analyses indicated that non-switcher bilinguals used significantly fewer movements and made fewer mistakes compared to their switcher counterparts. According to the authors, differences in language level are the most likely cause of the differences observed in language control.

Naeem et al. (2018) compared the planning skills of UBs and MLs using the Tower of London task, finding, contrary to what was expected, a monolingual advantage; and in another study, Papageorgiou et al. (2018) observed that MLs responded faster than UBs. According to the authors, these results refute the hypothesis of the bilingual advantage and are more consistent with the argument positing that bilingual advantages are in fact linked to socioeconomic factors.

Few studies have specifically sought to analyze the effects of bilingualism on WM, although some authors have observed a higher WM capacity (auditory memory and visuospatial memory) in UBs than in MLs (Bialystok et al., 2004; Blom et al., 2014; Kazemeini & Fadardi, 2016). Bialystok et al. (2004) examined the performance of young and old MLs and UBs in a version of the Simon task with different levels of difficulty, finding that the increase in WM load was handled better by UBs than by MLs. Regarding auditory memory, in their analysis of university students (30 UBs and 30 MLs; mean age 25.90) using the Backward Digit Span Test from the Wechsler Intelligence Scale for Adults (Wechsler, 1981). Kazemeini and Fadardi (2016) noticed a higher WM capacity in UBs than in MLs. In another study, Blom et al. (2014) observed the same advantage in children, in both auditory working memory (Backwards Digit Recall) and visuospatial working memory (Dot Matrix task). Their sample comprised 68 UB and 52 ML children aged 6 years, and they controlled for SES and language level.

Additional studies, however, such as the ones by Kousaie et al. (2014) (carried out with younger and older adults) and Papageorgiou et al. (2018) (conducted with older adults) found no significant differences between MLs and UBs in either auditory WM tasks (Digit Span Forward and Backwards) or visuospatial WM (evaluated using Change Blindness in the case of Papageorgiou et al., 2018).

Bialystok et al. (2014) compared the WM of two ML groups (youth: *n* = 36, mean age 21.4; elderly: *n* = 18, mean age 72.4), and two UB groups (youth: *n* = 36, mean age 20.2; elderly *n* = 18, mean age 69.1), differentiating between verbal (letters) and nonverbal (figures) tasks of equivalent cognitive complexity. Their results revealed that UBs had a certain advantage in figures but not in letters, and the authors argued that the figures task may have been more difficult to resolve than the letters one. Their findings on the bilingual advantage in nonverbal tasks were consistent with those reported by previous studies (Luo et al., 2013; Ye et al., 2017).

In the case of bimodal bilinguals (BBs), or in other words, those able to communicate effectively in both a spoken and a sign language, the two languages acquired involve different motor and perceptual systems. Each language is perceived by a different sensory system (it is either auditory or visually perceived) and produced using a different output channel (motor system or vocal tract). Furthermore, as in the case of unimodal bilingualism, the two languages have different syntactical rules, different lexicons, and different phonological systems (Sandler & Lillo-Martin, 2006). BBs also have to control what language must be used at any given time, subduing signs when speaking to nonsigners and subduing words when speaking to signers. However, this control is less strict in the case of BBs than in the case of UBs, since among BBs code-blending (i.e., the simultaneous production of signs and words) is frequent (Casey & Emmorey, 2008; Emmorey et al., 2008a). BBs are therefore a natural experimental group for determining whether the bilingual advantage for executive control stems from only being bilingual (i.e., from being fluent in two language systems) or from the specific need to attend to and discriminate between two spoken languages of the same modality (i.e., from the need to select only one language for production).

Despite theoretical and practical interest in examining the bilingual advantage for EFs among BBs, few studies have focused on this topic. One of them was carried out by Emmorey et al. (2008b), who evaluated a sample of 45 participants divided into MLs, UBs, and BB CODAs (Children of Deaf Adults), using a block of Flanker tasks. In contrast to UBs, BBs did not differ from MLs in either number of correct responses or reaction time. Emmorey et al. (2008b) attributed this lack of difference to the fact that the bilingual advantage occurs only with two languages in the same modality. According to their theory, UBs have greater control over interferences between one language and the other than BBs, since their two oral languages cannot be produced simultaneously. In contrast, BBs can, to a certain extent, simultaneously produce their two languages, because they belong to different modalities.

However, Shook and Marian (2012) observed in BBs that the phonological systems of two languages from different modalities were activated in parallel, meaning that interference between them was also generated. This study recorded the eye movements of 13 BBs—English and American Sign Language (ASL)—and 13 English MLs during a visual task. In critical trials, participants were shown a screen with four images: a target; a competitor whose ASL sign coincided phonologically with the target in three of the four parameters of sign language (handshape, movement, location, and palm orientation); and two distractors whose labels did not overlap with either the target or the competitor in either ASL or English phonology. Participants were verbally instructed to select an object on the screen by clicking on the one that best represented the target word. The analyses indicated that BBs looked more at competitor elements than distractor elements than their ML counterparts, despite the fact that the instructions were given orally.

These results are consistent with those found by Morford et al. (2011) and Villameriel et al. (2016). Morford et al. (2011) observed cross-language activation in 19 deaf BBs (ASL was their first language and English their second language). Participants had to judge the semantic relatedness of word pairs written in English and the results revealed that the phonological relationship between the equivalent signs of the English words influenced their reaction times for the semantic judgements. When the corresponding signs had commonalities in their form, less time was required for the semantic judgements when the word pairs in question were semantically related, whereas more time was required for semantically unrelated pairs. Consequently, phonological relations between signs produced a facilitation effect for the semantic judgement of related words, but an inhibitory effect for unrelated words.

A similar study was conducted by Villameriel et al. (2016), who recruited 20 Spanish MLs and 20 BB CODAs (Spanish and Spanish Sign Language - LSE) for a first experiment, and 40 Spanish MLs and 40 late BBs (who had learned LSE after the age of 18) for a second experiment. All BBs were LSE interpreters with at least two years of experience when the study was conducted. In both experiments, participants performed a semantic decision task, listening to pairs of words in Spanish and responding by pushing one of two buttons, depending on whether the words had a semantic relationship or not. Half of the word pairs had a semantic relationship and the rest did not. Within each semantic condition, half of the pairs associated with LSE signs had a phonological relationship and the other half did not. The analyses revealed that when the words were semantically related, the BB sample (CODAs and late BBs) had shorter response times with pairs of words that had a phonological relationship in LSE than with pairs of words that did not. However, when the pairs of words were not semantically related, the two BB groups had longer response times in pairs of words that had a phonological relationship in LSE. These effects were not observed in the ML groups.

In sum, the results reported by Morford et al. (2011), Shook and Marian (2012) and Villameriel et al. (2016) indicate that two languages from different modalities are activated simultaneously, regardless of the age at which the sign language was acquired or which language is dominant. This parallel activation of both languages may therefore generate a conflict in BBs' attention, similar to that observed among UBs and may lead to a bilingual advantage among BBs; also, although in this case, as the languages are produced in different modalities, inhibition levels may be lower than among UBs, meaning that the bilingual advantage would be weaker. Taking into account the scarcity of previous studies on the subject and the recognition of the parallel activation of two languages that do not share the same modality, the present study aims to determine whether UBs have an advantage over MLs in certain EFs (inhibition, planning, and WM), and whether this advantage is observed also among BBs. In this particular study, the effects of bilingualism on EFs were tested using samples with different linguistic backgrounds, but controlling for SES, immigrant status, and ethnic background. In light of the research aim, we formulated the following hypotheses: (1) in relation to inhibition, the advantage of bilingualism (unimodal and bimodal) over monolingualism will be evident in the absence of the incongruence effect in nonverbal tasks; (2) in relation to planning, the advantage of bilingualism (unimodal and bimodal) over monolingualism will result in a less time, fewer movements, and fewer errors in the Tower of Hanoi task; (3) in relation to working memory, the advantage of bilingualism (unimodal and bimodal) over monolingualism will be reflected in higher scores in auditory memory and visuospatial memory tasks, and in greater facilitation costs and lower interference costs in nonverbal memory tasks.

2. Methodological framework

2.1 Participants

The sample comprised 80 participants living in Andalusia (a large region in the south of Spain) with a medium SES, which were divided into three groups. The first group comprised 30 MLs (15 males) with a mean age of 25.50 years (*SD* = 5.69) in an age range of 18 and 40. More than half of this group had university qualifications (*n* = 17), others had vocational qualifications (*n* = 5), and the rest had primary or secondary qualifications (*n* = 7). All had studied English at school; however, since completing mandatory secondary education (up to age 16 years), 27 had had no exposure to any foreign language and only three had had minimal exposure.

The second group comprised 24 UBs (8 males) born in Brazil (n = 1), France (n = 4), Germany (n = 6), Portugal (n = 1), Spain (n = 7), the United Kingdom (n = 2), Russia (n = 1), Ukraine (n = 1), and the USA (n = 1). All participants in this group had a high level of Spanish and had learned their two languages in a family and/or social context before the age of 13 (*M* = 2.35; *SD* = 3.10). Their ages ranged between 18 and 40 (*M* = 24.75; *SD* = 4.10), and they were exposed to their second language, on average, 50.54% of the time (*SD* = 26.42). UBs were recruited through language schools and social media posts. The group spoke different languages (see Table 1). Most UBs had university qualifications (*n* = 19), others had vocational qualifications (*n* = 4), and one had only a secondary education diploma. Two UBs were eliminated from the analysis of the verbal Stroop and visuospatial span data (one in each respective test) due to incompletion.

The third group comprised 26 BBs (7 males), of which 14 were LSE interpreters with at least three years of experience and a second language acquisition age mean of 20.50 (*SD* = 5.26). In these cases, LSE was acquired in a formal context. The rest of the BB participants (*n* = 12) were CODAs, and therefore acquired both languages in a family context. Participants were recruited by contacting organizations for the deaf and through social media posts on sites most commonly used by this population. The age range of this group was 18 and 40 years (*M* = 30.69; *SD* = 6.61), and they were exposed to LSE, on average, 39.35% of the time (*SD* = 17.77). Most BB participants had university qualifications (*n* = 23), one had vocational qualifications, and two had only a secondary education diploma.

Bilingual participants classified their competence in L1 and L2 on a scale of 0 to 10, as shown in Table 1.

Table 1. *Linguistic competence of bilingual participants*

		UBs (*n* = 24)	BBs (*n* = 26)
L1	Expression (Maximum 10)	*M* = 9.22 (*SD* = 0.99) *Range* 7 - 10	*M* = 8.96 (*SD* = 1.25) *Range* 7 - 10
	Comprehension (Maximum 10)	*M* = 9.65 (*SD* = 0.57) *Range* 8 - 10	*M* = 9.54 (*SD* = 0.65) *Range* 8 - 10
	Age of acquisition	*M* = 0.49 (*SD* = 0.49) *Range* 0 - 2	*M* = 0.12 (*SD* = 0.59) *Range* 0 - 3
	Exposure percentage	*M* = 38 (*SD* = 24.65) *Range* 2 - 90	*M* = 51.65 (*SD* = 19.54) *Range* 20 - 88
	L1 languages (n participants)	English = 1 French = 2 German = 2 Spanish = 19	Spanish = 14 LSE = 12
L2	Expression (Maximum 10)	*M* = 9.17 (*SD* = 1.07) *Range* 7 – 10	*M* = 9.15 (*SD* = 1.12) *Range* 7 - 10
	Comprehension (Maximum 10)	*M* = 9.57 (*SD* = .66) *Range* 8 - 10	*M* = 9 (*SD* = 1.33) *Range* 7 - 10
	Age of acquisition	*M* = 2.35 (*SD* = 3.1) *Range* 0 - 10	*M* = 11.08 (*SD* = 11.05) *Range* 0 - 27
	Exposure percentage	*M* = 50.57 (*SD* = 27.01) *Range* 10 - 90	*M* = 39.35 (*SD* =17.77) *Range* 10 - 80
	L2 languages (n participants)	English = 6 French = 3 German = 5 Italian = 1 Portuguese = 2 Romanian = 1 Russian = 2 Spanish = 4	Spanish = 12 LSE = 14

Note. UBs = Unimodal bilinguals; BBs = Bimodal bilinguals.

The participants in the sample were all found to have a normal IQ, processing speed, and WM (between 80 and 120), after being measured with the Wechsler Adult Intelligence Scale (WAIS-IV; Wechsler, 2008). The three groups were comparable in IQ ($H(2) = 1.75$, $p > .05$), but not in age ($H(2) = 11.35$, $p = .003$). Specifically, the mean age of the BB group was higher than that of the ML ($U = 224.00$, $z = -2.73$, $p = .006$, $r = -.37$) and UB groups ($U = 152.00$, $z = -3.12$, $p = .002$, $r = -.44$).

2.2 Instruments

Data were collected using a sample characterization questionnaire, three questionnaires on linguistic capabilities (one for each group), and inhibition, planning, and WM evaluation tasks.

The sample characterization questionnaire provided information on medical history (injuries, illnesses, drug use, etc.), education level (completed courses and degrees), and employment status and occupation. In addition to providing descriptive information about participants, this questionnaire also allowed us to eliminate other variables that may have affected EFs.

To evaluate linguistic abilities, a specific questionnaire was used for each group. For MLs, a questionnaire was developed to collect data about the type of contact they had had with other languages. For UBs and BBs, we used two adaptations (one for each group) of a questionnaire by Marian et al. (2007)—translated by Rojas and Iglesias (2008) —designed to measure experience and linguistic capabilities. For UBs, the adaptation incorporated questions regarding sign language knowledge (to ensure they were not actually BBs), and for BBs, questions on language were adapted to sign language.

The following tasks were used to evaluate EFs:

- Inhibition
    - Verbal Stroop task: This test is a computerized version based on the Stroop Classic task (Golden, 1975). Participants must indicate the color of the word shown on the screen by pressing one of four buttons with four different colors as fast as they can. They should focus only on the color of the stimuli and ignore their semantic meaning. Stimulus characteristics (color and meaning) are manipulated to generate congruent and incongruent conditions. The experiment consists of three sections with a total of 112 stimuli. In the first section (4 stimuli), participants must read the words that indicate colors, written in black, and push the button corresponding to the color they read. The second section includes 36 stimuli (*****) in red, green, yellow, and blue. In this part, participants must press one of four buttons, in accordance to the color of the stimulus they see on the screen. Lastly, the third section

comprises a meaning/color conflict. In this part, participants must press the button corresponding to the color of the word and ignore its meaning. This third section consists of three lists, each with 24 stimuli (12 congruent and 12 incongruent). The specific list shown to participants is randomly selected. In the congruent condition, each of the four colors appears three times in each list. In the incongruent condition, in each list, one of the four words appears once in an incongruent color (a different incongruent color from the three possible colours for each list). The task was programmed using E-prime Profesional 2.0 (Psychology Software Tools). This task records information on the number of correct responses, reaction time in correct responses in each of the conditions, and the interference index, calculated as: reaction time in incongruent condition minus reaction time in congruent condition.

- Nonverbal Stroop task: This task is based on one designed by Blumenfeld and Marian (2013, 2014). The computerized version of the test consists of manipulating two characteristics of an arrow (direction and location) to produce incongruence. Participants must indicate the direction of the arrow (left or right) by pressing a key, ignoring its location on the screen (left or right). The trials are presented in both congruent and incongruent conditions. The congruent condition consists of 60 trials showing a right-pointing arrow on the right-hand side of the screen, and 60 trials showing a left-pointing arrow on the left-hand side of the screen. In the incongruent condition, 20 trials show a right-pointing arrow on the left-hand side of the screen, and 20 trials show a left-pointing arrow on the right-hand side of the screen. The task was programed using E-prime Professional 2.0 (Psychology Software Tools). Three measures were used for analysis: reaction time in correct responses, number of correct responses in each condition, and interference index (reaction time in the incongruent condition minus reaction time in the congruent condition).
- Verbal Simon task: This is an inhibition task designed by the authors of the present study, based on the nonverbal Simon tasks by Blumenfeld and Marian (2014). In the computerized version, a conflict occurs between two aspects of the stimuli shown: word association with an upward or downward movement and word location on the screen. Participants must press the left key when the word represents an upward motion, *despegar* (to lift off), or the right key when the movement is downward, *lluvia* (rain). The word can appear in the congruent condition (same word association and location, for example, ‘rain’ in the lower part of the screen), or the incongruent condition (conflicting association and location, for example, ‘rain’ in the upper part of the screen). The experiment consists of three lists with balanced administration. The ratio of incongruent trials to the total number of trials is

1: 3 in each list. Likewise, each list contains 72 trials: 48 congruent (24 upward associations and 24 downard associations), and 24 incongruent trials (12 upward associations in the lower part of the screen and 12 downward associations in the upper part of the screen). This task was programmed using E-prime Professional 2.0 (Psychology Software Tools). Participants conducted a practice run of three trials, after receiving instructions but before starting, to ensure that they fully understood the task. Data were recorded on the number of correct answers, reaction time in correct responses in each condition and the interference index (reaction time in the incongruent condition minus reaction time in the congruent condition).

- Nonverbal Simon task: This is an inhibition task designed by Blumenfeld and Marian (2014) and is equivalent to the aforementioned verbal task. It consists of a conflict between two aspects of a stimulus: location and response key. Participants are instructed to press the right key as quickly as possible when the arrow points downward and the left key as quickly as possible when the arrow points upward, ignoring location (right or left). The arrows are shown in the congruent (same direction and location) or incongruent (opposite direction to location) condition. The ratio of incongruent to congruent trials was 1: 3 in a total of 160 trials: 120 congruent and 40 incongruent. Specifically, the congruent condition includes 60 trials showing the upward-pointing arrow on the left-hand side of the screen and 60 trials showing the downward-pointing arrow on the right-hand side of the screen. In the incogruent condition, 20 trials show the upward-pointing arrow on the right-hand side of the screen, and 20 trials show the downward-pointing arrow on the left-hand side of the screen. This task was programmed using E-prime Professional 2.0 (Psychology Software Tools). Data were recorded on the number of correct answers, reaction time in correct responses in each condition, and the interference index (reaction time in the incongruent condition minus reaction time in the congruent condition).

- Planning
  - Tower of Hanoi: This is a task designed by SR Research (Ontario, Canada), based on a task by Borys et al. (1982). Three posts are shown, the first of which has a series of different-sized disks placed in order vertically from largest to smallest. Participants must use the computer mouse to move all the disks from the left hand post to the far right post, with the option of using the central post. The only requirements are to move the disks one at a time and to always place a smaller disk on top of a larger one. Participants are asked to complete the task as quickly as possible with the fewest movements. The task was programmed using SR Research Experiment

Builder (version 1.10.1630). It has five difficulty levels: the lowest level begins with one disk, and, as the targets are reached, the number of disks increases up to a maximum of five. Time, number of movements, and number of errors are recorded.

- Working memory
  - Auditory working memory: Measured using the Digits subtask (forwards and backwards) and the Letters-Numbers subtask of the WAIS-IV (Wechsler, 2008). The direct score for both tasks was recorded.
  - Visuospatial Memory: The Visuospatial Span task is a computerized version of the Corsi Cubes task (Corsi, 1972) used by Herrera et al. (2008). This task consists of nine 2 cm^2 cubes displayed on a 16x16 cm square on the screen. Paying attention to the color of the cubes, participants must reproduce the sequence in which the cubes are shown in accordance with their color. Each cube is shown during 1,000 ms and once the sequence is completed, they remain on the screen for an additional 500 ms. Next, a black screen is shown for 15 seconds. Once again, participants are shown the cubes, and they must select them in the same order in which they were presented. Participants use the computer mouse to select the cubes in the correct order. Sequences of two, three, four, five, six, seven, eight, and nine cubes are created. All sequences are presented to all participants in the same order. The starting level is two cubes. Each difficulty level consists of three trials, and the difficulty level progressively increases by adding cubes that must be memorized. The task ends if the participant does not respond correctly to at least two of the three trials. The number of cubes in the longest sequence correctly reproduced in at least two of the three trials is recorded.
  - Verbal and nonverbal working memory: The Letters task and the Figures task are two tasks used by Bialystok et al. (2014), based on those designed by Jonides and Nee (2006). The Letters task begins with a fixation point being shown on the screen for 1,000 ms, followed by a screen with five letters shown for 1,000 ms, and ending with a white screen shown for 3,000 ms. Afterwards, a letter appears and the participant must press one of two keys (yes or no) to indicate if the letter has been shown on the screen beforehand (trial n). The task has four conditions, created by combining the type of correct response to the isolated letter (whether or not it appeared previously) and whether the letter appeared in the previous trial (n-1):
    - Positive baseline: the letter appeared in trial n, therefore requiring a positive response, but did not appear in the previous trial (n-1).
    - Negative baseline: the letter did not appear in trial n, therefore requiring a negative response, nor did appear in trial n-1.

- Positive facilitation: the letter appeared in trial n, therefore requiring a positive response, but it also appeared in the previous trial (n-1), meaning that a facilitation effect is expected.
- Negative interference: the letter did not appear in trial n, therefore requiring a negative response, but it did appear in trial n-1, meaning that an interference effect is expected.

Nonverbal working memory is assessed similarly to verbal working memory with a few changes: figures are used instead of letters, and they are shown during a longer period of time, since it has been demonstrated that figures are harder to remember than letters (Bialystok et al., 2014). Thus, in order to maintain a comparable difficulty level between the two tasks, the display time was adjusted (presentation screen shown for 2,500 ms and white screen shown for 1,500 ms).

Both tasks (Letters and Figures) were programmed with E-Prime 1.0 (Psychology Software Tools). Each one begins with instructions and 12 practice trials. Each task consists of a block of 32 baseline trials (positive and negative), followed by two blocks of 64 trials with four types of condition (16 trials for each condition) and then another block of 32 baseline trials. Data are recorded on the proportion of correct responses and response time in correct responses in each condition (positive baseline, negative baseline, positive facilitation, and negative interference). The facilitation cost in correct responses (facilitation minus positive baseline) and reaction time (positive baseline minus facilitation) as well as the interference cost in correct responses (interference minus negative baseline) and reaction time (negative baseline minus interference) are recorded. Higher facilitation costs and lower interference costs in correct responses and a shorter reaction time are indicative of a bilingual advantage (Bialystok et al., 2014).

2.3 Procedure

After receiving information about the study, participants signed an informed consent form. The tasks were administered individually by a qualified professional in a quiet and well-lit location.

Participants began by responding to two questionnaires on sample characteristics and language abilities, respectively, followed by the WAIS-IV intelligence test. Those who met the inclusion criteria were evaluated using the EF tasks, which were randomly administered.

3. Results

The SPSS24 statistics package was used to analyze significant differences between the ML, UB, and BB groups in the EF tasks. The Bonferroni correction was applied in the group comparisons and effects are reported with a significance level of .017. A normality test (Shapiro-Wilk test) was conducted to determine the type of analysis to perform (Wilcoxon signed rank test, Freidman ANOVA, Kruskal-Wallis test, Mann-Whitney test, T-test, single factor ANOVA, and/or repeated measures ANOVA).

Age correlated only with verbal Stroop and verbal Simon tasks and was therefore not used as a covariable. Comparisons between age-matched groups are only reported for the two aforementioned tasks.

3.1 Inhibition

Descriptive data from the inhibition tasks are shown in Table 2. Trials with reaction times of less than 200 ms and those with values greater or less than 2.5 SD from the mean were excluded in all four tasks. As a result of this procedure, 4.55% of the data in verbal Stroop, 6.41% in nonverbal Stroop, 17.62% in verbal Simon, and 7.47% in nonverbal Simon were omitted. The high percentage of errors (more than 95%) committed by one BB in verbal Stroop, three MLs, and one UB in the incongruent condition of verbal Simon indicated that they did not understand the task and were therefore eliminated from the analyses.

Table 2. *Overall results in inhibition tasks*

		Total correct responses			Total reaction time		
Tasks	Conditions	MLs M (SD)	UBs M (SD)	BBs M (SD)	MLs M (SD)	UBs M (SD)	BBs M (SD)
Verbal Stroop	Congruent	.96 (.05)	.96 (.05)	.96 (.03)	574.96 (92.62)	603.82 (76.78)	677.31 (134.30)
	Incongruent	.91 (.08)	.87 (.19)	.90 (.10)	652.03 (131.57)	688.23 (135.37)	805.53 (203.77)
Nonverbal Stroop	Congruent	.96 (.16)	.99 (.01)	.99 (.01)	397.80 (53.35)	394.77 (39.55)	409.94 (36.04)
	Incongruent	.86 (.17)	.85 (.12)	.90 (.09)	480.20 (61.16)	492.18 (54.01)	507.38 (42.75)
Verbal Simon	Congruent	.83 (.16)	.86 (.13)	.89 (.07)	767.42 (34.69)	759.17 (57.13)	760.50 (53.59)
	Incongruent	.76 (.17)	.83 (.13)	.85 (.13)	793.77 (44.32)	786.22 (62.80)	783.99 (53.32)
Nonverbal Simon	Congruent	.98 (.03)	.98 (.03)	.99 (.02)	422.03 (43.96)	428.63 (41.17)	424.02 (40.28)
	Incongruent	.79 (.11)	.78 (.14)	.83 (.12)	515.45 (42.86)	519.20 (35.89)	519.99 (41.44)

Note. MLs = Monolinguals; UBs = Unimodal bilinguals; BBs = Bimodal bilinguals.

In relation to the verbal Stroop test, in order to determine whether the incongruence effect (fewer correct responses and higher reaction time in the incongruent than in the congruent condition) occurred in all groups, a non-parametric analysis for related samples was conducted using correct responses and reaction time.

The analysis revealed significant differences in correct responses between the congruent and incongruent conditions in all groups (ML: $z = -3.02$, $p = .002$, $r = -.55$; UB: $z = -2.82$, $p = .005$, $r = -.59$; BB: $z = -3.02$, $p = .003$, $r = -.60$). Differences in reaction time between the two conditions were also found in all three groups (ML: $z = -4.56$, $p < .001$, $r = -.83$; UB: $t(22) = -5.44$, $p < .001$, $r = 4.80$; BB: $z = -4.24$, $p < .001$, $r = -.85$).

Non-parametric tests for independent samples were used to test for performance differences between groups (Kruskal Wallis). The results revealed differences only for reaction time ($H(2, N = 78) = 9.65$, $p = .008$; $H(2, N = 78) = 9.46$, $p = .009$, for the congruent, and incongruent conditions, respectively). Specifically, MLs had a faster reaction time than BBs under both congruent ($U = 202.00$, $z = -2.92$, $p = .003$, $r = -.39$) and incongruent conditions ($U = 203.00$, $z = -2.91$, $p = .004$, $r = -.39$). However, no significant differences were found when the analyses were repeated using equivalent age groups.

Regarding the nonverbal Stroop test, the incongruence effect was evident in all three groups in terms of correct responses. In other words, correct responses were significantly higher in the congruent condition than in the incongruent condition (ML: $z = -4.62$, $p < .001$, $r = -.84$; UB: $z = -4.26$, $p < .001$, $r = -.87$; BB: $z = -4.29$, $p < .001$, $r = -.84$). The effect was also evident in all three groups in terms of reaction time (faster responses in the congruent than in the incongruent condition) (ML: $z = -4.78$, $p < .001$, $r = -.87$; UB: $z = -4.29$, $p < .001$, $r = -.87$; BB: $z = -4.46$, $p < .001$, $r = -.88$).

No significant differences were observed between groups in performance under either condition (congruent or incongruent) in either of the measures (correct responses or reaction time).

The same logic was applied in the analyses of the verbal and nonverbal Simon tasks: the incongruence effect was analyzed in each group, followed by performance differences between groups. In the verbal Simon test, the analysis of correct responses failed to reveal any incongruence effect in any group. However, when reaction time was analyzed, the effect was observed in the ML ($z = -3.56$, $p < .001$, $r = -.69$) and BB groups ($z = -2.45$, $p = .014$, $r = -.48$).

In relation to between-group differences in performance, no significant differences were observed in number of correct responses or reaction time for either condition. No differences were also found when the analyses were repeated using age-matched groups.

Regarding the nonverbal Simon test, the incongruence effect was observed in number of correct responses, with more correct responses being given in the congruent than in the incongruent condition in all three groups (ML: $z = -4.78$, $p <$

.001, $r = -.87$; UB: $z = -4.20$, $p < .001$, $r = -.86$; BB: $z = -4.46$, $p < .001$, $r = -.88$). The same incongruence effect was observed in reaction time, again in all three groups (ML: $z = -4.78$, $p < .001$, $r = -.87$; UB: $z = -4.29$, $p < .001$, $r = -.88$; BB; $z = -4.46$, $p < .001$, $r = -.88$). No significant between-group differences were found in performance (number of correct responses or reaction time) under either condition.

As a complementary measure, the interference index was calculated for each inhibition task (response time in the incongruent condition minus response time in the congruent condition). The results are shown in Table 3. The between-group comparison revealed no significant differences in the interference indices for either the verbal and nonverbal Stroop tasks, or the verbal and nonverbal Simon tasks. The same results were obtained when using age-matched group comparisons.

Table 3. *Results of the inhibition interference indices*

Variables	MLs *Mean (SD)*	UBs *Mean (SD)*	BBs *Mean (SD)*	*P*
Interf. Verbal Stroop	77.07 (59.82)	84.39 (74.34)	128.21 (115.90)	.306
Interf. Nonverbal Stroop	82.40 (25.45)	96.41 (37.10)	97.43 (29.35)	.123
Interf. Verbal Simon	26.35 (30.30)	25.92 (48.78)	23.49 (41.76)	.902
Interf. Nonverbal Simon	93.42 (28.33)	90.57 (33.05)	95.97 (24.53)	.802

Note. Interf. = Interference index; MLs = Monolinguals; UBs = Unimodal bilinguals; BBs = Bimodal bilinguals.

Finally, regarding inhibition, UBs were only found to have an advantage in reaction time in verbal Simon tasks. Specifically, unlike their counterparts in the other two groups, the reaction time of UBs was unaffected by incongruence.

3.2 Planning

Table 4 shows the results for each Tower of Hanoi difficulty level along with the differences between groups. The sample was the same as in the inhibition tasks.

Table 4. *Overall results in the Tower of Hanoi test*

Number of disks	Measures	MLs	UBs	BBs
1 Disk	Time Mean (SD)	6646.03 (2317.88)	8559.50 (5192.43)	9403.62 (6001.84)
	No. of movements Mean (SD)	1.07 (.37)	1.00 (0)	1.04 (.20)
	No. of errors Mean (SD)	.07 (.37)	1.00 (0)	.04 (.20)
2 Disks	Time Mean (SD)	8370.37 (4234.19) [c]	9637.38 (4161.09)	12356.81 (7355.45)
	No. of movements Mean (SD)	1.00 (0)	1.00 (0)	1.00 (0)
	No. of errors Mean (SD)	1.00 (0)	1.00 (0)	1.00 (0)
3 Disks	Time Mean (SD)	34327.77 (27071.12) [c]	48996.42 (52966.45)	58949.19 (34911.89)
	No. of movements Mean (SD)	9.97 (3.58)	9.67 (2.94)	10.62 (3.34)
	No. of errors Mean (SD)	2.97 (3.58)	2.67 (2.94)	3.62 (3.34)
4 Disks	Time Mean (SD)	92625.23 (87639.96)	108724.04 (61458.57)	120594.65 (91379.40)
	No. of movements Mean (SD)	28.60 (14.37)	24.04 (12.71)	29.04 (12.66)
	No. of errors Mean (SD)	13.60 (14.37)	8.63 (12.84)	14.04 (12.66)
5 Disks	Time Mean (SD)	258223.53 (176541.96)	313494.29 (253875.34)	320902.65 (243019.48)
	No. of movements Mean (SD)	81.93 (43.54)[a]	66.13 (51.73)	78.27 (43.04)
	No. of errors Mean (SD)	50.93 (43.54) [a]	35.13 (51.73)	47.27 (43.04)

Note. [a] Significant differences between MLs and UBs; [b] Significant differences between UBs and BBs; [c] Significant differences between MLs and BBs. MLs = Monolinguals; UBs = Unimodal bilinguals; BBs = Bimodal bilinguals.

The analyses revealed a significant difference between the groups in the time required to complete the two- ($H(2) = 6.91$, $p = .032$) and three-disk levels ($H(2) = 10.71$, $p = .005$), and in the number of movements ($H(2) = 6.70$, $p = .035$) and the number of mistakes made ($H(2) = 6.70$, $p = .035$) at the five-disk level. Specifically, as shown in Table 4, BBs were slower than MLs in resolving tasks at the two- and three-disk levels ($U = 243.00$, $z = -2.42$, $p = .016$, $r = -.32$ y $U = 201.00$, $z = -3.12$, $p = .002$, $r = -.43$, respectively). Regarding the differences observed at the five-disk level, the results reveal that UBs required fewer movements and made fewer mistakes than MLs (number of movements: *U* = 222,50, *z* = -2.40, *p* = .017, *r* = -.33; number of errors: *U* = 222.50, *z* = -2.40, *p* = .017, *r* = -.33).

Ultimately, UBs (although not BBs) seem to have some advantage over MLs in planning complex tasks, such as completing a five-disk Tower of Hanoi test.

3.3 Working memory

One ML participant did not complete the Digits task, one UB participant did not complete the Visuospatial Span task, and the data pertaining to one ML participant were omitted from the Letters and Figures analyses due to the absence of correct responses, which clearly indicated that they did not understand the task.

The means (*M*) and standard deviations (*SD*) of the Digits, Letters-Numbers, and Visuospatial Span tasks are shown in Table 5. A one-way analysis of variance (ANOVA) was conducted to test for significant differences between groups in the direct-order Digits task and non-parametric tests were conducted to do the same in the reverse-order condition. The results showed no significant differences between the groups in either condition (direct-order: *F* (2, 76) = 1.37; *p* > .05; reverse-order: *H* (2) = .04; *p* > .05). A one-way ANOVA was performed for the Letters-Numbers task, revealing statistically significant differences between the groups (*F* (2, 77) = 3.80; *p* = .027). Specifically, UBs had higher direct scores than MLs for this task (*t* (52) = 3.04; *p* = .004; r = .39). This advantage was not found for the BB group.

Table 5. *Means and standard deviations for the Digits, Letters-Numbers, and Visuospatial Span tasks*

Tasks	MLs *Mean (SD)*	UBs *Mean (SD)*	BBs *Mean (SD)*	*Comparison*
Digits				
Direct-order	9.37 (1.73)	9.04 (1.92)	8.54 (1.99)	*F* (2, 76) = 1.37; *p* > .05
Reverse-order	8.63 (1.33)	8.70 (1.36)	8.58 (2.16)	*H* (2) = .04; *p* > .05
Letters-Numbers	19.27 (1.20)	20.96 (2.07)	19.88 (2.64)	*F*(2, 77) = 3.80, *p* = .027
Visuospatial Span	4.93 (.91)	4.91 (1.08)	4.96 (1.00)	*H*(2) = 4.45, *p* > .05

Note. MLs = Monolinguals; UBs = Unimodal bilinguals; BBs = Bimodal bilinguals.

For the Visuospatial Span test, a non-parametric analysis was conducted for independent samples. The results did not reveal any statistically significant differences between the three groups.

Regarding the Letters and Figures tasks, Table 6 shows the means and standard deviations for the proportion of correct responses and reaction time in correct responses. Trials with reaction times of under 300 ms or over 3,000 ms or with values above or below a 1.5 interquartile range were excluded from the analyses. In the Letters task, this procedure resulted in the omission of 6.88% of the positive trials and 6.13% of the negative trials. In the Figures task, 6.37% of the positive trials and 7.89%

of the negative trials were excluded from the analyses. One ML participant was also excluded from this data set.

Table 6. *Descriptive data for correct responses and reaction time in the Letters and Figures tasks*

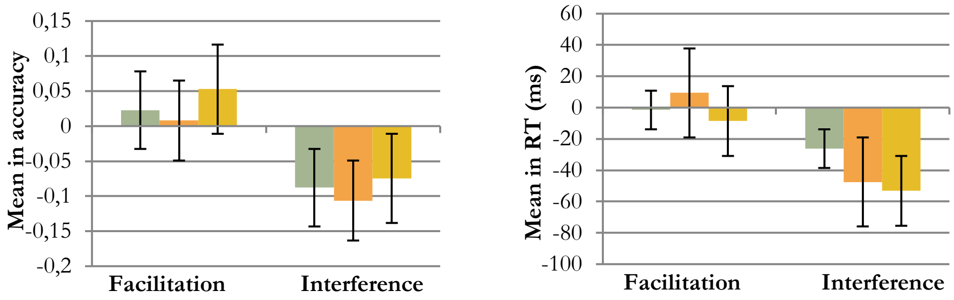
Type of test	MLs *Mean (SD)*	UBs *Mean (SD)*	BBs *Mean (SD)*
	Correct responses Letters		
Positive Baseline	.84 (.12)	.87 (.10)	.86 (.11)
Positive Facilitation	.86 (.10)	.88 (.12)	.92 (.09)
Negative Baseline	.92 (.10)	.99 (.03)	.96 (.05)
Negative Interference	.83 (.12)	.88 (.12)	.89 (.11)
Facilitation Cost	.02 (.10)	.01 (.12)	.05 (.09)
Interference Cost	-.09 (.09)	-.11 (.12)	-.08 (.10)
	Reaction time Letters		
Positive Baseline	840.88 (160.00)	844.23 (201.82)	884.32 (162.42)
Positive Facilitation	842.40 (186.73)	834.86 (205.23)	892.89 (176.24)
Negative Baseline	860.17 (169.15)	861.03 (185.81)	888.83 (155.78)
Negative Interference	886.38 (175.12)	908.50 (204.56)	942.01 (164.57)
Facilitation Cost	-1.52 (81.18)	9.37 (73.47)	-8.58 (85.20)
Interference Cost	-26.21 (89.96)	47.47 (92.52)	53.18 (81.79)
	Correct responses Figures		
Positive Baseline	.76 (.12)	.73 (.12)	.66 (.20)
Positive Facilitation	.77 (.14)	.78 (.13)	.73 (.15)
Negative Baseline	.80 (.15)	.76 (.20)	.81 (.16)
Negative Interference	.70 (.11)	.76 (.14)	.74 (.13)
Facilitation Cost	.01 (.15)	.05 (.16)	.07 (.17)
Interference Cost	-.10 (.16)	-.00 (.14)	.07 (.14)
	Reaction time Figures		
Positive Baseline	990.05 (195.19)	1024.95 (169.71)	1097.02 (226.09)
Positive Facilitation	975.61 (193.47)	1035.01 (160.74)	1094.81 (270.40)
Negative Baseline	1026.82 (192.17)	1114.42 (247.75)	1097.63 (234.38)
Negative Interference	1075.43 (189.29)	1191.79 (232.71)	1138.09 (262.22)
Facilitation Cost	14.44 (97.57)	-10.06 (128.22)	2.22 (144.93)
Interference Cost	-48.61 (107.82)	-77.38 (135.33)	-40.45 (134.68)

Note. MLs = Monolinguals; UBs = Unimodal bilinguals; BBs = Bimodal bilinguals.

The results of the verbal and nonverbal tasks were analyzed separately, first focusing on correct responses and then on reaction time. In the verbal task (Letters), correct responses were analyzed using non-parametric tests for independent samples, with the aim of conforming whether or not bilinguals (UBs and BBs) differed from MLs in terms of facilitation (facilitation minus positive baseline) and interference costs (interference minus negative baseline). The results failed to reveal any significant differences in either facilitation (H (2) = 1.60; $p > .05$) or interference costs (H (2) = .58; $p > .05$) in relation to accuracy (correct responses).

Kruskal-Wallis tests were conducted to analyze reaction time in the Letters task, in order to determine whether bilinguals (UBs and BBs) had higher facilitation costs and lower interference costs than MLs. The between-group comparisons failed to reveal any significant differences in either facilitation (*H* (2) = 1; *p* > .05) or interference costs (*H* (2) = .72; *p* > .05) in relation to reaction times.

Figure 1. *Facilitation and interference costs in correct responses and response time in the Letters and Figures tasks for each group.*

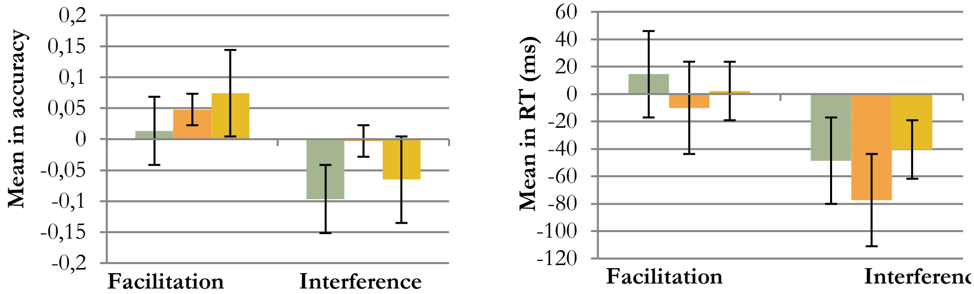


(a) Letter task accuracy

(b) Letter task RT

(c) Figures task accuracy

(d) Figures task RT



Note. Graphs based on Bialystok et al., 2014).

A similar analysis was conducted for the Figures task (the nonverbal equivalent of the Letters task). The results revealed no differences between the groups in either facilitation (H (2) = 1.40; p > .05) or interference costs (H (2) = 5.36; p > .05) in relation to accuracy.

A one-way analysis of variance (ANOVA) was performed to analyze reaction time in the Figures tasks. The analyses failed to reveal any differences between the groups in either facilitation (F (2, 76) = .26; p > .05) or interference costs (F (2, 76) = .59; p > .05) in relation to reaction time.

In conclusion, in relation to WM, the advantage of UBs over MLs was only clearly manifested in the Letters-Numbers tasks (auditory working memory), with UBs giving more correct responses.

4. Discussion

The purpose of the present study was to determine whether UBs demonstrated any advantages over MLs in inhibition, planning, and WM, and if these advantages were also found among BBs. The initial hypothesis with respect to inhibition was that incongruence would affect MLs more than bilinguals (UBs and BBs) in nonverbal tasks. The initial hypothesis in relation to planning was that bilinguals (UBs and BBs) would have an advantage over MLs in time, number of movements, and number of errors. Finally, in relation to WM, our hypothesis was that bilinguals (UBs and BBs) would score higher than MLs in auditory and visuospatial memory, and would have higher facilitation costs and lower interference costs in the nonverbal memory task.

The inhibition analyses seemed to indicate that UBs had an advantage in the Simon task, insofar as their reaction time was not affected by incongruence, unlike that of MLs and BBs. However, contrary to what would be expected according to previous studies (Pelham & Abrams, 2014; Ye et al., 2017) and our initial hypothesis, this advantage was observed only in one of the verbal tasks. Our results in relation to inhibition replicate those reported by Kousaie et al. (2014) in a sample of young and elderly UBs in which the bilingual advantage was observed in verbal but not nonverbal inhibition tasks. It is possible that these differences are unrelated to the nature (verbal or nonverbal) of the task itself and are linked instead to the degree of complexity: bilinguals, especially young ones, have been found to have an advantage in more complex tasks, such as the Simon task, but not in simpler ones such as the Stroop. Of the two Simon tasks, the verbal one seems to be more complex than its nonverbal counterpart, since the proportion of correct answers was lower in the former than in the latter and reaction times were higher. Indeed, 17.62% of the trials had to be discarded because they exceeded the established time limit and four participants (three MLs and one UB) were excluded because their error rate was higher than 95%. The influence of task difficulty in our study may have been greater due to the fact that participants were young and would therefore only have a bilingual advantage in complex tasks (Ye et al., 2017). This would explain why bilingual advantage was not observed in our sample in tasks such as Stroop or nonverbal Simon, which have an equivalent difficulty level. Furthermore, as Kousaie et al. (2014) argue, this type of task does not require monitoring processes in which the bilingual advantage tends to manifest. However, the advantage was evident in the Tower of Hanoi task in which this skill plays a more prominent role. Specifically, the Tower of Hanoi results revealed significant differences in planning between UBs and MLs. In particular, UBs performed better than MLs in terms of number of movements and number of errors at the five-disk level, when the task is more complex (Ye et al., 2017) and requires monitoring (Kousaie et al., 2014). These results partially confirm our hypothesis and concur with the study by Festman et al. (2010), which observed advantages among bilinguals with better control and language skills at the four and five-disk levels, compared to bilinguals with poorer control and language skills.

Regarding BBs, although the results failed to reveal any significant statistical differences at the five-disk level, this group made fewer movements and mistakes than MLs, although more than UBs. It seems that BBs tend to be at the midpoint between UBs and MLs in planning, in spite of the differences with respect to these two groups did not achieve statistical significance.

In relation to auditory WM, the results revealed significant differences in the more complex Letters-Numbers task, with UBs having an advantage over MLs, but not in the simpler Backwards Digits task. In a sample of university students who were set a Backwards Digits task from the WAIS test, Kazemeini and Fadardi (2016) also found that UBs outperformed MLs in auditory WM. In that study, bilingual participants spoke Kurdish and Persian, two languages with a similar linguistic structure and many shared lexical elements, meaning that the magnitude of the bilingual management demands would have been much greater than in our sample. According to Macnamara and Conway (2014), WM capacity increases as one gains more experience in handling those bilingual management demands, and in the case of the sample in Kazemeini and Fadardi's study (2016), this would most likely have led to a bilingual advantage even in simpler WM evaluation measures, such as the Backwards Digits tasks. The same result was observed by Blom et al. (2014) in children using the Backwards Digit Recall task. In this case, the lower difficulty of the task, along with the younger age of the participants, may explain the differences observed between UBs and MLs, since, as Ye et al. (2017) argue, bilingual children (and older adults) show more benefits in simpler tasks (Backwards Digit Recall) than in more complex ones (Letters-Numbers). Regarding BBs, the results observed for auditory working memory (Letters-Numbers tasks) were similar to those observed for planning (five-disk level), and although mean scores fell between those of the ML and UB groups, the differences did not reach statistical significance in any of the comparisons. It may be that mastery of two languages from different modalities (bimodal bilingualism) is not subject to the same interference as mastery of two oral languages, which share the same pathway. Consequently, in bimodal bilingualism, the scope of requirements for bilingual management would be narrower than in unimodal bilingualism, and this may explain the absence of the bilingual advantage among BBs.

Regarding visuospatial memory, our results revealed no advantages for UBs and were consistent with those reported by Papageorgiou et al. (2018) and Kousaie et al. (2014) using similar samples.

In terms of verbal WM (Letters tasks), bilinguals (UBs and BBs) were not observed to have any performance advantages over MLs in terms of either facilitation or interference costs, in relation to either correct responses or reaction time. These results in the Letters task are consistent with those found by Bialystok et al. (2014), although our results for the Figures task differ from those reported by these same authors and refute our initial hypothesis that bilinguals (UBs and BBs) would have higher facilitation costs and lower interference costs. According to Bialystok et al. (2014), the bilingual advantage in EFs depends on the characteristics of the participants (young or older) as well as on the features of the tasks themselves (simple or complex, verbal or nonverbal). In their study, they observed that the advantage in the Figures tasks was greater among older participants (M = 69.1 years) than among younger adults, who made up our sample. Perhaps the age difference between the older participants in the Bialystok study and the younger ones in our sample may explain the absence of any differences between UBs and MLs in the present study. According to Bialystok et al. (2014), "as EF are at their peak in young adults, they show a 'functional ceiling' in the sense that any further efficiencies associated with bilingualism have little effect, especially on relatively simple EF tasks that are performed quickly and accurately" (p. 12).

Our study has some limitations that need to be addressed. First, the ML group was not purely monolingual, given that they had taken required English classes at school; however, we consider this to be a common situation with monolingualism, at least in Western societies. Second, the sample of participants was fairly small, raising questions regarding whether certain trends observed in the results with respect to BB advantages would be significantly increased in a larger sample. Third, the BB sample was made up of both CODAs and interpreters, and the magnitude of the bilingual management demands may be different in the two groups. Therefore, treating them as a homogeneous group may have reduced our capacity to detect the potential advantages of bimodal bilingualism. However, one must bear in mind that there were no interpreters in the UB group, who nonetheless demonstrated bilingual advantages in some aspects of EFs. Also, despite the fact that in several studies with oral (Henrard & Van Daele, 2017; Chmiel, 2018) or signer interpreters (Macnamara & Conway, 2016; Van Dijk et al., 2012) and in different systematic reviews and meta-analyses (Hu & Fan, 2021; Mellinger & Hanson, 2019; Nour et al., 2020; Wen & Dong, 2019), an interpreter advantage has been observed in EFs such as shifting and working memory as well as, albeit less consistently, in inhibition and updating, in our study we observed no differences regarding EFs between CODAs and sign interpreters. This is most likely because CODAs usually act as interpreters for their parents, so the magnitude of the bilingual management demands in their case may not vary greatly from those of a professional interpreter, meaning that both groups face similar competition for their cognitive resources, giving rise to a similar advantage in EFs. For this reason, the two groups were merged into a single BB group when running the analyses.

Another limitation may have been responsible for the absence of differences between BBs and MLs in planning and auditory WM, even though BB scores fell between those of the ML and UB groups. BB participants reported using Spanish most of the time and not having to switch between languages, a circumstance that put them in a less demanding situation regarding cognitive resources. Indeed, the percentage of exposure to L2 was significantly lower for BBs (39.35) than for UBs (50.57). This prompts us to consider two possible avenues for future research: firstly, to observe how the bilingual advantage in EFs may be mediated by the magnitude of bilingual management demands, by comparing bilinguals with varying degrees of interference control between languages; and secondly, to explore the advantage of bimodal bilingualism in other aspects of EFs not contemplated in this paper, such as selective attention, processing speed, and mental flexibility.

CONCLUSIONS

In conclusion, the results seem to indicate that UBs have advantages in inhibition over MLs when dealing with complex tasks; however, these advantages are not observed among BBs. Regarding planning, UBs demonstrated a clear advantage over MLs in a fairly difficult task (five disks), although this advantage was not observed either among BBs. The same conclusion can be drawn from the WM analyses, carried out with the Letters-Numbers task. It may be that, as Emmorey et al. (2008b) assert, bilinguals are not exposed to the same degree of interference when mastering two languages from different modalities (bimodal bilingualism) as when they are forced to deal with two oral languages, which share the same pathway (unimodal bilingualism). Moreover, in the words of Macnamara and Conway (2014), the magnitude of bilingual management demands would be lower in bimodal than in unimodal bilingualism. All of this may explain why BBs do not acquire the same level of advantage in EFs as UBs.

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