Similar conceptual mapping of novel objects in mixed- and single-language contexts in fluent Basque-Spanish bilinguals

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Abstract

Participants learned the meaning of novel objects by listening to two complementary definitions while watching videos of the new object, in a single-language context (all in Spanish) or a mixed-language context (one definition in Basque, one in Spanish). Then, participants were asked to assess the degree of functional relatedness between novel and familiar objects in two conditions: Identical (both definitions overlap) or related (single definition overlap). Relatedness ratings differed significantly between conditions, but they were highly similar across language contexts. Furthermore, items in the identical condition elicited a P300-like event-related potential component, while related items elicited a wave of lesser amplitude. Critically, the amplitude differences between conditions did not differ between language contexts. No interaction was found with proficiency level across participants. In line with previous findings, we show no measurable impact of mixing languages during the establishment of a link between novel objects and existing conceptual representations in bilinguals.

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Author contributions: EA, GT, MD and JAD designed the experiment. EA and JAD created the materials and programmed the experiment. EA collected the data and analyzed the experiment under the supervision of GT and JAD. EA, GT, MD and JAD discussed the results and wrote, reviewed and approved the main manuscript text together.

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Introduction:

Bilingualism is now the norm rather than the exception worldwide (Grosjean, 2010) and it is a steadily increasing phenomenon (Crystal, 2018). The ability to speak more than one language has been argued to affect a range of speakers' cognitive (Bialystok, 2006; Paap, Johnson, & Sawi, 2015), linguistic (Kaushanskaya & Marian, 2009; Kovelman, Baker, & Petitto, 2008) and, crucially, social abilities. For instance, bilinguals often and spontaneously switch from one of their languages to the other, see Auer, 2013; de Bruin, Samuel, & Duñabeitia, 2018). In experimental contexts, such code-switching has beenº shown to hinder and slow down performance in tasks based on language perception (Grainger & Beauvillain, 1987; Thomas & Allport, 2000) and production (Costa & Santesteban, 2004; Meuter & Allport, 1999), as compared to analogous situations in monolingual contexts. Nonetheless, bilinguals often choose to switch between languages when they are free to do so (de Bruin et al., 2018; Gollan & Ferreira, 2009). Such switches do not seem to impair communication in real life, and bilinguals are accustomed to receiving and transmitting information in a mixed-language context.

This situation is particularly frequent in bilingual communities who are trying to preserve or strengthen a minority language (see, for example, the case of Wales; Lewis, 2008) or in communities with strong presence of a foreign language (e.g., teaching of English in South Korean high schools, Williams, 2017). In contrast with situations encountered in everyday life, alternated language use is often actively discouraged and effectively avoided by instructors in formal education. Probably because mixing languages is considered to have a potentially –albeit unproven– negative impact on learning, bilingual schools systematically avoid mixing language contexts when teaching particular academic subjects, instead recommending monolingual interaction within each given subject (e.g., the Two-Way Immersion program Alanís, 2000). However, this principle, sometimes referred to as the "one subject-one language" approach, is yet to receive a scientific validation. In fact, such practice might have some disadvantages. From the linguistic point of view, students only acquire relevant vocabulary and knowledge for each subject in a single language, and may thus be unable to fluently express their knowledge in the other language. In addition, some studies have recently reported cognitive benefits of learning in a dual-language contexts, showing that bilinguals who have to switch constantly between languages can outperform bilinguals in single-language contexts involving domain-general task-switching (Hartanto & Yang, 2016). Voluntary language switching has also been shown to facilitate bilinguals' language production in multilingual contexts as compared to single-language situations (de Bruin et al., 2018). It is thus possible that avoiding language mixing in the classroom may have some drawbacks.

The effects of mixing languages during tuition, and more specifically during learning, have seldom been tested. In an attempt to shed light on this issue on the basis of behavioral evidence, Antón and his colleagues (Antón, Thierry, & Duñabeitia, 2015) presented Basque-Spanish balanced bilingual children and adults with pictures of unknown objects along with two definitions written in Spanish (single-language context, SLC) or with one definition in Spanish and the other in Basque (mixed-language context, MLC). Participants learnt to associate each of the unknown objects with its definitions and complete a series of memory tasks. Given the cognitive cost associated with language switching, one could have expected learning in the MLC to be less effective. However, Antón et al. found no difference in learning accuracy or speed between contexts. In a subsequent study, Antón and colleagues (Antón, Thierry, Goborov, Anasagasti, & Duñabeitia, 2016) exposed unbalanced Russian-English bilingual children to speaking avatars who produced pairs of definitions describing common and well-known objects in an SLC or an MLC before children's recognition of the objects was evaluated. Although participants were not balanced in their use and knowledge of the two languages, no difference was found in object recall between exposure contexts. Absence of measurable difference at a behavioral level, however, does not imply absence of difference at a neurophysiological level (see, for example, Thierry &

Wu, 2007; Wu & Thierry, 2010, 2012, for brain potentials revealing between-language effects that weren't present in the behavioral measures) In other words, learning in an MLC could incurred an additional cost compensated by more efficient encoding or retrieval mechanisms, such that differences between contexts at a neural level would not transpire behaviorally. In order to investigate this question further, we turn to event-related brain potentials, which provide a more direct index of conceptual processing (e.g., the N400) and target detection (e.g., the P300) than behavioral measures and allow to track phases of information processing with high temporal resolution from the onset of a stimulus up to the stage of response planning (e.g., Kutas & Federmeier, 2011; Kutas & Hillyard, 1989). The goal here was thus to determine whether differences between a single- and mixed-language contexts could be detected in a concept matching task involving new objects, using the P300 wave as the index of choice.

Here, we invited highly proficient Basque-Spanish bilinguals (see Methods) to take part in a two-sessions experiment featuring a familiarization and a testing phase. In the familiarization phase, participants had to link novel objects with existing familiar objects based on two definitions, either delivered in the same language (Spanish, i.e., single language context) or one definition in Spanish and the second definition in Basque (i.e., mixed-language context). In the testing phase, we then measured the strength of the link between novel objects and existing conceptual representations by asking participants to make relatedness judgments on novel object – familiar object pairs. As in the study by Antón and colleagues (Antón et al., 2015), the degree of relatedness between novel objects and familiar objects was systematically manipulated between trials. Novel object primes and familiar object targets were considered *identical* when they shared two definitions and *related* when they shared only one of the two definitions. As for novel objects primes and familiar targets sharing neither of the two definitions, they were considered *unrelated* fillers. They were fillers because familiar object targets in the unrelated condition were different from those used in the identical and related conditions, in order to increase stimulus variability and reduce picture repetition effects leading to semantic satiation, whilst at the same time enhancing the P300 effect in the identical condition.

Since stimulus pairs in the identical condition formed one third of trials, we expected familiar object targets in this condition to elicit a P300 component, usually elicited by rarer target (match) trials within a series of more frequent trials that are not targets (standards). The P300 is known to be sensitive to repetition effects, with larger positivity for stimuli (e.g., words, nonwords, faces) that are immediately repeated in a sequence versus presented once (Bentin & McCarthy, 1994). The P300 is a good test of memory because it responds well to stimulus repetition across learning and testing phases of an experiment. For example, when Bentin & Moscovitch, 1990 presented participants with words they had previously seen in a familiarization phase (i.e., repeated) within a stream of new words (never presented before), repeated stimuli elicited a positive component of larger amplitude than the new ones, in both implicit and explicit memory tasks (see also Bentin, Moscovitch, & Heth, 1992). Such repetition effect was also found for faces and drawings of daily life objects in a study by Guillaume and colleagues (2009), who found that items previously presented (i.e., old or repeated items) elicit P300 modulations as compared to new items. Furthermore, it is noteworthy that the P300 responds not only to perceptual similarity of the target (Azizian, Freitas, Watson, & Squires, 2006) but also to semantic similarity independently of visual similarity (see Alexander & Zelinsky, 2013). The repetition effect is critical for our experiment, since our identity condition consists on a conceptual repetition between novel object primes and familiar targets. In the present study, we thus anticipated to measure the largest P300 amplitudes for items in the *identity* condition, that is, for best matches between novel and familiar objects, considering that only two definitions were provided during the familiarization. Assuming that language mixing would make the link between novel and familiar object more difficult to learn or 'blurrier', we would expect P300 amplitude to be reduced for mappings created in an MLC as compared to those created in an SLC. Whilst results from Antón et al. (Antón et al., 2015, 2016) suggest that differences between language contexts may not be behaviorally measurable in recall and recognition tasks, they may well be detectable at the neurophysiological level (Thierry & Wu, 2007; Wu & Thierry, 2010, 2012). In addition, we tested whether P300 amplitude would correlate with individual proficiency in the second language.

Methods

Participants

Forty-four graduate and undergraduate students (28 women, mean age 23.9, SD=2.9 years) took part in the experiment. All were right-handed speakers of Basque and Spanish, had no history of neurological impairments, and had normal or corrected-to-normal vision. Participants acquired both their languages early in life (mean age of Basque acquisition=1.4, SD=1.7; mean age of Spanish acquisition=0.6, SD=1.2) and self-reported a high level of mastery in both Basque (M=8.5, SD=1.6) and Spanish (M=9.5, SD=0.7) measured on a scale of 1 to 10. Participants gave their informed consent to participate in the experiment that was approved by the BCBL Ethics Committee and carried out in accordance with the relevant guidelines and regulations. Six participants were removed from the analyses due to excessive noise levels on their EEG recordings (see below), leading to a final sample of 38 participants.

Materials and Design

Forty-four tri-dimensional pseudo-objects were generated using Shapeshifter (Autodesk®, a free online computer assisted design software, after which they were modified using Cinema 4D (Maxon®) to increase discriminability (**Fig. 1**). The pseudo-objects were then displayed in the middle of a 19" CRT monitor (with a refresh rate of 100 Hz) on a white background, and video-recorded at a resolution of 1280 x 720 at a sampling rate of 25 fps while spinning around both their vertical and horizontal axes, using After Effects (Adobe®). Each resulting video clip was then trimmed to a duration of 8 seconds (video clip samples can be found here: https://figshare .com/s/276ed9a5f327cc1b77bb).

Pseudo-objects were each paired with two definitions conceptually connecting them to 44 highly familiar existing objects. Importantly, the familiar objects were also associated among them two-by-two so as to form 22 related object pairs (e.g., fork-spoon, candle-light bulb, scarf-glove) and thus any two related objects shared one of the two definitions used for novel object learning but not the other. For example, the novel object associated with *glove* was defined using the two definitions: "*it's a piece of winter clothing*" and "*you use it on your hands*", and the novel object associated with *scarf* was defined using "*it's a piece of winter clothing*" and "*you use it to protect your throat*", respectively. Thus, only one of the two definitions was discriminative and both had to be processed in order to successfully identify a novel object associate.

To ensure that both definitions were required to correctly associate novel and familiar objects, we asked 10 native speakers of Spanish to guess which object was defined by the first (shared) definition. These participants produced the names of the objects used in the experiment only 8.4 % (SD = 11.4) of the time. When they were provided with the two definitions, mean accuracy rose to 94.8 % (SD = 7.0). We also asked 10 other native speakers of Spanish to make semantic relatedness judgments on the familiar objects corresponding to the definitions. Familiar objects were presented by two in succession on a screen, with related pairs (e.g., glove-scarf) randomly intermixed with unrelated pairs (e.g., glove-calculator). Participants saw three different tokens for each familiar concept (e.g., three different types of glove) so as to reduce visual similarity effects and they rated the relatedness between prime and target on a scale from 1 ("completely unrelated") to 7 ("completely related"). Related pairs were rated 5.8 (SD = 1.2) on average, and unrelated pairs were rated 1.5 (SD = 0.5) on average.

The 44 pseudo-objects and the 44 familiar objects were then associated in pairs that overlap with regards to both definitions, hereafter the *identical* condition, and pairs that only overlapped with respect to one definition, hereafter the related condition. Another random set of 44 familiar objects completed unrelated to the familiar objects were also presented with the learned pseudo-object to serve as fillers (unrelated). The other critical independent variable manipulated in this experiment was the language context of learning. For each participant, 22 pseudo-objects were learned in a single-language context (SLC, both definitions in Spanish) and the other 22 in a mixed-language context (MLC, one definition in Spanish and the other in Basque) such that two related objects were assigned to a different learning context. To avoid baseline differences between contexts, we compared concept relatedness and informativeness of definitions across lists and found no significant difference (*p*s > .27). Another set of 10 native speakers of Spanish performed a conceptual relatedness decision task on the familiar objects that were later used as experimental materials. Thus, all the familiar objects were visually presented to them as prime and targets, which could either be the two items of a related pair (e.g., scarf-glove) or one of them with its associated unrelated/filler item (e.g., scarf-megaphone). Participants' task was to indicate, as quickly as possible, whether a conceptual relation existed between the prime and the target. Related pairs were responded to faster (an average of 588 ms) than unrelated filler pairs (mean RT= 687 ms, p<.01).

Definitions were voice recorded by the same male native bilingual speaker of Basque and Spanish. Each of the 44 tridimensional pseudo-objects were randomly paired with the definition of one of the 44 real objects from the related list (e.g., **Fig. 1**). These materials were first introduced in the learning phase prior to the testing phase.

Pseudo-object

Context of learning	Mixed Language	Single Language
Associated Concept	Glove	Scarf
Definition 1	*"It's a piece of winter clothing"*	*"It's a piece of winter clothing"*
Language of definition 1	Spanish	Spanish
Definition 2	*"You use it on your hands"*	*"You use it to protect your throat"*
Language of definition 1	Basque	Spanish

Figure 1. Example of the experimental materials. A related pseudo-object pair is shown together with information about the context in which they were presented, the associated concepts, and the two definitions that had to be learned with the pseudo-objects.

Procedure

The session was conducted in a soundproofed Faraday room. Experiment Builder (SR Research®) controlled stimulus presentation and recorded behavioral data. EEG data during the test phase were recorded using Brain Vision Recorder (Brain Products®). Participants sat approximately 70 cm away from a high-resolution CRT monitor and wore headphones (Sennheiser®, model PC 151).

In the learning phase, participants had to remember the meaning of the novel pseudo-objects by associating each of them with two definitions. In total, they learned the definitions of 44 pseudo-objects, half in a SLC and half in the MLC. The only way to successfully associate a novel object with a familiar concept was to assimilate both the definitions given, irrespective of the language in which they were presented. A trial of the learning phase unfolded as follows: First, a black fixation cross was presented on a white background appeared for 1000 ms; then a videoclip of a novel object (spinning in 3d) was presented for a duration of 8000 ms; the first definition was played through headphones starting 1000 ms after the video clip onset and the second definition was played 3000 ms after the end of the first; then, once the video had ended, a new fixation cross appeared for 1000 ms, announcing the next trial. After seeing all object-definition associations once, the definitions were presented again in a different order in a further two blocks. The order of videos and definitions was pseudo-randomized, such that participants never heard the same definition twice in the same block, and novel objects sharing a definition (one belonging to SLC and one to MLC) were never presented in immediate succession. Apart from those two conditions, item presentation was randomized across participants. Video display was automatized and participants did not have the freedom to control the speed of presentation.

After the learning phase, the EEG cap was set up over the course of 20-30 min. During the following testing phase, participants were instructed to make a relatedness judgment on pseudo-object–

familial object pairs presented in succession by pressing buttons on a response box (DirectIn 9 Buttonbox, Empirisoft®). In each trial, a black fixation cross appeared in the center of the screen for 1000 ms on a white background. Then the video depicting a pseudo-objects (prime) was presented for a maximum of 8000 ms and until the participant pressed the spacebar to indicate that they had identified the novel object depicted (the corresponding reaction time is hereafter referred to as stop latency). Whilst the resulting reaction time was admittedly contaminated by concurrent processes, this measure offered additional comparative behavioural assessment of the two language contexts, MLC and SLC. A 500 ms blank screen followed the spacebar press, and a checkerboard pattern was then shown in order to clear the visual memory buffer before another 500 ms blank screen. Finally, the picture of a familiar object was presented for 1000 ms as the target of a pair. As described above, familiar object targets could overlap with novel object primes in relation to both the definitions familiarized (i.e., *identical* condition), only one of the two definitions (i.e., *related* condition), or neither (i.e., unrelated filler). After a 500 ms blank screen following the presentation of a target, participants rated the association between the pseudo-object and familiar object in a pair on a scale from 1 (completely unrelated) to 7 (strongly related). Each novel objects was presented three times per condition, leading to a total of 9 presentations. In order to reduce repetition effects due to the repeated presentation of the same physical image, the three pictures used as targets in each of the three conditions were different, albeit referring to the same familiar concept (e.g., three different pictures of a glove). Item sequence was randomized, but trials containing the three different versions of the same target object were never presented in immediate succession.

Behavioral data analyses

As described above, two behavioural indicators were collected – the time taken by the participants to stop the presentation of the video showing the learned novel object (i.e., RTs) and the relatedness value given to each pseudo-object and familiar object pair (ratings). RTs above and below 2.5 standard deviations from the mean in each condition (identity, related) and in each context (SLC, MLC) were considered outliers, ending in a total of 3.5% of trials removed due to this. Averages for each condition and context were analysed (see below). Rating values were averaged for condition and context, and were subsequently analyzed without further processing.

EEG recordings and analyses

Continuous EEG signal was recorded using a 32-channel Brain-Amp system at a sampling rate of 250 Hz from 27Ag/AgCl electrodes mounted on an Easy Cap and positioned according to the 10-10 International system (Fp1/Fp2, F3/F4, F7/F8, FC1/FC2, FC5/FC6, C3/C4, T7/T8, CP1/CP2, CP5/CP6, P3/P4, P7/P8, O1/O2, Fz, Cz, Pz). Four additional electrodes allowed monitoring of eye movements and blinks, one situated above the right eye, one below it, and two situated over lateral canthi. An electrode placed over the left mastoid (A1) was used as the online reference. And the right mastoid was monitored separately (A2). Scalp impedances were kept below 5 kΩ, and those of the electrodes affixed to the face were kept below10 kΩ.

EEG signals were re-referenced offline to the algebraic mean of the left and right mastoids, and offline digital filters were applied (High-pass: 0.5 Hz, 24 dB/octave, Low-pass: 20 Hz, 24 dB/octave). Eye-blink artefacts and other electrical artefacts exceeding ±75 μV in amplitude were rejected automatically, and a further visual inspection was conducted to exclude any epoch with remaining artefacts. Only participants with at least 50% of clean trials were kept, which resulted in the exclusion of 6 participants. ERPs were computed by averaging EEG segments from 200 ms before target onset up to 1000 ms post-target presentation (i.e., the time that the target items remained on the screen) using pre-stimulus activity as baseline. After cleaning, 71% of the segments were kept on average, evenly distributed across conditions (range 66–76%). Based on previous literature, P300 mean amplitudes were collected and analysed between 350-450 ms after target presentation onset over centroparietal electrodes (CP1, CP2, P3, PZ and P4).

Results

Behavioural results

In the test phase, immediately after stopping the video introducing the novel object prime, participants were presented with a familiar object target and made a relatedness judgment concerning the novel-familiar object pair. Stop latencies did not differ significantly between language contexts, $t(378) = 0.88$, $p = .39$, MLC: M = 1479 ms, SD = 953 ms; SLC: M = 1493 ms, SD = 951 ms. Explicit relatedness ratings, used as index of perceived semantic similarity, were analysed using a 2 (Context: MLC, SLC) x 2 (Relatedness: identical, related)[i] repeated measures ANOVA (Table 1). We found a main effect of Relatedness, $F(1, 37) = 144.72$, $p < .001$, such that pairs in the identical condition were rated as more related than those in the related condition. There was also a main effect of Context, $F(1, 37) = 7.93$, $p < .01$, showing that ratings were higher for associations learnt in an SLC than an MLC. Critically, we found no interaction between Context and Relatedness, $F(1, 37) = 1.01$, $p =.32$, and thus ratings were not significantly differentially affected by language context.

Table 1. Mean ratings of the Relatedness Judgment task indicating the averaged value on a scale from 1 to 7 obtained in the experiment. Standard deviations are displayed between parentheses.

	Learning Context			
Relatedness	**Single-Language Context (SLC)**		**Mixed-Language Context (MLC)**	
Identical	6.44	(0.80)	6.32	(0.89)
Related	4.09	(1.14)	4.02	(1.13)

ERP Results

Mean ERP amplitudes in the P300 time window were significantly modulated by Relatedness, such that P300 amplitudes elicited in the identical condition were greater than in the related condition, $F(1, 37) = 38.65$, $p <. 01$, (see Fig. 2). There was no effect of language context, $F(1, 37) = 0.30$, $p =.59$. The interaction between the two factors was not significant, $F(1, 37) = 0.03$, $p =.86$.

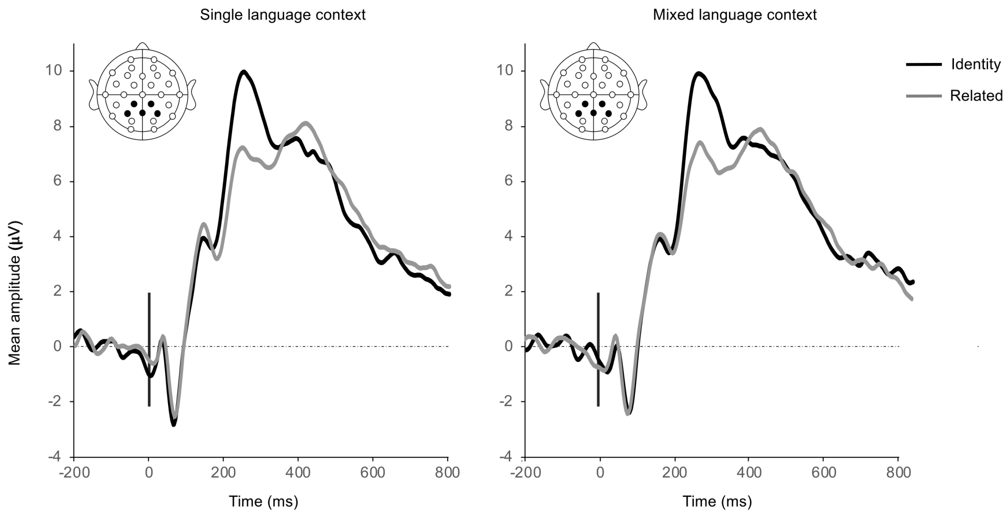

Figure 2. ERPs elicited in the Identical and related conditions, in the SLC and the MLC respectively.

Individual differences

In order to explore the potential role that participants' linguistic background might have played in their learning behaviour, additional analyses were conducted including individual Basque and Spanish proficiency and age of acquisition values as predictor variables together with the Context factor in a series of linear regression analyses with both the behavioural and the ERP data as dependent variables. To this end, the Relatedness effect was calculated both for the behavioural data (namely, the differences between language contexts in the ratings given in response to the identity and related conditions) and for the electrophysiological responses (namely, the difference in P300 mean amplitude across contexts), and linear regression analyses were run between said indices and the language characteristics of the participants. The analysis of the behavioural ratings showed a marginally significant linear regression model $F(5,70)=2.01$, $p=.088$, R=.354, and the only significant predictor of relatedness ratings was participants' age of acquisition of Spanish, $t=-2.98$, $p=.004$ (see **Table 2**). Participants who had acquired Spanish earlier in life showed the largest behavioural differences. The analysis on the magnitude of the

P300 replicated this observation, resulting in a significant regression model, $F(5,70)=2.87$, $p=.02$, R=.413, such that the Relatedness effect could be effectively predicted also by participants' age of acquisition of Spanish, $t=-2.54$, $p=.013$. No other factors contributed significantly to the magnitude of the relatedness effect (see **Table 2**).

Table 2. Results of the linear regression analysis conducted with behavioural (left) and ERP (right) Relatedness effects as dependent variables.

Behavioural

Predictor	Estimate	SE	t	p
Intercept	4.48	2.08	2.15	0.04
Context: SLC – MLC	0.05	0.27	0.17	0.86
Basque Proficiency	-0.04	0.15	-0.25	0.80
Spanish Proficiency	-0.15	0.20	-0.74	0.46
Basque AoA	-0.16	0.11	-1.43	0.16
Spanish AoA	-0.34	0.12	-2.98	0.00

EEG

Predictor	Estimate	SE	t	p
Intercept	5.57	3.68	1.52	0.13
Context: SLC – MLC	-0.07	0.47	-0.14	0.89
Basque Proficiency	0.02	0.26	0.06	0.95
Spanish Proficiency	-0.40	0.35	-1.15	0.26
Basque AoA	0.25	0.20	1.26	0.21
Spanish AoA	-0.52	0.20	-2.54	0.01

Discussion

To our knowledge, this is the first neurophysiological and behavioral comparison of conceptual mapping between novel and familiar objects in single- and mixed-language contexts. A robust behavioral and neurophysiological relatedness effect was found in both contexts (i.e., SLC and MLC): Participants judged item pairs sharing two functional properties (or definitions) as more semantically related than items pairs sharing only one definition. This can be taken as evidence for successful conceptual mapping in both contexts. However, we also found a main effect of language context on relatedness ratings, such that ratings tended to be greater in the SLC than the MLC.

Critically, we found no interaction between relatedness ratings and language context, suggesting that mapping occurred in a similar fashion in the two contexts. In addition, P300 amplitudes recorded at around 300 ms after target picture onset were largest in the identical condition and significantly greater in that condition than in the related condition. Such modulation was expected, given that P300 amplitude indexes target detection (or match trials) and can serve as an index of semantic similarity between a prime and a target (Alexander & Zelinsky, 2013). Indeed, previous studies of item memorization have shown that P300 manifests in response to the presentation of previously studied items and is greater in amplitude for repeated or old as compared to new items (Bentin & Moscovitch, 1990; Bentin et al., 1992). In the present study, participants were presented with a video of the learned object and then asked to rate its functional relatedness with a target concept, in a procedure somewhat similar to the paradigm employed by Flecken and colleagues (Flecken, Athanasopoulos, Kuipers, & Thierry, 2015). Flecken and colleagues (Flecken et al., 2015) found a similar modulation of the P300 component, with fully matching targets evoking a more positive going component as compared to partially matching targets.

Hence, after a short exposure only, bilingual participants were able to map new objects with existing concepts, whether this was achieved through one or two languages. In other words, this is new evidence for comparable levels of learning performance in bilingual and monolingual contexts, and this effect obtains for both behavioural and electrophysiological correlates of visual recognition. To our knowledge, this is the first time that successful semantic encoding/retrieval is shown both at a behavioural and neurophysiological level for concepts acquired from definitions in a setting emulating a bilingual learning context. Importantly, the different responses obtained in the identical and related conditions show that participants did not only learn contingencies or merely associate each item with a category, but rather identified and assimilated specific traits of similarity between them. Thus, participants must have engaged in individual processing of the definitions presented for each object, independently of the number of languages introduced in the familiarization phase. It is worth noting that the materials were created so as to discourage participants focusing on only one language, given that the pairs in the identical and related conditions could only be discriminated by taking into account the definition presented in a different language, the common-language definitions being identical across conditions (see Methods).

The second, and perhaps more important, observation from the current study relates to the absence of differences between the depth and strength of semantic mappings of the concepts learned in the two language contexts. There was no behavioural difference between contexts in the magnitude of the relatedness effects measured, since behavioural outcomes were comparable between learning contexts, which is consistent with previous findings showing no measurable behavioural difference induced by language mixing during learning (see Antón et al., 2015, 2016). If one considers the ERP amplitude in the P300 range as an index of conceptual mapping strength, these results provide no evidence for weaker conceptual mapping in a mixed-language context. The only sign of a difference was found between contexts overall, with items learned in the SLC yielding overall higher relatedness judgments than items learned in the MLC. This finding does not speak to learning differences between contexts, however, since the difference between related and identical conditions had the same magnitude within each language context. This observation might relate to the way in which information given in particular language is processed in bilinguals, independently of language mixing (see, for instance, the “anchoring contraction effect” or ACE, De Langhe, Puntoni, Fernandes, & Van Osselaer, 2011), suggesting that bilinguals can respond more or less intensely depending on the language in which information is presented.

In light of the current results, we believe that neural encoding of information acquired in a mixed- and single-language contexts are so far indistinguishable in highly proficient bilinguals who have acquired their two languages early in life, in line with preceding evidence suggesting that mixing languages has no measurable impact on the behavior of the participants (see also Antón et al., 2015, 2016). Moreover, the individual difference approach exploring a possible relationship between linguistic background (i.e., the age of acquisition of the two languages and proficiency levels) and markers of conceptual mapping, whether behavioral or electrophysiological, failed to show any consistent modulation as a function of self-reported proficiency. The only significant effect was one of age of acquisition of Spanish: The earlier participants had acquired Spanish, the greater the behavioral and electrophysiological relatedness effects. As a cautionary note, however, it should be kept in mind that variability between participants in our study was low, and future studies will have to ascertain whether such results would replicate in samples of less proficient and/or late bilinguals.

There is currently no empirical evidence supporting the widespread belief that mixing languages is detrimental to learning, and indeed, in the current study, such practice did not affect the neural mechanisms involved in mapping newly learned objects onto existing conceptual representations. Recall that the hypothesis tested here was formulated on the basis of educational practice in bilingual environments, whether natural (e.g., in the Basque country or in Wales; Lewis, 2008) or strategic (e.g., South-Korea; Williams, 2017, or The Netherlands). Since learning is hardly ever assessed on the basis of neurophysiological measures, the potential effects of mixing languages on new semantic representations have been overlooked so far. Given that we found no evidence of a detrimental effect of mixing languages on new conceptual link formation, one could argue that a mixed language context may not be costly for at least some phases of conceptual processing during learning. This could invite experimentation with mixed-language learning contexts in the classroom, provided the teacher or educator masters the languages in question, rather than using one only, thus benefitting from the wide collection of cognitive and cultural advantages associated with a rich bilingual environment (see e.g., Hartanto & Yang, 2016).

The question remains, however, as to whether learning in a single- or a mixed-language context yields semantic memories that are equally stable over time, and whether the neural and behavioural patterns observed evolve differently during the construction and maintenance of long-term memory representations. Furthermore, for these findings to be generalizable, they would need to be replicated using different objects types, richer definitions, and entirely novel concepts rather than simply novel objects to be mapped on existing concepts, and also different language pairs. In the present data, there is a substantial risk of a ceiling effect since most of the participants performed very well in a relatively easy task, and this was likely aided by high levels of proficiency in both languages. Also the context employed here involved inter-sentential code-switching since languages were never mixed within definition but only between consecutively presented definitions. Recent studies in children have shown that inter-sentential code-switching incurs relatively little cost in terms of cognitive resources as compared to intra-sentential code-switching (Byers-Heinlein, 2013; Byers-Heinlein, Morin-Lessard, & Lew-Williams, 2017). In future research, it might be interesting to use harder-to-remember or more abstract definitions, fewer repetitions, more definitions, and conceptual novelty. Importantly, the same hypotheses should be tested in other bilingual populations. The participants tested here were all Basque-Spanish bilinguals, and the Basque Country is a truly bilingual community were both languages are official. Everyone there is fluent in Spanish, but only around half of the population is fluent in Basque, meaning that Basque-Spanish bilinguals need to switch languages constantly, depending on the contexts and the interlocutors. This highly-switching profile could make them less susceptible to be affected by mixing as presented in the present research.

The present study offers new insights into the behavioural and neurophysiological effects of language mixing during learning. Mixing languages does not directly impede conceptual mapping and memorization from a performance point of view, and event-related potential data showed that underlying neurophysiological processes underlying such conceptual mapping are indistinguishable for concepts acquired in a single and dual language context, at least in the conditions established in the present study. Future studies will hopefully continue addressing important questions concerning learning in a multilingual context with implications for educational practice and use neurophysiological evidence to inform educational practitioners and policy makers regarding the impact of language context or lack thereof on learning.

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[i] It should be noted that familiar stimuli unrelated to the learnt pseudo-objects were not included in the analysis, given that they were fillers involving familiar objects that were different from the those presented in the *identity* and *related* conditions (see Methods section).

References

Alanís, I. (2000). A Texas Two-way Bilingual Program: Its Effects on Linguistic and Academic Achievement. *Bilingual Research Journal*, *24*(3), 225–248. https://doi.org/10.1080/15235882.2000.10162763

Alexander, R., & Zelinsky, G. (2013). The P300 is an electrophysiological correlate of semantic similarity. *Journal of Vision*, *13*(9), 501–501. https://doi.org/10.1167/13.9.501

Antón, E., Thierry, G., & Duñabeitia, J. A. (2015). Mixing Languages during Learning? Testing the One Subject-One Language Rule. *PloS One*, *10*(6), e0130069. https://doi.org/10.1371/journal.pone.0130069

Antón, E., Thierry, G., Goborov, A., Anasagasti, J., & Duñabeitia, J. A. (2016). Testing Bilingual Educational Methods: A Plea to End the Language-Mixing Taboo. *Language Learning*, *66*(S2), 29–50. https://doi.org/10.1111/lang.12173

Auer, P. (2013). *Code-Switching in Conversation*. *Code-Switching in Conversation*. Routledge. https://doi.org/10.4324/9780203017883

Azizian, A., Freitas, A. L., Watson, T. D., & Squires, N. K. (2006). Electrophysiological correlates of categorization: P300 amplitude as index of target similarity. *Biological Psychology*, *71*(3), 278–288. https://doi.org/10.1016/J.BIOPSYCHO.2005.05.002

Bentin, S., & McCarthy, G. (1994). The effects of immediate stimulus repetition on reaction time and event-related potentials in tasks of different complexity. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*(1), 130–149. https://doi.org/10.1037/0278-7393.20.1.130

Bentin, S., & Moscovitch, M. (1990). Psychophysiological indices of implicit memory performance. *Bulletin of the Psychonomic Society*, *28*(4), 346–352. https://doi.org/10.3758/BF03334040

Bentin, S., Moscovitch, M., & Heth, I. (1992). Memory with and without awareness: Performance and electrophysiological evidence of savings. *Journal of Experimental Psychology: Learning, Memory, and*

Cognition, *18*(6), 1270–1283. https://doi.org/10.1037/0278-7393.18.6.1270

Bialystok, E. (2006). Effect of bilingualism and computer video game experience on the simon task. *Canadian Journal of Experimental Psychology*, *60*(1), 68–79. https://doi.org/10.1037/cjep2006008

Byers-Heinlein, K. (2013). Parental language mixing: Its measurement and the relation of mixed input to young bilingual children's vocabulary size. *Bilingualism*, *16*(1), 32–48. https://doi.org/10.1017/S1366728912000120

Byers-Heinlein, K., Morin-Lessard, E., & Lew-Williams, C. (2017). Bilingual infants control their languages as they listen. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(34), 9032–9037. https://doi.org/10.1073/pnas.1703220114

Costa, A., & Santesteban, M. (2004). Lexical access in bilingual speech production: Evidence from language switching in highly proficient bilinguals and L2 learners. *Journal of Memory and Language*, *50*(4), 491–511. https://doi.org/10.1016/j.jml.2004.02.002

Crystal, D. (2018). *The Cambridge Encyclopedia of the English Language*. *The Cambridge Encyclopedia of the English Language*. Cambridge University Press. https://doi.org/10.1017/9781108528931

de Bruin, A., Samuel, A. G., & Duñabeitia, J. A. (2018). Voluntary language switching: When and why do bilinguals switch between their languages? *Journal of Memory and Language*, *103*, 28–43. https://doi.org/10.1016/J.JML.2018.07.005

De Langhe, B., Puntoni, S., Fernandes, D., & Van Osselaer, S. M. J. (2011). The Anchor Contraction Effect in International Marketing Research. *Journal of Marketing Research*, *48*(2), 366–380. https://doi.org/10.1509/jmkr.48.2.366

Flecken, M., Athanasopoulos, P., Kuipers, J. R., & Thierry, G. (2015). On the road to somewhere: Brain potentials reflect language effects on motion event perception. *Cognition*, *141*, 41–51. https://doi.org/10.1016/J.COGNITION.2015.04.006

Gollan, T. H., & Ferreira, V. S. (2009). Should I stay or should I switch? A cost–benefit analysis of voluntary language switching in young and aging bilinguals. *Journal of Experimental Psychology: Learning, Memory,* *and Cognition*, *35*(3), 640–665. https://doi.org/10.1037/a0014981

Grainger, J., & Beauvillain, C. (1987). Language blocking and lexical access in bilinguals. *The Quarterly Journal of Experimental Psychology Section A*, *39*(2), 295–319. https://doi.org/10.1080/14640748708401788

Grosjean, F. (2010). *Bilingual*. Cambridge, MA and London, England: Harvard University Press. https://doi.org/10.4159/9780674056459

Guillaume, C., Guillery-Girard, B., Chaby, L., Lebreton, K., Hugueville, L., Eustache, F., & Fiori, N. (2009). The time course of repetition effects for familiar faces and objects: An ERP study. *Brain Research*, *1248*, 149–161. https://doi.org/10.1016/J.BRAINRES.2008.10.069

Hartanto, A., & Yang, H. (2016). Disparate bilingual experiences modulate task-switching advantages: A diffusion-model analysis of the effects of interactional context on switch costs. *Cognition*, *150*, 10–19. https://doi.org/10.1016/j.cognition.2016.01.016

Kaushanskaya, M., & Marian, V. (2009). The bilingual advantage in novel word learning. *Psychonomic Bulletin & Review*, *16*(4), 705–710. https://doi.org/10.3758/PBR.16.4.705

Kovelman, I., Baker, S. A., & Petitto, L.-A. (2008). Age of first bilingual language exposure as a new window into bilingual reading development. *Bilingualism (Cambridge, England)*, *11*(2), 203–223. https://doi.org/10.1017/S1366728908003386

Kutas, M., & Federmeier, K. D. (2011). Thirty years and counting: finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology*, *62*, 621–647. https://doi.org/10.1146/annurev.psych.093008.131123

Kutas, M., & Hillyard, S. A. (1989). An Electrophysiological Probe of Incidental Semantic Association. *Journal of Cognitive Neuroscience*, *1*(1), 38–49. https://doi.org/10.1162/jocn.1989.1.1.38

Lewis, W. G. (2008). Current challenges in bilingual education in Wales. *AILA Review*, *21*, 69–86. https://doi.org/10.1075/aila.21.06lew

Meuter, R. F. I., & Allport, A. (1999). Bilingual Language Switching in Naming: Asymmetrical Costs of Language

Selection. *Journal of Memory and Language*, *40*(1), 25–40. https://doi.org/10.1006/jmla.1998.2602

Paap, K. R., Johnson, H. A., & Sawi, O. (2015). Bilingual advantages in executive functioning either do not exist or are restricted to very specific and undetermined circumstances. *Cortex*, *69*, 265–278. https://doi.org/10.1016/j.cortex.2015.04.014

Thierry, G., & Wu, Y. J. (2007). Brain potentials reveal unconscious translation during foreign-language comprehension. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(30), 12530–12535. https://doi.org/10.1073/pnas.0609927104

Thomas, M. S. ., & Allport, A. (2000). Language Switching Costs in Bilingual Visual Word Recognition. *Journal of Memory and Language*, *43*(1), 44–66. https://doi.org/10.1006/JMLA.1999.2700

Williams, D. G. (2017). *Understanding the Interplay between Context and Agency in a South Korean High School English Classroom. Understanding Students' EMI Perceptions in South Korean Higher Education View project The use of English as a medium of instruction in South Korean universities View project*. Retrieved from https://www.researchgate.net/publication/313658913

Wu, Y. J., & Thierry, G. (2010). Chinese-english bilinguals reading english hear chinese. *Journal of Neuroscience*, *30*(22), 7646–7651. https://doi.org/10.1523/JNEUROSCI.1602-10.2010

Wu, Y. J., & Thierry, G. (2012). Unconscious translation during incidental foreign language processing. *NeuroImage*, *59*(4), 3468–3473. https://doi.org/10.1016/j.neuroimage.2011.11.049