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Language experience modulates bilingual language control: The effect of proficiency, age of acquisition, and exposure on language switching

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A B S T R A C T

The ability to selectively access two languages characterises the bilingual everyday experience. Previous studies showed the role of second language (L2) proficiency, as a proxy for dominance, on language control. However, the role of other aspects of the bilingual experience – such as age of acquisition and daily exposure – are relatively unexplored. In this study, we used a cued language switching task to examine language switching and mixing in two groups of highly proficient bilinguals with different linguistic backgrounds, to understand how the ability to control languages is shaped by linguistic experience. Our analysis shows that the ability to switch between languages is not only modulated by L2 proficiency, but also by daily L2 exposure. Daily L2 exposure also affects language mixing. Finally, L2 age of acquisition predicts naming latencies in the L2. Together, these findings show that language dominance is characterised by multiple aspects of the bilingual experience, which modulate language control.

1. Introduction

Bilinguals need to selectively access the appropriate language, both in comprehension and in production, according to the context and the interlocutor. This process is fast and often apparently seamless. Various studies have investigated bilinguals' ability to switch languages in order to understand the mechanisms of language control (e.g. Abutalebi & Green, 2008; Baus, Branzi, & Costa, 2015; Costa, Santesteban, & Ivanova, 2006; Hartanto & Yang, 2016; Ma, Li, & Guo, 2016); however, it is not clear yet what factors affect this ability, and ultimately, how this ability relates to different types of bilingual experience. Bilingualism varies on many dimensions, such as proficiency (high or low, active or passive), age of language acquisition (early or late), and quantity and quality of language exposure (Bak, 2016; Luk & Bialystok, 2013). Identifying which of these dimensions affect language control is important for a cognitive model of this ability, and to understand its relationship with other linguistic and non-linguistic processes. In this study, we ask how bilingual experience modulates language control by examining both mix and switch costs through a cued language-switching task in two very different bilingual populations: late Italian-English highly proficient bilinguals, and early Italian-Sardinian balanced bilinguals.

Current research on bilingualism suggests that language selection represents the main cognitive challenge for the bilingual mind, since the two languages are simultaneously active, to some degree, and compete with each other. For instance, lexical access is subject to phonological interference across languages in comprehension (Blumenfeld & Marian, 2013; Marian & Spivey, 2003; Thierry & Wu, 2007; Wu & Thierry, 2010) and in production (Costa, Caramazza, & Sebastian-Galles, 2000; Costa, Miozzo, & Caramazza, 1999); syntactic processing is also prone to interference, as structures present in one language are activated when processing the other language (Bernolet, Hartsuiker, & Pickering, 2007; Sanoudaki & Thierry, 2015; Vaughan-Evans, Kuipers, Thierry, & Jones, 2014). Hence, at every level of linguistic processing, bilinguals need to restrict access to the relevant language and reduce competition from the irrelevant one. This process is referred to as 'language control'.

Research on the mechanisms underlying language control using language switching tasks has primarily examined switch costs in word production, that is, the delay when switching language between successive trials (see Declerck & Philipp, 2015). A prominent account of language control – Green's (1998) Inhibitory Control (IC) model – assumes that inhibition suppresses the competition from the irrelevant language. According to the IC model, the amount and time course of inhibition depend on the amount of activation of each language, which in turn depends on the specific language task demands. Evidence in

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support of this account comes from studies showing asymmetric switch costs between languages: switching into the dominant L1 takes longer than switching into the weaker L2 (Costa & Santesteban, 2004; Costa et al., 2006; Meuter & Allport, 1999). Asymmetric switch costs reflect the fact that more inhibition is required to suppress the dominant L1 during L2 access than vice versa. This explanation is supported by studies on highly proficient balanced bilinguals, showing symmetric switch costs between L1 and L2 (Calabria, Hernández, Branzi, & Costa, 2012; Costa & Santesteban, 2004; Costa et al., 2006).

However, symmetric switch costs have also been found in low proficiency bilinguals (Christoffels, Firk, & Schiller, 2007; Prior & Gollan, 2011). In addition, some studies found overall faster naming (i.e. independently of switch costs) in L1 than in L2 (e.g. Macizo, Bajo, & Paolieri, 2012), consistent with the idea of higher activation of L1, whereas some of the previously mentioned studies (e.g. Costa & Santesteban, 2004) found shorter overall naming latencies in L2 than L1, suggesting that the L1 may be inhibited at a global level (i.e., language-wide) with respect to the L2 (Meuter & Allport, 1999), an effect also referred to as 'reversed dominance' (Gollan & Goldrick, 2016). Other studies on language switching suggest further mechanisms to explain asymmetrical switch costs, beyond L1 inhibition. Specifically, asymmetric switch costs reflect the relative activation of L1 and L2, and not only (or not at all: Finkbeiner, Gollan, & Caramazza, 2006) inhibition of L1 (Philipp, Gade, & Koch, 2007). Relative activation of L1 and L2 in turn depend on proficiency (Declerck, Thoma, Koch, & Philipp, 2015) and on task-specific parameters such as preparation time (Verhoef, Roelofs, & Chwilla, 2009).

Taken together, these findings raise questions about the relation between language dominance and inhibitory processes responsible for language switch costs. Specifically, the discrepancies between these patterns suggest that besides a local (word- or trial-specific) effect of competition during language switching, there is a global (i.e., language-wide) effect that may be modulated by further control mechanisms as a function of the context: that is, depending on the languages spoken in the current situation and by the interlocutor, as well as the amount and type of code-mixing that characterises the situation (Green & Abutalebi, 2013; see also Declerck, Thoma, et al., 2015). One such mechanism is proactive control, responsible for goal maintenance and preparatory attention. Studies analysing 'mix costs' (i.e., the global delay that occurs between a single language context and a mixed language one, such as in a cued language-switching task between blocked trials and mixed trials) found larger costs in L1 than in L2 (Ma et al., 2016; Prior & Gollan, 2011). This pattern has been interpreted as reflecting the amount of proactive control needed to facilitate access to the L2, that is, to preemptively counteract the higher activation level of L1 (Ma et al., 2016; Wu & Thierry, 2017). Hence, both mix and switch costs represent relevant measures of language control.

The hypothesis of a dynamic interplay of reactive and proactive control processes in language selection parallels an influential model of cognitive control – the dual mechanisms framework (Braver, 2012; Braver, Gray, & Burgess, 2007) – and, more broadly, a large body of research on executive functions in bilinguals that highlights the interaction of different control mechanisms (e.g., Friedman, 2016; Miyake & Friedman, 2012). In fact, numerous studies have addressed the relation between language control and cognitive control, albeit with mixed evidence. Domain-general control mechanisms seem to contribute to language selection (Gollan & Goldrick, 2016), and, conversely, language control in bilinguals seems to be implicated in non-linguistic cognitive tasks (Branzi, Calabria, Gade, Fuentes, & Costa, 2016; Garbin et al., 2010). Various studies posit an overlap between language control and cognitive control: language control may rely, at least in part, on domain-general control abilities, as suggested by correlations between linguistic and non-linguistic switching tasks (Declerck, Grainger, Koch, & Philipp, 2017; Prior & Gollan, 2011) and the overlap of cortical areas engaged in linguistic and non-linguistic control (Abutalebi & Green, 2008; Coderre, Smith, van Heuven, & Horwitz, 2016; De Baene, Duyck, Brass, & Carreiras, 2015; Hernandez, 2009). In contrast, other studies support the specialised and partly independent nature of language control, as they find no correlation between linguistic and non-linguistic switching tasks (Branzi, Calabria, Boscarino, & Costa, 2016; Calabria, Branzi, Marne, Hernández, & Costa, 2015; Calabria et al., 2012).

The relation between language control and cognitive control is at the heart of much recent research on bilingualism, as some researchers claim that the computational challenge of language selection leads to the transfer of switching abilities to other cognitive domains, such as executive functions. Many studies have found that bilinguals outperform monolinguals on tests of executive functions (Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Craik, & Luk, 2008; Bialystok, Craik, & Luk, 2012; Costa, Hernández, & Sebastián-Gallés, 2008; Costa & Sebastián-Gallés, 2014). However, other studies have not found such an advantage (Duñabeitia et al., 2014; Gathercole et al., 2014; Paap & Greenberg, 2013; Paap & Sawi, 2014). Thus, the evidence is mixed, and theoretical approaches that explicitly relate executive functions to specific aspects of the bilingual experience are sparse (Li & Grant, 2015). Understanding what factors affect the ability to select and access languages is, therefore, important not only to describe language control, but also to relate different dimensions of the bilingual experience to its cognitive effects.

Studies focusing on cued language switching show how some aspects of the bilingual experience affect language control. Specifically, much research on asymmetric switch costs has focused on dominance, operationalised as proficiency: the higher the L2 proficiency, the smaller the asymmetry in switch costs between the L1 and the L2 (Costa & Santesteban, 2004; Costa et al., 2006; Meuter & Allport, 1999). Higher levels of L2 proficiency have also been related to a qualitative difference in mechanisms of language control: highly proficient bilinguals may recruit different language control strategies from low proficient bilinguals, as suggested by the lack of asymmetry in switch costs between L1 and a much weaker L3 in highly proficient bilinguals (Calabria et al., 2012; Costa & Santesteban, 2004; Costa et al., 2006). Neuroimaging studies support this qualitative difference between high and low proficient bilinguals, as balanced bilinguals use the same cortical areas when performing lexical access tasks in their two languages, whereas unbalanced bilinguals recruit additional frontal areas, dedicated to domain-general cognitive control (Abutalebi, 2008; Abutalebi & Green, 2007).

This qualitative difference suggests that the effect of proficiency on mechanisms of language control could be mediated by other dimensions of the bilingual experience. Indeed, studies show that other aspects interact with proficiency in the modulation of language control, such as frequency of language switching (Christoffels et al., 2007; Prior & Gollan, 2011) and interactional contexts of use (Hartanto & Yang, 2016). Beside these, two further factors related to language dominance, which could also mediate language control abilities, are language exposure and age of acquisition (AoA). With regards to the first, research shows that exposure – defined in terms of quantity and quality of linguistic input – is an important factor in dominance in early bilingualism (Unsworth, 2015, 2016; Unsworth et al., 2014), and it is related to L1 maintenance and processing in adult bilinguals (Chamorro, Sorace, & Sturt, 2016). In addition, neuroimaging studies show that the amount of exposure modulates cortical activity during lexical retrieval (Perani et al., 2003). As for age of acquisition, it plays an extensive role in second language learning (Birdsong, 1999) and is strongly related to language dominance (Birdsong, 2014). It also affects the architecture of the bilingual brain, in terms of cortical activation relative to lexical access (Perani et al., 2003), language lateralization (Hull & Vaid, 2007), and cortical thickness of the inferior frontal gyri (Klein, Mok, Chen, & Watkins, 2014). Moreover, some studies on the cognitive effects of bilingual experience relate age of acquisition to enhanced domain-general cognitive control (Luk, De Sa, & Bialystok, 2011; Tao, Marzecová, Taft, Asanowicz, & Wodniecka, 2011).

Exposure and age of acquisition seem therefore to constitute additional aspects of language dominance, but no study has directly addressed the specific role of exposure on language switching, and only one study has addressed the role of age of acquisition. Costa et al. (2006, experiment 1) tested highly proficient early Spanish-Basque bilinguals and highly proficient late Spanish-English bilinguals on a cued language switching task and found symmetric switch costs in both groups and no difference between the two groups, suggesting no effect of age of acquisition on the relative magnitude of switch costs in L1 and L2. However, in that study the late bilingual group consisted of students enrolled in a professional school for interpreters, who may have already possessed considerable expertise in simultaneous language access. Simultaneous interpreters appear to control language differently from other bilinguals, as reflected by reduced and symmetric language switch costs (Aparicio, Heidlmayr, & Isel, 2017; Babcock & Vallesi, 2017; Ibáñez, Macizo, & Bajo, 2010; Morales, Padilla, Gómez-Ariza, & Bajo, 2015). In addition, the small sample size of Costa et al. (2006) may have reduced their study's statistical power.

In this study, we therefore examine what aspects of the bilingual experience, beyond proficiency, modulate language control, with a particular interest in L2 exposure and age of acquisition. To do so, we analyse both mix and switch cost in a cued language switching task in two bilingual samples, whose experience differs in terms of age of acquisition, language exposure, proficiency, and language distance: Italian-English bilinguals and Italian-Sardinian bilinguals. The Italian-English bilinguals are late bilinguals (i.e. they were first exposed to English in school after the age of 6 but only became fluent on average at the age of 19), who are currently primarily exposed to their L2 in their daily life, and whose proficiency, while high for both languages, is unbalanced. The Italian-Sardinian bilinguals are early bilinguals (they acquired both languages informally before the age of 6), highly proficient and balanced, and are currently exposed daily to both languages, in a diglossic pattern of use (i.e., a clear separation of contexts for Italian, used at work and school, and Sardinian, spoken with family and friends).

First, we are interested in the pattern of switch and mix costs in these two groups. In line with previous research (e.g. Meuter & Allport, 1999; Costa & Santesteban, 2004; Costa et al., 2006) higher proficiency in L1 than L2 should lead to a larger switch cost into L1 than into L2. Hence, we predict an asymmetric switch cost in the (unbalanced) Italian-English bilinguals and a symmetric switch cost in the (balanced) Italian-Sardinian bilinguals. As dominance – operationalised as proficiency – has also been related to bigger mix costs in the L1 than in the L2 (Ma et al., 2016; Prior & Gollan, 2011), we expect to find asymmetric mix costs (L1 > L2) in the Italian-English group, however, we would not predict such asymmetry in the Italian-Sardinian group.

Second, to shed light on the specific aspects of the bilingual language experience that affect mix and switch costs patterns, we treat bilingual experience as a continuous variable when analysing both groups' performance (pooled together) with respect to both mix and switch costs. Specifically, we investigate the role of L2 proficiency in the active modalities (speaking and writing) and in the passive modalities (listening and reading); amount of daily exposure, age of acquisition (i.e. beginning of consistent exposure) and age of acquired fluency; and daily frequency of language switching. This regression analysis allows us to investigate the relationship between these variables and language control in a more sensitive way, and it is theoretically motivated by the proposal that bilingualism is not a categorical variable (Birdsong, 2014; Hernandez, 2009; Luk & Bialystok, 2013). As we hypothesise that language proficiency is not the only factor that modulates language control, we expect to see effects of these variables on naming latencies and on the relative mix and switch costs in the two languages.

Table 1
Responses to the language history questionnaire in the two groups, and comparison (*t*-test for numerical variables, Wilcoxon test for ordinal variables).

	Italian-English	Italian-Sardinian	Comparison
Age (years)	26.3 (5.23)	30.41 (6.38)	**
Years of education	17.32 (2.65)	15.48 (3.56)	*
L1 AoA (years)	0.03 (0.16)	0.5 (1.11)	*
L1 AoA fluent	3.05 (0.57)	3.67 (1.79)	*
L1 speaking	6.54 (0.56)	6.11 (0.77)	**
L1 writing	6.3 (0.66)	6.07 (0.9)	
L1 listening	6.78 (0.42)	6.54 (0.62)	
L1 reading	6.73 (0.45)	6.48 (0.66)	
L1 exposure	4.25 (0.69)	4.87 (1.04)	**
L2 AoA (years)	7.76 (3.12)	0.93 (1.76)	***
L2 AoA fluent	19.03 (6.43)	8.3 (7.26)	***
L2 speaking	5.49 (0.84)	5.83 (0.93)	
L2 writing	5.38 (1.04)	4.98 (1.61)	
L2 listening	5.84 (0.9)	6.43 (0.65)	**
L2 reading	6.19 (0.78)	5.98 (1.29)	
L2 exposure	3.92 (0.71)	3.54 (1.01)	*
Switching frequency	4.92 (1.79)	5.24 (1.72)	

* $p < .05$.
** $p < .01$.
*** $p < .001$.

2. Method

2.1. Participants

We tested 83 participants divided in two groups. The criteria for selection were to be native speakers of Italian and highly proficient speakers of English (group 1) or Sardinian (group 2), to be aged between 18 and 40, and to have no record of linguistic or cognitive impairment. All participants completed a language history questionnaire that provided measures of their proficiency and exposure to their different languages (Luk & Bialystok, 2013; Marian, Blumenfeld, & Kaushanskaya, 2007), rated on Likert scales from 1 to 7 (where 1 is the minimum). Table 1 shows the differences across the groups.

1. Italian-English bilinguals (N = 37, 14 males, mean age 26.3 years, SD = 5.3). These participants were Italian native speakers who had been living in Scotland on average for 3.7 years at the time of testing (SD = 3.5, range: 6 months–18 years). They were recruited through the University of Edinburgh and through the Italian community in Edinburgh.
2. Italian-Sardinian bilinguals (N = 46, 22 males, mean age 30.4 years, SD = 6.4). These participants were recruited through word of mouth and social networks. Nine further participants were tested but later excluded because they were aged over 40 (N = 7), the task was interrupted (N = 1), or the participant made a high number of word substitutions when performing the task (N = 1, see below for details).

As shown in Table 1, responses to the language history questionnaire revealed that the main differences between the two groups were age of L2 acquisition (i.e. of English or of Sardinian) and extent of language exposure, as the Italian-English bilinguals were late bilinguals, and their daily exposure to English was on average higher than exposure to Sardinian in the Italian-Sardinian group. L2 proficiency was comparable in the two groups, with the exception of oral comprehension, as the average rating for Sardinian, in the Italian-Sardinian group, was higher than the average rating for English, in the Italian-English group ($p = .001$). However, the comparison of L1 and L2 proficiency within groups showed that Italian-English bilinguals gave higher ratings for their oral production ($p < .001$), written production ($p < .001$) and oral comprehension ($p < .001$) in Italian than in English. Italian-Sardinian participants, in contrast, rated only their written production higher in Italian than in Sardinian ($p < .001$), consistent with the predominantly oral nature of Sardinian. Therefore, the Italian-English bilinguals were highly proficient but less balanced bilinguals, whereas the Italian-Sardinian bilinguals were more balanced.

Italian-English participants also gave higher ratings of their Italian oral proficiency than Italian-Sardinian participants; moreover, age and years of education (used as a proxy for socio-economic status), and age of L1 acquisition differed across groups. As these differences were unexpected, we evaluated the intra-reliability of the questionnaire with a correlational analysis to check for spurious correlations between the variables. Unexpected correlations may reflect a confounding effect of age and years of education. We found correlations between age, years of education, self-rated Italian proficiency, and age of acquired fluency in Italian. Specifically, the number of years of education was positively correlated with ratings of Italian proficiency (speaking, writing, listening, and reading, all $r > 0.387$, all $p < .001$), and there was a negative correlation between years of education and age of acquired fluency in Italian ($r = -0.321$, $p = .003$). Age was also correlated with years of education ($r = 0.278$, $p = .010$). For this reason, in order to exclude the confounding effects of age and years of education on performance in the language switching task, these two measures were regressed out of the analysis (see below).

2.2. Materials, design and procedure

We created two versions of a cued language switching experiment to measure both mix and switch costs. The design was identical for the two versions, except for the language combination (Italian-English and Italian-Sardinian) and the list of words. The experiment presented pictures of common objects one by one, displayed with a cue that indicated the language to use. For each version of the task, we chose 16 words of common objects with high frequency in each language. Italian words had a mean frequency of 232.9 (SD = 512.7, CoLFIS, Bertinetto et al., 2005); English words had a mean frequency of 2871.1 (SD = 3870.7, BNC, the University of Oxford, 2007). Frequencies were not comparable due to the difference in size of the corpora, which cannot be resolved through normalisation (CoLFIS: 3 million words, BNC: 100 million words). For the Italian-Sardinian set of words, a list of 50 highly frequent Italian words was examined and translated by 6 Sardinian speakers from different parts of Sardinia, in order to check for regional differences, and then rated for frequency (on a scale from 0 to 5, where 0 was the minimum; mean: 4.9, SD = 0.2). In both versions of the task, words were further selected on the basis of number of syllables and of phonemes; in the Italian-Sardinian version we selected words that agreed in gender and number in Italian and Sardinian, and that had an identical or minimally different translation in all parts of Sardinia. For this reason, the Sardinian set presented regional alternatives for some words. If the two alternatives were different in length, the longer one was used in the comparison (see Table 2 for the lists of words). For each word, we selected a black-and-white drawing on-line, which we evaluated through an on-line survey (15 Italian native speakers named a set of 38 pictures; we selected pictures with unanimous name agreement).

Participants named each picture as quickly and accurately as possible. Their verbal responses were recorded, and their response latencies constituted the dependent measure. To measure both mix and switch costs, there were two blocks of trials: 'blocked' (always use the same language) and 'mixed' (choose the language according to the cue). Half of mixed trials were 'switch' trials (change language from the previous trial) and half were 'repeat' trials (same language as the previous trial). In total, there were two sets of blocked trials (one for each language) and four sets of mixed trials (two switch sets and two repeat sets, one for each language), so that for each language there were 64 trials for each type. The experiment began with two sets of blocked trials, first in Italian, and then in English or in Sardinian, and then it presented the four mixed sets. The total number of experimental trials was 384 (see Fig. 1 for a schematic representation of the design).

In each set of trials, and for each participant, pictures were randomized avoiding consecutive repetitions; all pictures appeared 27 times in the experiment. In mixed trials, the sequence of switch and repeat trials was pseudo-randomized by participant, so that the number of trials for each language and type was the same (switch or repeat). Also, to avoid any possible effect of the sequential order of repeat and switch trials, no more than three consecutive trials of the same type (switch or repeat) appeared sequentially. Every 32 trials, participants could take a break. In mixed blocks, after each break, given the impossibility to determine whether the first trial of the block was a switch or repeat trial, we inserted an extra dummy trial, i.e. neither switch or repeat, but identical to experimental trials (8 in total, so that 8 pictures could appear one extra time, or one picture could appear 8 extra times, or up to 7 pictures could appear more than one extra time). Half of the dummy trials were in Italian, and half were in English or in Sardinian, alternated (in Italian for the first half set of mixed trials, in L2 for the second half set, in Italian for the third and so forth) and counterbalanced across participants (in L1 for the first half set of trials for participant 1, in L2 for participant 2, and so forth).

In each trial, a fixation dot was presented for 300 ms. Then the picture appeared in the centre of the screen for 1500 ms, presented simultaneously with a language cue. After that, a black empty screen was presented for 930 ms. Participants' responses were recorded from the appearance of the picture until the appearance of the following fixation dot (see Fig. 1). To dissociate cue switching and language switching, we chose two cues for each language (i.e. two Italian flags, two flags of the United Kingdom, and two Sardinian flags; for all languages, the second flag presented the same type of visual distortion relative to the first flag, see Fig. 2, Heikoop, Declerck, Los, & Koch, 2016). The cues alternated regularly independently of the type of trial in all blocks.

The experiment began with a practice session, which included 16 blocked trials in each language (the whole set of pictures was presented first in L1 and then in L2) and 16 mixed language trials. At the end of practice trials, if a word different from the intended word was selected, the experimenter suggested the correct word. If the participant reported knowing the word, it was used in the experiment, otherwise the experiment proceeded with the alternative word spontaneously produced by the participant. This procedure allowed Italian-Sardinian participants to complete the task using the regional variants of the words that they were familiar with. Variants typically varied in one or two phonemes (e.g. "ulléras"/"ullérasa", 'glasses'); we ignored these differences after ensuring post-hoc that their length matched in number of syllables and phonemes with the Italian words. However, 13 participants

Table 2
Sets of words. Number of syllables (‘n syll’) and of phonemes (‘n phon’) matched between L1 and L2 (*t*-tests, all p > .3).

Italian-English						Italian-Sardinian					
Italian	n syll	n phon	English	n syll	n phon	Italian	n syll	n phon	Sardinian	n syll	n phon
farfalla	3	8	butterfly	3	7	farfalla	3	8	mariposa	4	8
dito	2	4	finger	2	5	dito	2	4	poddighe	3	7
gomito	3	6	elbow	2	4	gomito	3	6	cuidu/cuvidu	3	6
occhiali	3	7	glasses	2	6	occhiali	3	7	ulleras/ispijitos	4	8
tenda	2	5	curtain	2	5	chiave	2	5	giae/crai	2	4
mela	2	4	apple	2	4	ciliegia	3	7	cariasa	3	7
fiore	2	5	flower	2	4	cavallo	3	7	caddu/covaddu	3	7
scimmia	2	6	monkey	2	5	gallina	3	7	pudda	2	5
fungo	2	5	mushroom	2	6	formaggio	3	8	casu	2	4
doccia	2	5	shower	2	3	gamba	2	5	anca	2	4
torre	2	5	tower	2	3	gonna	2	5	munnedda/vardetta	3	8
matita	3	6	pencil	2	6	porta	2	5	ghenna/gianna	2	5
zucca	2	5	pumpkin	2	7	sedia	2	5	cadrea/cadira	3	6
fiume	2	5	river	2	4	uccello	3	7	puzone/pilloni	3	7
scala	2	5	ladder	2	4	croce	2	5	rughe	2	5
re	1	2	king	1	3	casa	2	4	domo	2	4
Mean	2.18	5.18		2	4.75		2.5	5.93		2.63	5.93
St. dev.	0.54	1.32		0.36	1.34		0.51	1.34		0.61	1.5

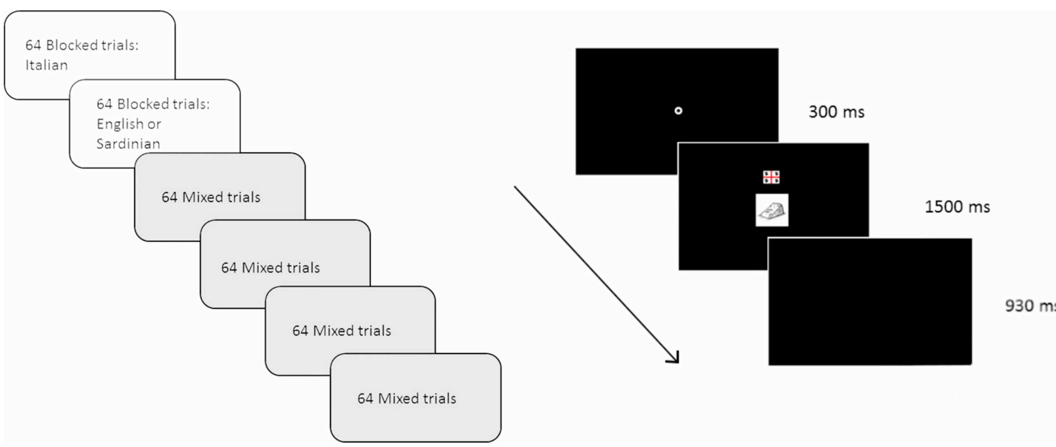

Fig. 1. Left: structure of the experiment. Right: structure of the trial.

substituted up to 4 Sardinian words with an Italian cognate (e.g. sard. “occhiàlese” instead of “ulléras” for ita. “occhiali”, ‘glasses’), 4 participants substituted up to 3 Sardinian words with the Italian translation, and 2 participants substituted 1 Italian word with a Sardinian cognate. Cognate words were excluded from the analysis; Italian forms were also excluded, together with the following trial and their corresponding trial in Italian (see Table 7 for the percentage of items excluded from the analysis by type of trial). Participants who substituted > 6 out of 16 words were excluded from the experiment (N = 1).

The experiment lasted about 30 min. It was presented on a 13″ laptop on OpenSesame 3.0 (Mathôt, Schreij, & Theeuwes, 2012). The task was administered in an experimental session (total duration: 90 min) that included the language history questionnaire, a further linguistic experiment and a test of executive functions for the purpose of another study. The order of tasks was varied between participants and groups, so that 14 participants in the Italian-English group took the language switching task first, 8 seconds, and 15 third. In the Italian-Sardinian group, 11 took it first, 12 seconds and 23 third. The order of the other two tasks was also varied across participants. To control for any possible effect of order of administration, we coded the order of the language switching task for each participant as a categorical variable with three levels, and regressed it out from all our analyses, in the same way as we dealt with age and years of education (see next section). The instructions and the language history questionnaire were in Italian. All participants signed a consent form and received £7/h in Scotland and €7/h in Sardinia for their participation.

2.3. Data pre-processing and analysis

We used an algorithm to determine voice-onset in Matlab© R2015a (the MathWorks, Inc., 2015) and conducted manual analysis to check for miscalculations of the algorithm and to determine response accuracy. Responses were coded as errors if the participant did not answer or used the wrong language or the wrong word. In such cases, the trial was marked as wrong and excluded from the analysis; the following trial was also excluded from the analysis. Trials in which the participant hesitated, or produced incomplete or “corrected” answers or non-verbal sounds before answering, were also counted as errors and excluded from the analysis; the following trial was retained. Practice and dummy trials were excluded from the analysis. Three trials in the Italian-

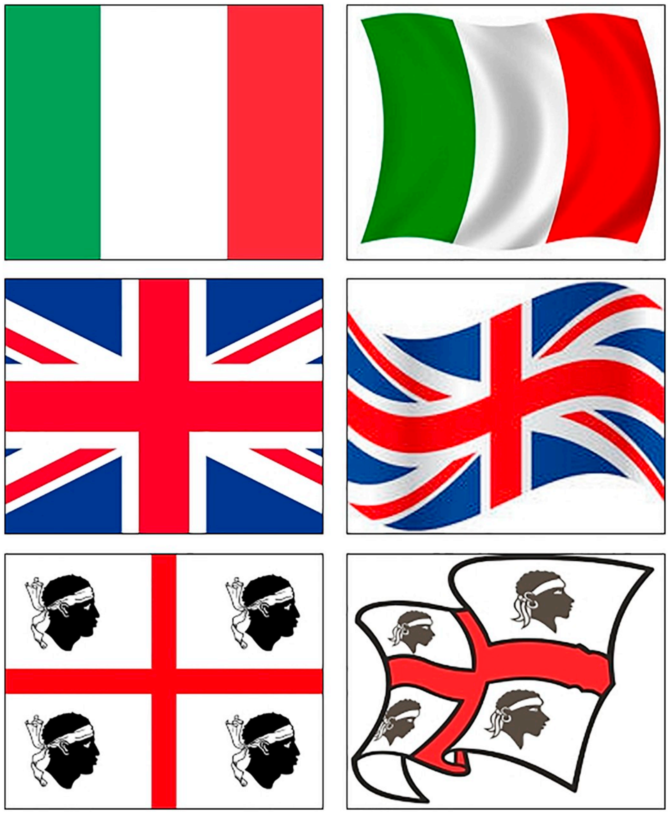

Fig. 2. Language cues. From top to bottom: Italian, English and Sardinian. Cue 1 on the left, cue 2 on the right.

Table 3
Percentage of errors and excluded data in the Italian-English group. The percentages of correct and excluded data do not sum to 100 because of different coding of incorrect responses (see Data pre-processing and analysis).

Type of trial	% correct	% outliers	% excluded
Blocked (English)	98.78	1.65	3.08
Blocked (Italian)	98.14	1.48	3.89
Repeat (English)	98.48	1.56	3.84
Repeat (Italian)	96.28	1.1	6.59
Switch (English)	97.13	1.31	5.45
Switch (Italian)	94.05	0.93	7.26
Total	97.15	1.34	5.02

Table 4
Mean RT in ms (and SD in parentheses) in Italian and English. Mix cost = repeat – blocked; switch cost = switch – repeat.

Type of trial	Italian	English
Blocked trials (RT)	814 (84)	798 (67)
Repeat trials (RT)	928 (99)	884 (89)
Switch trials (RT)	973 (108)	948 (113)
Mix cost	114 (59)	86 (46)
Switch cost	45 (43)	64 (39)

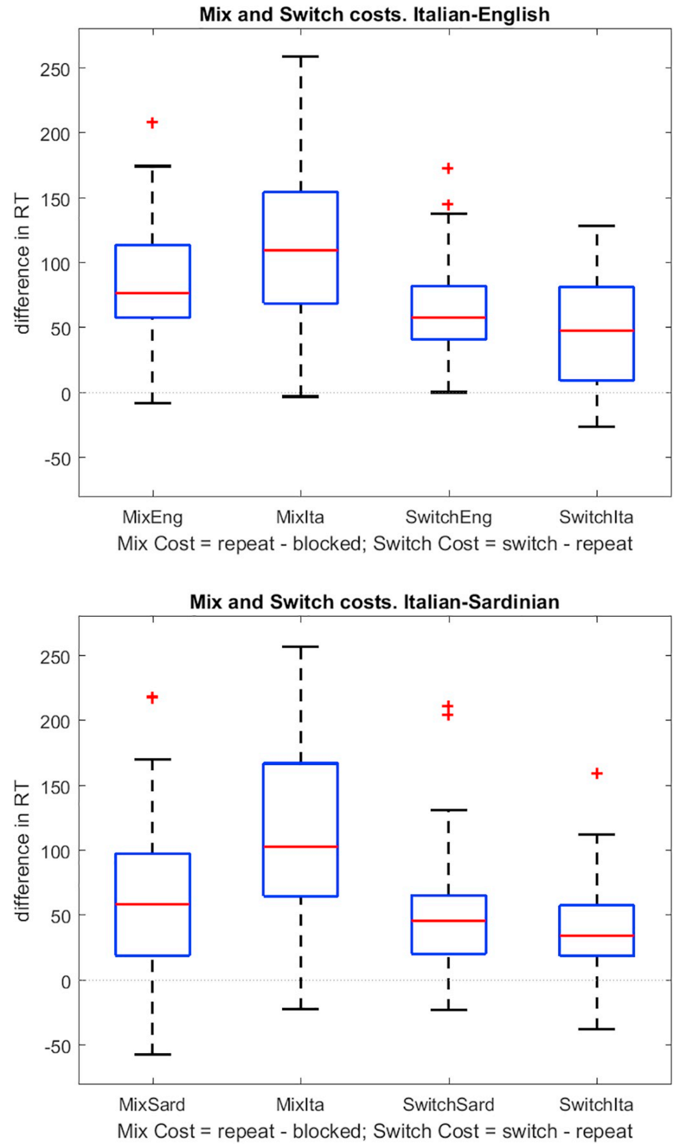

Fig. 3. Mix and switch costs in the Italian-English group (top) and in the Italian-Sardinian group (bottom). Types of costs from left to right: mix cost in L2 ('MixEng', top, and 'MixSard', bottom), mix cost in Italian ('MixIta'); switch cost in L2 ('SwitchEng', top, and 'SwitchSard', bottom), switch cost in Italian ('SwitchIta').

Table 5
Model for the analysis of Switch costs in Italian and English. Formula: ResidualRT ~ type ∗ language + (1 + type | subject) + (1 + language | subject) + (1 + language | item).

Fixed effects	Estimate	Std. error	t value
(Intercept)	−3.718	19.255	−0.193
typeswitch	46.038	6.277	7.335
languageL2	−44.064	14.024	−3.142
typeswitch:languageL2	16.809	6.545	2.568

Sardinian dataset were excluded for environmental noise that did not allow detection of voice onset.

Given the small percentage of errors, as well as the impossibility of determining accuracy when Italian forms were used in Sardinian, accuracy rates were not further analysed (presented in Tables 3 and 7). For each participant and type of trial, we calculated the mean and the standard deviation of response times (RT), and excluded as outliers RT that were 3 standard deviations from the mean (Calabria et al., 2012; Costa & Santesteban, 2004; Costa et al., 2006; Macizo et al., 2012) (Tables 4 and 8).

To control for any possible effect of age, years of education, and order of administration of the tasks, we first fitted a linear regression model on RT including these three variables as predictors. We then extracted the residuals of these models and analysed them using mixed-

Table 6
Model for the analysis of Mix costs in Italian and English. Formula: ResidualRT ~ type * language + (1 + type | subject) + (1 + language | subject) + (1 + language | item).

Fixed effects	Estimate	Std. error	t value
(Intercept)	−40.226	18.306	−2.197
typeswitch	114.090	8.004	14.253
languageL2	−16.490	14.198	−1.161
typerepeat:languageL2	−27.750	5.777	−4.804

model regression (Coco & Keller, 2015). Specifically, we fitted a model on residuals of RT, and type of trial and language as fixed effects; for the random structure, we specified a random intercept by subject and by item (i.e. word), as well as random slopes for type of trial by subject, for language by subject, and for language by item. The significance of each factor was evaluated through forward model comparison.

3. Results

First, we present a by-group analysis of switch and mix costs separately, in line with previous studies (e.g. Ma et al., 2016). Mix and switch costs in the two groups are visualised in Fig. 3. Then, we directly examine the role of specific aspects of bilingual language experience as continuous predictors (proficiency, age of acquisition, exposure and daily frequency of switching) on both costs on the whole dataset.

3.1. Italian-English

The analysis of switch cost (RT in repeat and switch trials) showed a main effect of type of trial ($p < .001$), reflecting the fact that switch trials were slower than repeat trials ($\beta = 46.038$, $SE = 6.277$, $t = 7.335$), as well as a main effect of language ($p = .011$), as both repeat and switch trials were faster in English than in Italian ($\beta = -44.064$, $SE = 14.024$, $t = -3.142$). We also found an interaction between type of trial and language ($p = .010$), as the switch cost when switching into English was larger than when switching into Italian ($\beta = 16.809$, $SE = 6.545$, $t = 2.568$) (Table 5).

The analysis of mix cost (RT in blocked and repeat trials) showed a main effect of type of trial ($p < .001$), as repeat trials were slower than blocked trials ($\beta = 114.090$, $SE = 8.004$, $t = 14.253$), as well as a main effect of language ($p = .033$): trials in English were faster than trials in Italian ($\beta = -16.490$, $SE = 14.198$, $t = -1.161$). There was also an interaction between type of trial and language ($p < .001$), as the mix cost in English was smaller than in Italian ($\beta = -27.750$, $SE = 5.777$, $t = -4.804$) (Table 6).

3.2. Italian-Sardinian

The analysis of switch cost (RT in repeat and switch trials) showed a main effect of type of trial ($p < .001$), as switch trials were slower than repeat trials ($\beta = 40.743$, $SE = 5.103$, $t = 7.984$), as well as a main effect of language ($p = .007$), as repeat and switch trials were faster in Sardinian than in Italian ($\beta = -38.758$, $SE = 12.303$, $t = -3.150$). The interaction between type of trial and language did not reach significance ($p = .081$), indicating no prominent asymmetry in switch cost between Italian and Sardinian (Table 9).

The analysis of mix cost (RT in blocked and repeat trials) showed a main effect of type of trial ($p < .001$), reflecting the fact that repeat trials were slower than blocked trials ($\beta = 110.913$, $SE = 8.891$, $t = 12.474$). The effect of language was not significant ($p = .238$), but the interaction between type of trial and language was significant ($p < .001$), as the mix cost in Sardinian was smaller than in Italian ($\beta = -45.410$, $SE = 5.878$, $t = -7.725$) (Table 10).

Table 8
Mean RT in ms (and SD in parentheses) in Italian and Sardinian. Mix cost = repeat – blocked; switch cost = switch – repeat.

Type of trial	Italian	Sardinian
Blocked trials (RT)	843 (81)	852 (64)
Repeat trials (RT)	956 (78)	918 (86)
Switch trials (RT)	995 (88)	968 (95)
Mix cost	112 (70)	66 (61)
Switch cost	40 (37)	50 (49)

Table 9
Model for the analysis of Switch costs in Italian and Sardinian. Formula: ResidualRT ~ type * language + (1 + type | subject) + (1 + language | subject) + (1 + language | item).

Fixed effects	Estimate	Std. error	t value
(Intercept)	−4.138	15.583	−0.266
typeswitch	40.743	5.103	7.984
languageL2	−38.758	12.303	−3.150
typeswitch:languageL2	10.695	6.145	1.741

Table 10
Model for the analysis of Mix costs in Italian and Sardinian. Formula: ResidualRT ~ type * language + (1 + type | subject) + (1 + language | subject) + (1 + language | item).

Fixed effects	Estimate	Std. error	t value
(Intercept)	−48.794	14.547	−3.354
typeswitch	110.913	8.891	12.474
languageL2	8.399	12.307	0.682
typerepeat:languageL2	−45.410	5.878	−7.725

3.3. Regression analysis with continuous predictors

To explore the relation between language control and bilingual experience, we further analysed RT by type of trial and language,

Table 7
Percentage of errors and excluded data in the Italian-Sardinian group. The percentages of correct and excluded data do not sum to 100 because of different coding of incorrect responses (see Data pre-processing and analysis).

Type of trial	% correct	% cognates	% Italian	% outliers	% excluded
Blocked (Sardinian)	98.91	10.43	1.63	1.66	16.27
Blocked (Italian)	99.12	0.14	1.63	1.26	5.74
Repeat (Sardinian)	97.96	10.9	1.9	1.12	17.22
Repeat (Italian)	98.03	0.07	1.6	1.12	7.61
Switch (Sardinian)	97.11	10.19	1.46	0.88	17.39
Switch (Italian)	96.94	0.14	1.43	0.95	8.15
Total	98	5.34	1.6	1.17	12.11

Table 11
Final model of Mix and Switch costs in the two groups and effects of language experience variables. Formula: ResidualRT ~ type + language + type:language + scale(ProficiencyActive) + scale(ProficiencyActive) + scale (L2BeginLearn) + scale(L2BeginLearn):language + scale(L2Exposure) + scale (L2Exposure):type:language + (1 + type | subject) + (1 + language | subject) + (1 + language | item).

Fixed effects	Estimate	Std. error	t value
(Intercept)	−78.306	11.496	−6.812
typerepeat	112.348	6.084	18.467
typeswitch	155.595	6.763	23.008
languageL2	−1.119	9.575	−0.117
scale(ProficiencyActive)	−5.279	7.29	−0.724
scale(L2BeginLearn)	−13.573	8.481	−1.6
scale(L2Exposure)	14.615	10.327	1.415
typerepeat:languageL2	−37.399	4.29	−8.718
typeswitch:languageL2	−23.872	4.297	−5.555
typerepeat:scale(ProficiencyActive)	−7.719	5.839	−1.322
typeswitch:scale(ProficiencyActive)	−17.833	6.568	−2.715
languageL2:scale(L2BeginLearn)	−15.851	5.777	−2.744
typeblocked:languageL1:scale(L2Exposure)	−12.456	8.526	−1.461
typerepeat:languageL1:scale(L2Exposure)	−20.039	6.325	−3.168
typeswitch:languageL1:scale(L2Exposure)	−10.385	5.834	−1.78
typeblocked:languageL2:scale(L2Exposure)	−8.319	6.96	−1.195
typerepeat:languageL2:scale(L2Exposure)	−5.748	3.97	−1.448

introducing continuous variables extracted from the language history questionnaire as predictors. Specifically, we pooled together data from the two groups of participants and used the following as predictors: second language proficiency, age of second language acquisition, average daily exposure to the second language, and daily frequency of language switching. With regards to second language proficiency, we considered both active proficiency (an aggregated score of speaking and writing) and passive proficiency (listening and reading). With regards to age of acquisition of the second language, we analysed age of acquisition as both onset of exposure and age of acquired fluency. For this analysis, we ran a model on RT in the three types of trials, as we were interested in comparing the role of these measures of linguistic experience on both types of language costs. We first fitted a model with age, years of education, and order of tasks as predictors. We then analysed the residuals of that model through mixed-model regression specifying the same random effect structure as in the previous analyses, and using as predictors type of trial, language (L1 vs. L2) and active and passive proficiency, age of acquisition and age of acquired fluency, daily exposure and daily frequency of language switching (Table 11).

Active language proficiency, age of acquisition, and language exposure significantly improved the model (in addition to language and type of trial, i.e. the experimental manipulations used as fixed factors). Specifically, the interaction of active language proficiency with type of trial was significant ($p = .12$), reflecting the fact that faster switch trials (in both languages) were related to higher L2 proficiency ($\beta = -17.833$, $SE = 6.568$, $t = -2.715$). Passive proficiency, however, was not significant ($p = .733$). The interaction of age of language acquisition with language was significant ($p = .008$), as a later age of L2 acquisition accounted for faster naming in L2 ($\beta = -15.851$, $SE = 5.777$, $t = -2.744$). However, age of acquired fluency was not significant ($p = .806$). Finally, daily exposure to L2 also improved the model, as it interacted marginally with type of trial ($p = .053$) and significantly with language ($p = .029$): higher exposure to L2 predicted smaller mix costs in L1 ($\beta = -20.039$, $SE = 6.325$, $t = -3.168$); it also marginally predicted smaller switch costs in L1 ($\beta = -10.385$, $SE = 5.834$, $t = -1.780$). Daily frequency of switching was not significant ($p = .331$).

4. Discussion

In a cued language switching task involving Italian-English and Italian-Sardinian bilinguals, we found an asymmetric switch cost in Italian-English bilinguals when we analysed performance by group. Interestingly, the switch cost was larger in L2 than in L1. This was surprising according to previous studies where switch costs were larger for L1 than for L2, and related accounts of language control that link proficiency, as a proxy for dominance, to strength of inhibition (e.g., Costa & Santesteban, 2004; Costa et al., 2006; Meuter & Allport, 1999, but see Declerck, Stephan, Koch, & Philipp, 2015, who also obtained bigger switch costs in L2 than L1, and related this pattern to the effect of overall L2 activation, beyond local L1 inhibition). In the Italian-Sardinian group, in contrast, we found a symmetric switch cost, in line with the previously mentioned studies on highly proficient, balanced bilinguals. Mix costs were asymmetric in both groups: mix costs into Italian were larger than into English and into Sardinian. In the case of the Italian-English bilinguals, i.e. the less balanced of our groups, this is consistent with previous findings on language mixing that relate mix costs and dominance (Ma et al., 2016; Prior & Gollan, 2011). However, this is unexpected in the case of the Italian-Sardinian participants, whose two languages were more balanced, at least from the point of view of proficiency. These patterns of mix and switch costs, across the two languages in each group, support the view that mix and switch costs index different mechanisms of language selection, as suggested by previous research that interprets switch costs in relation to reactive inhibitory processes (e.g. Costa & Santesteban, 2004; Costa et al., 2006) and mix costs in relation to proactive processes (e.g. Ma et al., 2016; Wu & Thierry, 2017).

In addition, these patterns of mix and switch costs may reflect the effects of different aspects of language experience. We tested this hypothesis through the analysis of variables related to the bilingual experience, which supported it in a number of respects. First, L2 proficiency affected switch costs. The effect of proficiency is in keeping with previous research (Costa & Santesteban, 2004; Costa et al., 2006; Meuter & Allport, 1999), but extends its impact on switch costs to both languages, and localises its effect to active proficiency (as opposed to passive proficiency): higher active L2 proficiency predicted faster switch trials in both languages.

Second, L2 daily exposure also affected switch costs: higher L2 exposure predicted both reduced switch and mix costs in L1. In relation to switch costs, higher L2 exposure appears to reduce the burden of reactively inhibiting L1; in relation to proactive control accounts of mix costs (Ma et al., 2016; Wu & Thierry, 2017), it appears to alleviate the load of proactively suppressing L1. These data show that more exposure to the L2 makes it generally easier to access and switch between the two languages, as it seems to reduce the dominance of the L1. This suggestion is in line with research on linguistic attrition, that shows that exposure to the L2 affects how the L1 is processed and ultimately maintained (e.g. Chamorro et al., 2016).

Third, in this language switching context, later age of acquisition predicted faster naming in L2, in line with Costa et al. (2006). This result does not point to a direct role for age of acquisition on local language selection (i.e., age of acquisition did not interact with trial type), but clarifies how this variable affects language access. Specifically, we suggest that, in contexts of language competition like the current experiment, early L2 acquisition relates to longer word-naming latencies in L2 in the same way as longer naming latencies in L1 are related to L1 dominance in previous research (e.g. Costa & Santesteban, 2004). That is, age of acquisition seems to complement the definition of dominance: the earlier acquired, the more dominant the language. Thereby this variable represents an important aspect in the ability to access a language.

Last, and contrary to previous studies (Christoffels et al., 2007; Prior & Gollan, 2011), our results did not show an effect of daily frequency of language switching on the modulation of either naming times or mix/switch costs. This unexpected result should be considered in the light of one possible limitation of our study, specifically our use of self-reported measures of variables describing the language experience. Self-reported measures are considered reliable, as they correlate to objective measures for instance of proficiency (Luk & Bialystok, 2013; Marian et al., 2007). We evaluated the inter-reliability of our measurements through post-hoc analyses in which we checked that measures of L1 proficiency correlated with each other, and similarly for measures of L2 proficiency. In this way, we were able to identify potential confounds such as those described in the procedure section (i.e., age and years of education). Nevertheless, it could be the case that some of our variables of interest were not captured precisely, as participants may have interpreted the questions in different ways, despite our care to avoid any ambiguity in wording. If participants differed in their interpretation of some questions, we would expect to find no effect of the variables most affected by ambiguity. This may be the case of daily frequency of switching, as our question referred to various conversational contexts (i.e., sentences, conversations, situations). This could also be the case of age of acquired fluency in L2, as participants may have interpreted more or less strictly what 'fluency' means, for example in reference to different contexts of use of English or Sardinian.

A further limitation of our study lies in the fact that the differences between the two groups are not only captured by the continuous variables examined in our regression analysis, but also by language distance. Italian and Sardinian are of course more closely related than Italian and English, in that they are both Romance languages, and they display numerous similarities. In addition, Italian, Sardinian and English do not have the same status: Sardinian is a minority language in Sardinia, and it only became an official language (alongside Italian) in the 1990s.

Language distance very likely represents an important factor for bilingual language processing (for example because closely related languages may give rise to more interference, and therefore require more control processes[1]). In this study, we controlled for language distance at the local level by checking for cognate status, and matching words across languages using the same criteria in both the Italian-English and the Italian-Sardinian version of the task. However, we did not include this factor in the across-group analysis, as we focused our attention on continuous variables of language experience and excluded the group predictor to avoid collinearity with those variables. Hence, our regression analysis could not have detected effects of language distance. While we believe that language distance effects on language control at the global level have not been previously reported, we believe they represent an important venue for future research on language control.

5. Conclusion

Our study shows a dynamic interplay of multiple dimensions of the bilingual experience in the modulation of language access and control. Beyond L2 proficiency, language switching is also modulated by daily L2 exposure, which also mediates language mixing. Finally, L2 age of acquisition predicts overall latencies in accessing the L2. These results show that language dominance is not only language proficiency, and provide a bridge between mechanisms of language control and specific aspects of language experience. Our study suggests that future research should focus on aspects of bilingualism that extend beyond proficiency, and emphasises the importance of adopting a multidimensional perspective to accurately capture the multifaceted nature of bilingualism and its relationship to language control.

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Declarations of interest

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