Bilingual language control across modalities

The relationship between mixed-language comprehension and production

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Bilingual language control has previously been tested separately in tasks of language comprehension and language production. Whereas these studies have suggested that local control processes are selectively recruited during mixed-language production, the present study investigated whether measures of global control show the same dependence on modality, or are shared across modalities. Thirty-eight Dutch-French bilingual young adults participated by completing two tasks of bilingual language control in both modalities. Global accuracy on mixed-language comprehension was related to mixing costs on bilingual verbal fluency, but only when compared to the L2-baseline. Global performance on mixed-language production was related to forward (L1-to-L2) switch costs. Finally, a significant correlation was found between the mixing cost on verbal fluency and forward switch costs on the comprehension task. The results are interpreted as evidence for the involvement of monitoring processes in bilingual language control across modality. The results also highlight the relevance of language switch directionality.

Keywords: bilingualism, cognitive control, language control

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1. Introduction

Bilingual language control refers to the mental processes that a bilingual speaker may recruit to manage two (or more) language systems (e.g., Christoffels, Firk, & Schiller, 2007). These processes are required even when bilinguals use only one of their languages because of the automatic activation of both language systems (for a recent study, see, for instance, Sauval, Perre, Duncan, Marinus, & Casalis, 2017), and this involuntary activation applies to both language comprehension and language production. In single-language production tasks, such as during picture naming, the non-verbal stimulus triggers competition in the bilingual mind between lexical items in the target and the non-target language (e.g., Hoshino & Thierry, 2011; Roelofs, Piai, Rodriguez, & Chwilla, 2016), and this cross-language competition must be resolved by processes of bilingual language control. In single-language comprehension tasks, such as during lexical decision, the speed and accuracy of decisions by bilingual individuals on a lexical stimulus are not only affected by the number of potential same-language competitors, but also by the number of potential competitors from the other language (e.g., Dijkstra, Van Heuven, & Grainger, 1998; Dimitropoulou, Dunabeitia, & Carreiras, 2011). Importantly, cross-language activation during language comprehension has both been observed in tasks of recognition that involve reading of visually presented words or sentences (e.g., Schwartz & Kroll, 2006) and in tasks involving auditory perception of spoken linguistic stimuli (e.g., van Hell & Tanner, 2012)

Bilingual language control processes are particularly important when bilinguals actively use their two language systems within one conversational setting. Behavioural costs related to bilingual language control can be observed in two different ways: either by a mixing cost or increased response times in mixed-language compared to single-language conditions (e.g., Hernandez, Martinez, & Kohnert, 2000), or by a switching cost or increased response times on switch trials versus repeat trials within a mixed-language condition (see, for instance, Wang, Kuhl, Chen, & Dong, 2009). This distinction between switching and mixing costs can be interpreted in terms of differences in duration, scope and temporal properties of the control processes involved. As for duration, switching costs can be seen as an index of short duration or transient language control and mixing costs as an index of long duration or sustained language control, each of these two activating separate neural regions (Christoffels et al., 2007; Hernandez & Kohnert, 2015; Wang et al., 2009). In terms of scope, a similar distinction can be made between local control (or inhibition) over a previously activated linguistic set, as indexed by switch costs, and global control (or monitoring) over the activation levels of the two language sets, as indexed by mixing costs (e.g., Tse & Altarriba, 2015). Accounting for the temporal properties of control, behavioural costs of mixed-language processing are interpreted as instances of reactive control (over a previously activated linguistic set) and proactive control (over the activation levels of two language sets in anticipation of upcoming switches), with the former related to switching costs and the latter to mixing costs (Ma, Li, & Guo, 2016).

As for language production, most experimental studies on bilingual language control have used cued-picture naming tasks to elicit verbal responses in mixed-language conditions (for a recent overview, see Reynolds, Schloffel, & Peressotti, 2016). An important finding from these studies is that the size of the switch cost, as a reflection of transient, local or reactive control, is related to the switch direction with, in general, higher switch costs for backward switches from the non-dominant to the dominant language than for forward switches in the inverse direction (Meuter & Allport, 1999). The inhibitory control model (Green, 1998) may explain this pattern: on non-dominant language trials, the dominant language must be inhibited to such an extent that the reactivation of that language comes with an additional cost. This reactivation cost applies selectively to the backward and not to the forward switch trials, and thereby creates an asymmetry in switch costs. However, this effect is not present in all bilinguals: switch costs become symmetrical if proficiency in a second language is high enough such that inhibition of the first language is no longer needed to access lexical items in that language (Costa & Santesteban, 2004; Fink & Goldrick, 2015). Similar to patterns of switch costs in mixed-language production, mixing costs have a higher impact on the dominant than on the non-dominant language, with a larger decline in response times for L1 than for L2 on mixed-language as compared to single-language conditions of the same language production task (Ma et al., 2016).

An alternative way of investigating language switching in bilinguals is by administering a verbal fluency task, during which participants have to produce as many words as possible starting with a specific letter (letter fluency) or belonging to a specific category (semantic fluency). Woumans, Ceuleers, Van der Linden, Szmalec, and Duyck (2015) instructed three groups of unbalanced bilinguals, balanced bilinguals, and interpreters to alternate between two languages on a mixed-language condition of a semantic verbal fluency task; and performance on this condition was compared to L1 and L2 single-language conditions. Interestingly, the size of the mixing costs depended on the baseline language. While all three groups scored considerably higher on the L1 condition than on the mixed-language condition (between 32% and 54% for each of the groups, individually), only two of the three groups (balanced bilinguals and interpreters) showed a slight advantage on the mixed-language over the L2 condition (11% and 15% for each of the groups, respectively), and the unbalanced bilinguals even scored better on the mixed-language condition than on the L2 condition. This mixing cost is not only seen in forced language switching tasks, but may also apply to bilingual fluency tasks that allow for voluntary switching. In the mixed-language verbal fluency condition reported by Gollan, Montoya, and Werner (2002), participants were allowed to produce exemplars in any of their two languages. The number of correct items was expected to be higher on a mixed-language condition as compared to the single-language condition because of the correlation between the number of correctly produced words and the number of exemplars in a specific category. For a bilingual who is allowed to use exemplars from any known language, category size is nearly doubled. However, the participants showed equal performance on the single-language and the mixed-language condition, and the authors interpreted this as evidence for a mixing cost during voluntary switching.

To investigate bilingual language control in language comprehension, studies have used lexical decision and semantic categorisation paradigms with stimuli in two (or more) languages (e.g., Macizo, Bajo, & Paolieri, 2012; Orfanidou & Sumner, 2005). Even though these tasks also generate switch costs; remarkably, none of these studies have revealed asymmetrical switch costs or an effect of switch direction on the size of the costs (Reynolds et al., 2016). If asymmetrical switch costs are seen as an indication of the involvement of inhibitory processes, these results lead to the conclusion that inhibitory control is not required in decision or categorisation tasks. However, alternative positions on this matter exist. In an interesting experiment with a switching and a non-switching participant taking turns naming pictures, Gambi and Hartsuiker (2016) found that for both participants, language production (either in L1 or L2) was slowed down if they had heard the other participant producing the target word on the previous trial in the other language. This finding that the pattern of switch cost across modalities (from comprehension to production and back) is similar to the costs within a single modality was interpreted as evidence in favour of a shared control mechanism for comprehension and production. In another experiment using a maze task, Wang (2015) found involvement of inhibitory control in bilinguals reading code-switched sentences and suggested an extension of the inhibitory control model (Green, 1998) from production to comprehension.

The study of bilingual language control is particularly relevant for the ongoing discussion on the so-called bilingual advantage in domain-general cognitive control abilities (e.g., Bak, 2016; Marton, 2016; Watson, Manly, & Zahodne, 2016). The main assumption that drives the quest for these advantages is that bilinguals are being trained in controlling their language systems through daily usage of these systems, and that this training transfers into enhanced performance on domain-general control (Friedman, 2016). This transfer across domains relates to the issue whether cognitive and language control build on the same or a similar construct because it would be illogical to anticipate any connection between both types of control if they are totally independent. The literature on this question has also led to conflicting findings with some studies finding correlations between control in both domains (e.g., Festman, Rodriguez-Fornells, & Munte, 2010; Linck, Schwieter, & Sunderman, 2012; Prior & Gollan, 2011), and others reporting no such dependency (e.g., Branzi, Calabria, Boscarino, & Costa, 2016; Calabria, Branzi, Marne, Hernandez, & Costa, 2015; Calabria, Hernandez, Branzi, & Costa, 2012; Prior, Degani, Awawdy, Yassin, & Korem, 2017). To resolve this issue, an answer should be formulated on the question of which control abilities are being trained by active bilingualism, not only during language production but also during language comprehension.

Moreover, in light of the bilingual advantages debate, it is also important to take into account potential differences in the duration, scope and temporal properties of language control. In an experimental study where switching and mixing costs on a non-verbal switching task were compared to each other in bilingual and monolingual participants, superior performance for the bilingual group was selectively found on the size of the mixing cost but not on the switching cost (Wiseheart, Viswanathan, & Bialystok, 2016). Furthermore, one correlational study on the relationship between language and cognitive control found a significant dependency between both factors when mixing costs on mixed-language production were included (Woumans et al., 2015), while other studies with a similar design have revealed mixed results when only switch costs are taken into account (Branzi et al., 2016; Linck et al., 2012). These findings can be seen as support for the idea that only global, sustained and proactive control processes are being trained through daily and active bilingualism, as they resemble more the bilingual situation of constant decision making on which language to use than the transient, retroactive and local control processes that are measured by the switching costs on the same tasks (Soveri, Rodriguez-Fornells, & Laine, 2011). It is also in line with the recurrent finding that bilingual advantages on cognitive control tasks are more frequently found on global performance than only on one specific trial type (Costa, Hernandez, Costa-Faidella, & Sebastian-Galles, 2009; Hilchey & Klein, 2011). If global language control (as indexed by mixing costs) is particularly trained through active and daily bilingualism, it is logical to expect a transfer effect into global performance on domain-general control instead of an effect on specific trial types. This transfer effect may stem from equivalent monitoring requirements during language-specific control as measured by mixing costs on mixed-language tasks because this pattern of increased global performance is often interpreted as a domain-general monitoring advantage (Singh & Mishra, 2015; Teubner-Rhodes et al., 2016).

The electrophysiological investigation of (monolingual) language production and comprehension using event-related potential (ERP) has provided some support for the recruitment of monitoring processes across modalities (e.g., van de Meerendonk, Kolk, Vissers, & Chwilla, 2010). Central to these studies is the manipulation of the P600 or late positivity effect, an ERP component which is often observed after ambiguous sentences and thought to reflect syntactic repair (e.g., Kaan, Harris, Gibson, & Holcomb, 2000). The Monitoring Theory suggests that the role of the P600 is more general, involving checking for errors by comparing the expected representation of an event to the actual one (Kolk, Chwilla, van Herten, & Oor, 2003; Vissers, Kolk, van de Meerendonk, & Chwilla, 2008). Whereas monitoring processes have traditionally been associated with speech production (Levelt, 1983), errors may affect both language comprehension and production and it is therefore interesting that the Monitoring Theory has been tested in perception tasks involving matching pictures to sentences (Vissers et al., 2008) and general sentence reading (van de Meerendonk, Chwilla, & Kolk, 2013; van de Meerendonk, Indefrey, Chwilla, & Kolk, 2011). In bilinguals, language comprehension can even be expected to be more error-prone because of constant interference from the other language (e.g., Libben & Titone, 2009). Therefore, it is logical to assume that monitoring processes are recruited across modalities in bilinguals.

1.1 The present study

The present study intends to investigate the relationship between bilingual control processes in language comprehension and production by conducting correlational analyses between measures of fluency in switching between two languages (language production) and measures of semantic categorisation in a mixed-language condition (language comprehension). In previous studies, these processes have been tested across modalities, in tasks of language comprehension (e.g., Macizo et al., 2012; Orfanidou & Sumner, 2005; Thomas & Allport, 2000) and of language production (e.g., Fink & Goldrick, 2015; Martin et al., 2013; Meuter & Allport, 1999), separately. However so far, to the best of our knowledge, there have been no studies on the relationship between performance on mixed-language processing in these tasks of language production and comprehension within a same group of individuals. Whereas previous studies have suggested that local (or inhibitory) control processes are selectively recruited during mixed-language production but not during comprehension (e.g., Macizo et al., 2012), this study will investigate whether measures of global (or monitoring) processes show a similar dependence on modality, or are shared across modalities.

We intend to answer three research questions. The first question is to what extent measures of global performance (irrespective of performance on a specific trial type) on mixed-language comprehension and production are related. Global performance on mixed-language tasks can be taken as an index of sustained language control that resembles the monitoring processes recruited by bilinguals when they switch between languages in a natural conversation as indicated by the bilingual advantage on global performance in nonverbal control tasks (Costa et al., 2009). In line with the Monitoring theory (Kolk et al., 2003; Vissers et al., 2008), we expect these processes to be modality-independent, thus showing a correlation between mixed-language comprehension and production.

The second question is to what extent the behavioural costs of mixed-language comprehension and production are related to each other. We will consider the cost related to switching between languages on a recognition task, as a reflection of local, reactive and transient language control, and the cost related to mixing languages during production as a reflection of global, proactive and sustained language control (e.g., Christoffels et al., 2007; Tse & Altarriba, 2015). We specifically expect the measure of sustained control (either on the language production or language comprehension task) to be correlated with global performance on the other task, as they may both reflect the monitoring processes that are implemented during bilingual language use when they switch between languages.

Finally, we will investigate to what extent these relationships between mixed-language comprehension and production are determined by switch directionality. At first sight, such a question may seem awkward in light of the often replicated finding of equal costs for both switch directions (L1 > L2 and L2 > L1) in mixed-language comprehension (for a recent overview, see Reynolds et al., 2016). However, whereas this switch symmetry has been attributed to the absence of inhibitory processes in mixed-language comprehension as opposed to production (e.g., Macizo et al., 2012), little can be said about monitoring on the basis of these findings. Compatible with the predictions of the Monitoring Theory regarding the recruitment of monitoring processes across modalities (Kolk et al., 2003; Vissers et al., 2008), we expect switch directionality to be relevant not only for mixed-language production, but also for comprehension.

2. Method

2.1 Participants

Participants in this study were 38 unbalanced Dutch-French multilingual undergraduate students at the Dutch-medium Vrije Universiteit Brussel (Free University of Brussels) in Belgium (18 females; mean age = 20.48 years; *SD* = 1.89). All participants filled out an adapted version of the Language Experience and Proficiency Questionnaire (LEAP-Q, Marian, Blumenfeld, & Kaushanskaya, 2007) to assess their linguistic, socio-economic and migration background. Participants had no reported reading problems. All participants indicated knowledge of three or more languages ($n = 31$, of three, $n = 5$, of four, and $n = 2$, of five languages, which was the maximum number they could list). Dutch was the most dominant language (L1) and the language they had started acquiring from birth in a monolingual or a mixed-language family (Dutch-French). French was for all participants the second most dominant language (L2) and either the language they had started acquiring from birth in a mixed-language family (Dutch-French) or the language they had started acquiring before age six outside of the home environment. Even though some participants ($n = 4$) mentioned that French was the first language they had acquired in early childhood, Dutch was for all participants the only language they had been exposed to throughout their entire educational trajectory; it was their preferred language for communication, reading and writing; and it was also the language to which they had been most exposed over the last twelve months. All participants reported high proficiency in listening, speaking and reading in both languages (above 7 out of 10 on a Likert scale, see Table 1). Wilcoxon signed-rank tests revealed highly significant differences with large effect sizes between L1 and L2 scores for self-reported listening proficiency, $z = -4.36$, $p < .001$, $r = -0.50$; speaking proficiency, $z = -4.71$, $p < .001$, $r = -0.54$; reading proficiency, $z = -4.51$, $p < .001$, $r = -0.52$; and exposure, $z = -5.32$, $p < .001$, $r = -0.61$, which is why the participants in this study were qualified as unbalanced bilinguals with Dutch as their dominant and French as their non-dominant language. Despite these differences between the two languages, all participants reported daily exposure to both languages. Moreover, all participants reported knowledge of English, but

Table 1. Mean values of participants' language background characteristics with standard deviations between brackets. Current exposure is given in percentages, onset ages in number of years (only for L2). Proficiency is given on a scale from zero to ten. L1 = first language. L2 = second language.

Language	Self-reported background measure	Scores
L1-Dutch	Current exposure	56.97 (5.99)
	Speaking proficiency	9.92 (0.27)
	Listening proficiency	9.97 (0.16)
	Reading proficiency	9.97 (0.16)
L2-French	Current exposure	35.26 (4.18)
	Onset age of acquisition	2.03 (2.59)
	Speaking proficiency	8.63 (0.94)
	Listening proficiency	9.13 (0.81)
	Reading proficiency	9.00 (0.81)

their current exposure to that language was below 20%. None of the participants reported language or learning disabilities. All of the participants were born and raised in Belgium. The descriptive statistics of the participants' L1 and L2 self-reported proficiency measures are given in Table 1.

2.2 Tasks

2.2.1 *Mixed-language semantic categorisation task*

This reading task was included in the test battery to measure bilingual language control on a language comprehension task, involving crucial processes of single-word recognition and access to the mental lexicon (e.g., Hugdahl et al., 1999). Participants were instructed to respond as quickly as possible to the animacy of the stimulus with a left or right button press. The stimuli of the bilingual categorisation task were 156 nouns that were equally divided over two factors: 'animacy' and 'language'; each consisting of two levels: animate and inanimate for 'animacy'; and Dutch and French for 'language'. The 156 stimuli thus consisted of 39 Dutch animate nouns; 39 Dutch inanimate nouns; 39 French animate nouns; and 39 French inanimate nouns. All words were selected from the CELEX database (Baayen, Piepenbrock, & Van Rijn, 1993) and were matched across languages and categories for word length in terms of number of letters and syllables, and frequency. T-tests revealed that the number of letters was the same for both languages, $t(154) = -1.14$, $p = .26$, with equal scores for L1-Dutch ($M = 5.73$, $SD = 0.82$) and L2-French ($M = 5.87$, $SD = 0.73$), and for both semantic categories $t(154) = 0.31$, $p = .76$, with equal scores for animal names ($M = 5.82$, $SD = 0.80$) and object names ($M = 5.78$, $SD = 0.75$). Also, the number of syllables was the same for both languages, $t(154) = -0.86$, $p = .39$, with equal scores for L1-Dutch ($M = 1.74$, $SD = 0.44$) and L2-French ($M = 1.81$, $SD = 0.49$), and for both semantic categories, $t(154) = -0.52$, $p = .61$, with equal scores for animal names ($M = 1.79$, $SD = 0.44$) and object names ($M = 1.76$, $SD = 0.49$). Cognates between languages were not included.

The task was designed such that language switches were unpredictable and that the same trial type did not occur more than three times in a row. Stimulus-response mapping was counterbalanced across participants: animacy of the stimulus was linked to a left button press for half of them and to a right button press for the other half. Each stimulus was preceded by a fixation cross which remained in the centre of the screen for 500 milliseconds. The stimuli were presented in black Courier font, size 36, for up to 2000 milliseconds in the centre of a white screen or until the participant responded. Apart from the first four trials, which were removed from further analysis, the task contained 76 language repeat trials and

76 language switch trials. This task was programmed in E-Prime 2 (Psychology Software Tools, Pittsburgh, PA).

2.2.2 *Single- and mixed-language verbal fluency*

This task was included in the test battery to measure bilingual language control in a language production task. The behavioural mixing cost measured by this task is related to domain-general control (Woumans et al., 2015). Participants were instructed to name as many words that start with a given phoneme in a one-minute period. This task had three conditions: two single-language conditions in Dutch-L1 and French-L2, and a mixed-language condition. All participants started with the two single-language conditions, and ended with the mixed-language condition. Half of the participants started with the L1 condition of the task; the other half started with the L2 condition. In the mixed-language condition, participants were asked to alternate between Dutch-L1 and French-L2 with no translation equivalents allowed. The participants could start with their language of choice. Three phonemes with an equal distribution as onset sound in Dutch and French words were selected from the CELEX database (Baayen et al., 1993): /l/, /t/, and /m/. These three phonemes could be presented to the participants in six different orders. The order of presentation was randomly distributed across participants. All spoken instructions were digitally pre-recorded by a Dutch-French bilingual speaker and they were administered to the participants through headphones with a microphone attached. Instructions on the single-language condition were given in the same language as the language of response. On the mixed-language condition, the instructions were given in the same language as that of the first single-language condition. For half of the participants, instructions on the mixed-language condition were thus given in L1-Dutch, for the other half in L2-French. The following measures were extracted from this task: global performance as indicated by the number of words in the mixed-language condition, the mixing cost with L1-Dutch and L2-French as baseline by subtracting the number of words on the mixed-language condition from that on the single-language L1-condition, and L2-condition, respectively.

2.3 Procedure

2.3.1 *General procedure*

All participants sat down on a comfortable chair in a dimly lit and soundproof cabin in the laboratory of psycholinguistics at the Vrije Universiteit Brussel and they were tested individually. Half of the participants started with the mixed-language categorisation task; the other half started with the verbal fluency tasks. Both tasks were presented on a Dell Latitude E6500 personal computer with a 15.4-inch screen. The verbal responses on the verbal fluency task were recorded through the microphones of the computer and automatically saved on the computer's hard disk. The responses on the categorisation task were collected via keyboard presses.

2.3.2 *Data analysis*

2.3.2.1 *Mixed-language semantic categorisation task.* For all 156 trials of the mixed-language semantic categorisation task, response times (in milliseconds) and accuracy scores (one for correct trials and zero for incorrect trials) were collected. Response times on incorrect trials were removed from further analysis. The trials were classified into four different trial types, based on the language of the current trial (two levels: L1 or L2) and the language of the previous trial (two levels: same or different): L1-repeat trials, L2-repeat trials, L1-switch trials and L2-repeat trials. On repeat trials, the language of the current trial was the same as on the previous trial. On switch trials, the language of the current trial was different from that on the previous trial. One-sample Kolmogorov-Smirnov tests were conducted on response times and accuracy scores to test for normality.

To investigate the effects of language and switch and the related presence or absence of switch symmetry, two-way analyses of variance were conducted on the mean response times and accuracy rate of each trial type. Mean accuracy rates and response times (only on correct trials) were calculated for all trials, and they were interpreted as an indicator of global performance on mixed-language comprehension.

Mean accuracy rates and response times for switch and repeat trials irrespective of the language of the trial, were used to calculate switch costs. Switch costs in accuracy rates were calculated by subtraction of the percentage of correct trials on switch trials from that on repeat trials. Switch costs in response times were calculated by subtraction of the mean response times on repeat trials from that on switch trials. In both cases, negative values were indicative of faster responding or higher accuracy on switch trials than on repeat trials. Mean accuracy rates and response times for each of the four trial types were used to calculate the effect of directionality (forward or backward) on switch costs. Forward switch costs (from the dominant to the non-dominant language) were calculated by subtraction of the percentage of correct trials on L2-switch trials from that on L2-repeat trials for accuracy and by subtraction of the mean response times on L2-repeat trials from those on L2-switch trials for speed. Backward switch costs (from the non-dominant to the dominant language) were calculated by subtraction of the percentage of correct trials on L1-switch trials from that on L1-repeat trials for accuracy and by subtraction of the mean response times on L1-repeat trials from those on L1-switch trials for speed. In all cases, negative values were indicative of faster responding or higher accuracy on switch trials than on repeat trials. Based on the three criteria of duration, scope and temporal properties (see above for a more detailed discussion of these criteria), switch costs were interpreted as an example of transient, local and reactive control.

2.3.2.2 *Single and mixed-language verbal-fluency.* For the verbal fluency task, two researchers counted all correct responses on the three conditions: (1) single-language L1, (2) single-language L2, and (3) mixed-language, to check for inter-rater reliability. Words were only counted if they were included in the most comprehensive editions of the online Van Dale dictionary (for Dutch, Van Dale Online Professioneel, 2017), and the Grand Robert dictionary (for French, Le Grand Robert Langue française, 2017). On the mixed-language conditions successive words in the same language or translation equivalents of words previously named in the other language were treated as incorrect responses. The number of correct words in the mixed-language condition was interpreted as an indicator of global performance on mixed-language production, analogous to the analysis of the semantic categorisation task.

Mixing costs were calculated with the single-language L1- and L2-conditions as baselines. Negative values indicate a higher number of correct words in the mixed-language condition than in the single-language condition. One-sample Kolmogorov-Smirnov tests were conducted on global performance, and on mixing costs, to test for normality.

Based on the three criteria of duration, scope and temporal properties (see above for a more detailed discussion of these criteria), mixing costs were interpreted as an example of sustained, global and proactive control. As compared to the switch cost, which can be seen as an instance of transient, local and reactive control that entails inhibition over the language that was active on the previous trial, the mixing cost reflects control processes over a longer time period (one minute instead of a few seconds) that monitor the activation level of both language systems.

2.3.2.3 *Correlational analyses.* To test for dependency between measures of mixed-language production and comprehension, we conducted Pearson's correlational analyses among response times and accuracy scores on the mixed-language semantic categorisation task and performance on the mixed-language verbal fluency task. We distinguished between three measures at three levels which correspond to the three research questions of the present study: first, we took into account global performance on these two tasks (for the mixed-language categorisation both in terms of response times and accuracy rates; for the mixed-language verbal fluency only in terms of number of words); second, we looked at switch costs for the bilingual categorisation task (both in terms of accuracy and response times) and at mixing costs for the verbal fluency task (with two different baselines); third, we considered language directionality for the bilingual categorisation task in terms of backward and forward switch costs in response times and accuracy rates. In total, we conducted correlational analyses on eight measures of the mixed-language categorisation task and on three measures of the mixed-language verbal fluency task, which resulted in 24 (eight times three) correlation coefficients. Statistical significance was corrected for multiple comparisons by controlling the false discovery rate (Benjamini & Hochberg, 1995).

3. Results

3.1 Measures of mixed-language semantic categorisation task

Figure 1 shows average response times, and Figure 2 shows average accuracy scores on each of the trial types. Mean accuracy scores are reported in percentages as a ratio of correct trials to the total number of trials.

3.1.1 *Effects of language, switch and switch directionality*

A two-way analysis of variance was conducted on the mean response times of these four trial types with language (two levels: L1 and L2) and switch (two levels: repeat and switch) as within-subject variables. Response times on 10% of all trials were removed because the response on these trials was incorrect. We found a significant main effect of language, $F(1, 37) = 46.67$, $p < .001$, $\eta_p^2 = .56$, with higher response times (all response times in this section are reported in milliseconds) for L2- ($M = 855.96$; $SD = 143.42$) than for L1-trials ($M = 744.42$; $SD = 128.78$); a significant main effect of switch, $F(1, 37) = 8.36$, $p = .006$, $\eta_p^2 = .19$, with higher response times for switch ($M = 807.44$; $SD = 140.97$) than for repeat trials ($M = 792.93$; $SD = 131.23$); but no significant interaction effect between both variables, $F(1, 37) = 2.82$, $p = .10$. The same analysis was conducted on the mean accuracy rates of these four trial types. We found a significant main effect of language, $F(1, 37) = 55.64$, $p < .001$, $\eta_p^2 = .60$, with a higher accuracy rate (all accuracy rates in this section are reported in percentages of correct trials) for L1- ($M = 96.61$; $SD = 2.86$) than for L2-trials ($M = 82.90$; $SD = 11.72$); a (marginally) significant interaction effect between language and switch, $F(1, 37) = 4.17$, $p = .05$, $\eta_p^2 = .10$; but no main effect of switch, $F(1, 37) = .76$, $p = .39$, with equal accuracy rates for repeat trials ($M = 89.41$, $SD = 7.40$) and switch trials ($M = 90.10$, $SD = 7.19$).

The mean switch costs on this task were 14.51 milliseconds ($SD = 30.45$) for response times and −1% ($SD = 4.89$) for accuracy rates (for descriptive statistics of switch and repeat trials, see above). This means that participants were on average slower on switch trials than on repeat trials, but their accuracy was the same on switch and on repeat trials. It should be noted that the effect of switch was not significant (see above). 10 out of 38 participants (26%) showed negative switch costs on response times with slower responding on repeat trials than on switch trials, and 22 out of 38 participants (58%) showed negative switch costs on accuracy rates with lower accuracy on repeat than on switch trials.

The mean backward switch cost on this task was 25.87 milliseconds (*SD* = 37.23) for response times and 1% (*SD* = 3.57) for accuracy rates, with slower responses for L1-switch trials (*M* = 857.54; *SD* = 154.38) than for L1-repeat trials (*M* = 731.47; *SD* = 130.01), and same accuracy for L1-switch trials (*M* = 96.24; *SD* = 2.68) than for L1-repeat trials (*M* = 96.98; *SD* = 3.04). Paired samples *T*-tests revealed that this difference was highly significant with a large effect size for response times, $t(37) = -4.28$, $p < .001$, $d = -0.69$, but not for accuracy rates, $t(37) = 1.27$, $p = .21$. Eight out of 38 participants (21%) showed negative switch costs on response times with slower responding on repeat trials than on switch trials, and 12 out of 38 participants (32%) showed negative switch costs on accuracy rates with lower accuracy on repeat than on switch trials.

The mean forward switch cost on this task was 3.16 milliseconds (*SD* = 62.78) for response times and −2% (*SD* = 8.50) for accuracy rates, with same responses for L2-switch trials (*M* = 857.54; *SD* = 154.38) and L2-repeat trials (*M* = 854.38; *SD* = 132.45), and same accuracy for L2-switch trials (*M* = 83.96; *SD* = 11.69) and L2-repeat trials (*M* = 81.83; *SD* = 11.75). Paired samples *T*-tests revealed that this difference was neither significant for response times, $t(37) = -0.31$, $p = .76$, nor for accuracy rates, $t(37) = -1.54$, $p = .13$. Seventeen out of 38 participants (45%) showed negative switch costs on response times with slower responding on repeat trials than on switch trials, and 27 out of 38 participants (71%) showed negative switch costs on accuracy rates with lower accuracy on repeat than on switch trials.

3.1.2 *Global mixed-language comprehension*

The mean response time on the mixed-language semantic categorisation task was 818.41 milliseconds (*SD* = 120.21). The mean accuracy rate on this task was 90% (*SD* = 5.62).

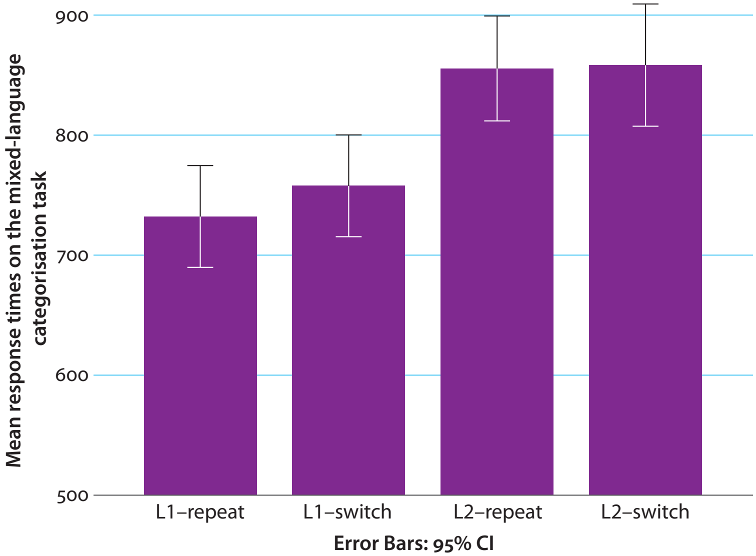

Figure 1. Mean response times (and error bars representing 95% Confidence Intervals) on each trial type of the mixed-language catagorisation task. L1 = first language, Dutch. L2 = second language, French. Note the absence of a switch cost on L2-trials

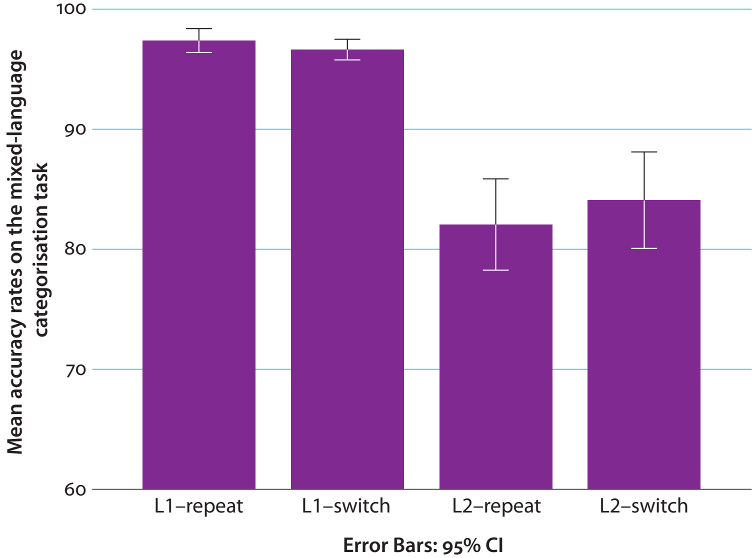

Figure 2. Mean accuracy rates (and error bars representing 95% Confidence Intervals) on each trial type of the mixed-language categorisation task. L1 = first language, Dutch. L2 = second language, French

3.2 Measures of single- and mixed-language verbal fluency

Only on two occasions did the counters report a different score for the same condition. In both instances, this variance concerned words that were initiated just before (in the order of milliseconds) the one-minute limit, but only fully produced outside this limit because of a hesitation. It was determined that only words that were fully produced within the one-minute limit would be counted as correct responses.

3.2.1 *Single-language conditions*

The average number of correct words on the single-language L1-condition (Dutch) was 11.11 ($SD = 3.29$). The average number of incorrectly produced words on this condition was 0.21 ($SD = 0.53$). Individual scores ranged between 6 and 18 words. The average number of correct words on the single-language L2-condition (French) was 8.00 ($SD = 3.49$). The average number of incorrectly produced words on this condition was 0.97 ($SD = 0.88$). Individual scores ranged between 3 and 15 words. A paired-samples *T*-test on the number of correctly produced words revealed that the difference between the L1- and L2-conditions was significant with a large effect size, $t(37) = 4.90$, $p < .001$, $d = 0.80$.

3.2.2 *Mixed-language condition*

The average number of correct words in the mixed-language condition was 8.32 ($SD = 2.13$). The average number of incorrectly produced words on this condition was 1.13 ($SD = 1.07$). A closer analysis of incorrectly produced words showed that a minority of mistakes was due to successive words in the same language or translation words (21% for each of these categories). 42% of all mistakes could be attributed to within-language repetitions of the same word. The remainder of mistakes were words that did not exist in the L2 (12%) or L1 (5%). The proportion of correctly produced words was 51% for L1 and 49% for L2. Individual scores ranged between 3 and 13. A paired-samples *T*-test on the number of correctly produced words on the single-language and the mixed-language conditions revealed that only the difference between the single-language L1-condition and the mixed-language reached significance with a large effect size, $t(37) = -4.92$, $p < .001$, $d = -0.80$. The difference between the single-language L2-condition and the mixed-language condition did not reach significance, $t(37) = .53$, $p = .60$.

3.2.3 *Mixing costs*

When compared to the single-language L1-condition, the mean mixing cost was 2.79 ($SD = 3.50$). Individual scores ranged from −4 to 13. Eight out of 38 participants (21%) showed negative mixing costs with more correct words in the mixed-language condition than in the L1-condition. When compared to the single-language L2-condition, the mean mixing cost was 0.32 (*SD* = 3.68). This means that participants had on average equal scores on the mixed-language and single-language L2-conditions. Sixteen out of 38 participants (42%) showed negative mixing costs with a higher number of correct responses in the mixed-language condition than in the L2-condition. Figure 3 gives a graphical overview of the scores on the verbal fluency task.

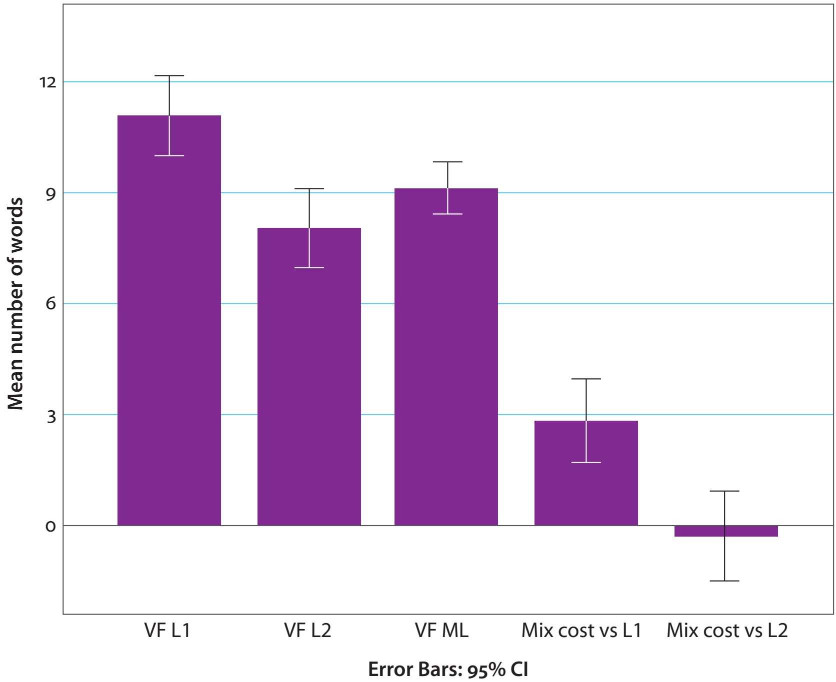

Figure 3. Mean number of words (with error bars representing 95% Confidence Intervals) on the single-language and mixed-language conditions of the verbal fluency task. VF = Verbal fluency; L1 = first language, Dutch; L2 = second language, French; ML = mixed-language. Mixing costs indicate mean difference between mixed-language condition and L1- and L2-single-language conditions, respectively. Note the mean negative mixing cost when compared to the L2-condition, indicating equal performance on the mixed-language condition and the L2-condition

3.3 Correlations between measures of mixed-language production and comprehension

The results of the analyses are given in Table 2. Among the 24 correlational analyses that were conducted between the measures of mixed-language production and comprehension, only six reached significance at alpha = .05. After correction for multiple comparisons (Benjamini & Hochberg, 1995), only three of these were still significant: the correlation between global performance in terms of accuracy on mixed-language comprehension and the mixing cost on mixed-language production with the single-language L2-condition as baseline, the correlation between the switch cost in terms of response times on mixed-language comprehension and global performance on mixed-language production, and the correlation between the forward switch cost in terms of response times on mixed-language comprehension and global performance on mixed-language production.

4. Discussion

The aim of this study was to investigate the similarities and differences between the behavioural costs associated with mixed-language processing across two modalities: language comprehension and language production. Therefore, we administered two tasks to the participants: a mixed-language semantic categorisation task as a measure of control processes during language comprehension and a mixed-language verbal fluency task as a measure of control processes during language production. We conducted correlational analyses between several of these tasks' measures to establish the relationship between the language processes involved.

In line with previous studies on mixed-language comprehension (e.g., Macizo et al., 2012; Orfanidou & Sumner, 2005), we found significant switch costs in response times on the bilingual semantic categorisation task. We interpret this finding as a cost related to the shifting back and forth between lexical items from two mental language sets. Also in accordance with most of the evidence on mixed-language comprehension (for a recent overview, see Reynolds et al., 2016), we did not observe asymmetric switch costs or significantly higher switch costs on L1- than on L2-trials. Previous studies have interpreted this outcome as a crucial difference between mixed-language production and comprehension: asymmetrical switch costs are mainly observed in tasks of mixed-language production, especially in unbalanced bilinguals (Costa & Santesteban, 2004; Meuter & Allport, 1999).

In line with previous studies on mixed-language production (Wang et al., 2009; Woumans et al., 2015), we found significant mixing costs on the bilingual verbal fluency task. Importantly, we only found mixing costs for the comparison with the L1- but not with the L2-condition. This finding is in line with the pattern of results reported in Woumans et al. (2015), where the group of unbalanced bilinguals produced more exemplars on the L1-condition than on the mixed-language condition, but, inversely, more exemplars on the mixed-language condition than on the L2-condition. It may be logical to expect that verbal fluency will be impaired when

Table 2. Correlation coefficients among measures of mixed-language comprehension and production. L1 = first language, Dutch. L2 = second language, French

Measure of mixed-language comprehension	Measure of mixed-language production	Correlation coefficient
Global performance RT	Global performance	ns.
	Mixing cost (baseline L1)	ns.
	Mixing cost (baseline L2)	ns.
Global performance ACC	Global performance	ns.
	Mixing cost (baseline L1)	−.32*
	Mixing cost (baseline L2)	−.58**
Switch cost RT	Global performance	−.45**
	Mixing cost (baseline L1)	−.33*
	Mixing cost (baseline L2)	ns.
Switch cost ACC	Global performance	ns.
	Mixing cost (baseline L1)	ns.
	Mixing cost (baseline L2)	ns.
Backward switch cost RT	Global performance	ns.
	Mixing cost (baseline L1)	ns.
	Mixing cost (baseline L2)	ns.
Backward switch cost ACC	Global performance	ns.
	Mixing cost (baseline L1)	ns.
	Mixing cost (baseline L2)	ns.
Forward switch cost RT	Global performance	−.52**
	Mixing cost (baseline L1)	−.32*
	Mixing cost (baseline L2)	ns.
Forward switch cost ACC	Global performance	ns.
	Mixing cost (baseline L1)	ns.
	Mixing cost (baseline L2)	ns.

ns. $p > .05$;
*$p < .05$;
**significant after correction for multiple comparisons, $N = 38$

an unbalanced bilingual is being asked to alternate between his two languages as compared to speaking in his dominant language only because of slower lexical access in the non-dominant language (e.g., Cook & Gor, 2015); however, previous research suggests that this only applies to cued or involuntary language switching as indicated by the disappearance of switch costs or even switch facilitation when individuals are allowed to mix languages voluntarily (Gollan & Ferreira, 2009; Gollan, Kleinman, & Wierenga, 2014). The language switching task used in the current study has some similarities to these involuntary switching paradigms (e.g., the absence of a cue to indicate when a switch must occur), which could explain why we found no additional processing requirements that hamper verbal fluency during language mixing compared to fluency in the non-dominant language.

The main interest of this study lay in the investigation of the relationship between language control in mixed-language comprehension and production. While the equivalent indices of global performance on both tasks were not related to each other, global performance on each of the tasks separately was related to some of the non-equivalent measures of the other task. Global accuracy (but not global speed) on mixed-language comprehension was related to mixing costs on bilingual verbal fluency, but only when compared to the single-language L2-condition. This indicates a dependency between mixing languages in production and accurately evaluating language input when two language systems must be kept activated. Global performance on mixed-language production was related to switch costs, in general, and forward (but not backward) switch costs, in particular. After controlling for multiple comparisons, however, only the correlation with the forward switch cost remained significant. This suggests that the process of shifting back and forth between recognising lexical items from two mental language sets, especially from the dominant to the non-dominant language, shares some similarities with the control requirements of producing words in two languages. A final set of significant correlations was found between the mixing cost on bilingual verbal fluency and, again, switch costs in general, and forward (but not backward) switch costs in particular. Again, only the dependency between the mixing cost and the forward switch cost remained significant after controlling for multiple comparisons. This finding reveals, for the first time, a dependency between sustained, global or proactive language control during language production (e.g., Christoffels et al., 2007; Wang et al., 2009), as measured by the mixing cost on the bilingual verbal fluency task, and transient, local or reactive language control during language comprehension (Gambi & Hartsuiker, 2016), as measured by the switch costs on the bilingual categorisation task.

Our findings reveal that at least some of the processes involved in language control are modality-independent or shared by both language comprehension and production, alike, and they are, as such, compatible with the Monitoring Theory which suggests involvement of monitoring processes across modalities (Kolk et al., 2003; Vissers et al., 2008). Interestingly, these correlations do not only involve the behavioural costs that have previously been associated to bilingual language control processes, such as switching and mixing costs (e.g., Christoffels et al., 2007), but also affect global performance on these tasks. We suggest that this is analogous to what previous studies have reported on the so-called bilingual advantage in domain-general control abilities: bilinguals do not only outperform monolinguals on the behavioural costs associated to cognitive control such as the Simon or Flanker-effect (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004; Costa, Hernandez, & Sebastian-Galles, 2008; but also see, von Bastian, Souza, & Gade, 2016), but also on global performance on these tasks (e.g., Hilchey & Klein, 2011; Yang & Yang, 2016). The hypothesis has been put forth that this global advantage reflects monitoring demands related to the continuous need for assessing the probability of a language switch in a mixed-language condition with unpredictable switches, especially when the stimuli are evenly distributed over both languages (Costa et al., 2009). As both tasks of the present study contained as many stimuli (for the bilingual categorisation task) or responses (for the bilingual verbal fluency task) in L1 as in L2, they also pose high monitoring requirements; therefore, we suggest a specific role for monitoring processes in global performance on mixed-language tasks.

Another important finding of our study is that the switch directionality determines the relationship between bilingual control processes in language production and comprehension. Significant correlations could only be found between measures of mixed-language production and the forward, but not the backward switch cost. This means that this relationship is probably not mediated by inhibitory control processes (see Green, 1998). We suggest an alternative explanation: if global performance is indeed a reflection of the efficiency of monitoring processes, the correlational analyses suggest a dependency between these monitoring processes and the forward switch cost (but not with the backward switch cost). This suggests that in addition to inhibitory processes related to the backward switch cost, the efficiency of monitoring processes in an individual language user may manipulate the size of the forward (but not the backward) switch cost in a mixed-language setting, possibly because bilinguals need to monitor more the comprehension of words in a non-dominant language (than in a dominant language).

Our results should be interpreted in light of the specific characteristics of our participants and the limitations of our research design. Even though the bilingual individuals who were included in our sample were early bilinguals with high proficiency in both languages, the analysis of their self-reported exposure rates and proficiency ratings revealed that they were unbalanced bilinguals with Dutch as their dominant and French as their non-dominant language. This explains their relatively high error rate (almost 20%) on the mixed-language semantic categorisation task. The observed effects on this study's tasks of mixed-language processing may be a side effect of these differences in proficiency levels and thus may not be easily generalisable to balanced bilinguals or L2 learners. Also, the research design could have an impact on the degree of involvement of these processes and the pattern of observed results. The semantic categorisation that we used to measure bilingual language control processes in language comprehension was composed of an equal number of L1 and L2 trials with unpredictable switches, and as a result, required extensive monitoring. We do not expect to find the same degree of correlation with mixed-language production on low-monitoring versions of the same task with an unequal distribution of L1 and L2 trials and/or predictable language switches.

5. Conclusion

Our findings demonstrate that some of the processes involved in bilingual language control overlap across modalities, and they suggest a role for processes of monitoring in managing two language systems. Given a bilingual's constant exposure to two languages, the question may be raised to what extent these monitoring processes can be influenced by daily language use, and exactly which variables (second-language proficiency, age of acquisition, balanced bilingualism, etc.) contribute to this training effect. Once this has been established, a subsequent question would be to investigate the degree by which these processes are domain-specific and thus restricted to the language domain, or rather transferable into domain-general processes of cognitive control. This issue of domain-specificity (or generality) of language control processes is at the heart of the bilingual advantage debate (e.g., Bak, 2016). As such, these results may constitute a starting point for future research on the trainability and transferability of domain-specific monitoring processes.

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