Is inhibition implemented during bilingual production and comprehension? N-2 language repetition costs unchained.

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Abstract

Many models assume that inhibition plays an integral role during bilingual language control, a process that restricts bilingual language processing to the target language. However, there is limited evidence for such a claim. In the current study, we set out to investigate one known marker of bilingual inhibition (n-2 language repetition costs) that has, so far, mainly been investigated with digits in a production task. Hence, we ran a n-2 language repetition study with other types of stimuli (i.e., pictures and written words) in a production and a comprehension task. The results showed that n-2 language repetition costs were found with both stimulus types in a production task. In the comprehension tasks, n-2 language repetition costs were only observed with one of the two stimulus types and in only one language. These results indicate that inhibition is implemented during bilingual production, and is possible, but not necessary, during bilingual comprehension.

(words: 150)

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It has typically been assumed that bilingual language control mainly relies on inhibition (e.g., Declerck, Koch, & Philipp, 2015; Grainger & Dijkstra, 1992; Grainger, Midgley, & Holcomb, 2010; Green, 1998; Schwieter & Sunderman, 2008) in order to reduce cross-language interference and to reduce the chances that a word of the nontarget language gets selected. In the present study we wanted to further investigate this inhibitory process with n-2 language repetition costs with different stimulus types during both bilingual production and comprehension.

Language control models and inhibition

According to several, but not all (e.g., Costa, Miozzo, & Caramazza, 1999; La Heij, 2005; Roelofs, 1998), bilingual production models, inhibition plays an important role during language control. Most inhibition-based models assume a persisting, reactive inhibition process to occur during bilingual production (e.g., Declerck et al., 2015; Green, 1998; Schwieter & Sunderman, 2008). Reactive inhibition refers to the amount of inhibition that is put on non-target languages. More specifically, the higher the activation of non-target languages, the more inhibition will be implemented. This inhibition is assumed to persist into the following words (i.e., persisting inhibition). While all of these inhibition-based models propose an inhibitory process to occur at the lexical-semantic level, some models assume other loci as well, such as processing stages prior to language processing (i.e., between task schemas; e.g., Green, 1998).

Next to these production-based language control models, there are also language control models that assume inhibition to play a substantive role during bilingual language comprehension. The bilingual interactive activation model (BIA; Grainger & Dijkstra, 1992), similar to the BIA-d (Grainger et al., 2010), accounts for language control through bottom-up activation of word representations, which then activate their respective language node(s). In turn, these language nodes inhibit all word representations that are not part of this language.

Capturing inhibition with the language switching paradigm

One of the main paradigms to investigate language control, and more specifically language inhibition, is the language switching paradigm (for a review, see Declerck & Philipp, 2015). Language switching experiments typically consist of visual digits or pictures to specify the concepts that need to be named. Since multiple languages are implemented in language switching, visual language cues (e.g., differently colored squares) are generally used to indicate in which language the stimuli need to be produced.

Several markers have been proposed to measure inhibition with the language switching paradigm, with the main measure being asymmetrical switch costs. Asymmetrical switch costs indicate that switching languages, relative to repeating the same language in two consecutive trials, entails a cost (i.e., switch costs) that is larger when switching into L1 than when switching into L2 (e.g., Meuter & Allport, 1999; Peeters, Runnqvist, Bertrand, & Grainger, 2014). This marker can be explained with reactive, persisting inhibition: When on trial n-1 a certain language has to be produced, the non-target language will be inhibited. This inhibition will be larger for L1 than L2, since L1 is used more often and thus will be more active (cf. reactive inhibition). Yet, when the previously inhibited language is required for production on trial n (i.e., switch trial), the inhibition that was exercised on trial n-1 will persist into trial n and thus will have to be overcome. Because more inhibition was used on L1, more inhibition will persist. Hence, it should be harder to switch to L1 than to L2.

Similar to most measures of inhibition in language switching, there are several other interpretations for asymmetrical switch costs (for reviews, see Bobb & Wodniecka, 2013; Declerck & Philipp, 2015; Koch, Gade, Schuch, & Philipp, 2010), such as persisting activation (Philipp, Gade, & Koch, 2007), differences in response availability (Finkbeiner, Almeida, Janssen & Caramazza, 2006), and in terms of differences in interference across different trial types (Verhoef, Roelofs, & Chwilla, 2009). Since asymmetrical switch costs can also be explained without inhibition, they do not necessarily indicate that inhibition is implemented.

In contrast to most measures of inhibition, n-2 language repetition costs, so far, cannot be explained without assuming inhibition (Babcock & Vallesi, 2015; Branzi, Calabria, Boscarino, & Costa 2016; Declerck, Thoma, Koch, & Philipp, 2015; Guo, Liu, Chen & Li, 2013a; Guo, Ma & Liu, 2013b; Philipp et al., 2007; Philipp & Koch, 2009). Unlike other markers of language switching, n-2 language repetition costs require three languages to be measured. Consequently, performance on language A is measured in CB*A* and AB*A* sequences, with "A", "B" and "C" being trials with different languages. The results typically show that performance of language "*A*" is worse in AB*A* sequences than in CB*A* sequences. This performance difference is explained with persisting inhibition: In any given trial the non-target languages are assumed to be inhibited, the size of which depends on the activation of the non-target language. The activation of the non-target language, in turn, depends on both language proficiency (Green, 1998) and recency of language use. As the inhibition persists, it will be stronger when producing in the same language as two trials prior to the current trial (AB*A*), relative to having to produce in a language that last occurred at least three trials ago (CB*A*).

While theoretically important within the field of language control, n-2 language repetition costs have mainly been examined with digits (1-9) in a production task. The sole exceptions are Philipp and Koch (2009), where the participants had to name colors and digits, and Branzi et al. (2016), where participants had to name pictures. In the current study, we wanted to investigate whether such a cost could also be observed in other contexts, namely with other types of stimuli and during bilingual language production and comprehension.

Outline of the present study

Picture naming. As mentioned above, the recent study of Branzi et al. (2016) already examined and found substantial n-2 language repetition costs with pictures. This was important, since there is evidence that there are differences with respect to language control when naming pictures and digits (Declerck, Koch, & Philipp, 2012). More specifically, Declerck et al. (2012) found that it was harder to switch languages when naming pictures than when naming digits.

This seemed to be due to many digits being cognates, as no difference in switch costs was observed between cognate pictures and digits. Because n-2 language repetition costs have already been established with picture naming, we added a condition where participants had to name pictures to assess our experimental setup.

Pictures vs. written words. Next to pictures, we also set out to investigate n-2 language repetition costs with written words. Several studies on lexical-semantic processing have found that less thorough lexical-semantic processing takes place during reading aloud of written words than during picture naming. A semantic blocking effect for example, which entails worse performance when naming semantically-related items throughout a block than when naming semantically-unrelated items throughout a block, has only been observed with pictures, but not with written words (e.g., Belke, 2008, 2013; Belke, Brysbaert, Meyer, & Ghyselinck, 2005; Damian, Vigliocco, & Levelt, 2001; Herrera & Macizo, 2011). A similar discrepancy between reading aloud and picture naming has been observed with other paradigms (e.g., Glaser & Düngelhoff, 1984; Glaser & Glaser, 1989; La Heij, Happel, & Mulder, 1990; Roelofs, 2007).

However, a lexical-semantic effect during reading aloud has been observed. Some production studies have for example observed a semantic priming effect during reading aloud (e.g., Tabossi & Laghi, 1992). Yet, this was not always the case (e.g., Frost, Katz, & Bentin, 1987; Katz & Feldman, 1983). These semantic priming results indicate that some lexical-semantic processing can occur when reading aloud written words. However, the studies discussed above, and several other studies (e.g., Carr, Mccauley, Sperber & Parmelee, 1982; Smith & Magee, 1980), indicate that lexical-semantic processing is more thorough when using pictures than with written words.

Thus, investigating reading aloud with n-2 language repetition costs will allow us to examine inhibition when less lexical-semantic processing takes place. This is important, as several language control models assume that the inhibitory process arises during lexical-semantic processing (see above).

Production vs. comprehension. Finally, we were also interested in whether n-2 language repetition costs, which have often been found with production tasks, could also be observed with a comprehension task. Similar to models of bilingual production (e.g., Declerck et al., 2015; Green, 1998; Schwieter & Sunderman, 2008) there are also bilingual comprehension models that assume language control to rely on inhibition (e.g., Grainger & Dijkstra, 1992; Grainger et al., 2010; see above for a description of these models). Moreover, according to the BIA-d (Grainger et al., 2010) language control during bilingual production and comprehension both rely on the same inhibitory process. In this model, production-based language control is triggered *endogenously*, which entails that the goal to speak a specific language will activate the corresponding language node, which in turn will inhibit other language representations. Comprehension-based language control, on the other hand, is triggered *exogenously*, being driven by the language of the stimulus, which automatically activates its corresponding language node, in turn resulting in inhibition of other language representations. Taken together, although inhibition is triggered differently, both production and comprehension rely on inhibitory processes regulated by language nodes in this model.

A recent study found evidence for an overlap in language control between bilingual language production and comprehension (Peeters et al., 2014). In this study, French-English bilinguals had to switch between languages, while switching between language production (i.e., picture naming) and comprehension (i.e., semantic categorization task). Naming of the pictures was always in the same language, whereas the written words, based on which the participants had to perform a language decision or semantic categorization task, switched between languages. Switch costs, which are considered a marker of language control (Declerck & Philipp, 2015; Green, 1998), should be observed when switching languages across modalities if both modalities rely on the same underlying language control system, as assumed by Grainger et al. (2010). The results of Peeters et al. (2014) showed language-switch costs across modalities, in line with the assumptions of Grainger et al. (2010; for a similar finding, see Gambi & Hartsuiker, 2016).

However, not all evidence points towards an overlap in language control between bilingual language production and comprehension: different neural correlates have been observed for language switching with a production task and a comprehension task (Blanco-Elorrieta & Pylkkänen, 2016). Furthermore, the markers of inhibition that have been observed during bilingual production, such as asymmetrical switch costs, are typically not observed with comprehension tasks, and thus provide little indication of inhibition during bilingual language comprehension (e.g., Hirsch, Declerck, & Koch, 2015; Thomas & Allport, 2000). Even though we know that some of these are dubious markers of inhibition (cf. Declerck & Philipp, 2015), it did compel us to look into this matter with n-2 language repetition costs.

Method

Participants

Twenty-four participants (fifteen females; mean age 23.5 years) took part and received 6 € or partial course credit. For all participants the native language was German, whereas English (on average 8.0 years) and French (on average 4.4. years) were learned in school.

Tasks and stimuli

The experiment consisted of four different tasks: Picture naming, reading aloud, picture categorization, and written word categorization. The stimuli were either six pictures (in the picture naming and picture categorization tasks) or six written words (in the reading aloud and written word categorization tasks) concerning the same six concepts (see the Appendix for a list of all words).

In each trial, a language cue (colored rectangles; 4.2 × 4.2 cm) indicated the relevant language. For all tasks and all participants, a green rectangle indicated German, a blue rectangle English, and a red rectangle French. An instruction sheet indicating the colour-to-language mapping was placed in front of each subject throughout the experiment. Pictures (3.8 × 3.8 cm) and written words (written in capital letters) were presented inside the cue.

Responses were either vocal naming responses in German, English, or French (in the picture naming and reading aloud tasks) or manual categorization responses (in the picture categorization and written word categorization tasks). For the categorization task, participants had to decide whether the written word or the word corresponding to the picture contained an S or L (response with the right index finger on the ALT Gr key of a keyboard) or not (response with the left index finger on the ALT key).

Speech onset of the vocal responses was recorded using a voice-key. Errors in speech production were offline coded by the experimenter in a subject-file. Response times and errors in the categorization task were registered by the program.

Procedure

Each participant was tested individually. The experiment lasted approximately 45 minutes. Instructions were presented on the screen at the beginning of the experiment and emphasized speed as well as accuracy. Cues and stimuli were presented at the center of a black screen (15“ monitor) connected to an IBM-compatible PC. The viewing distance was approximately 60 cm.

A trial started with a black screen followed by a cue. After 100 ms, the stimulus (picture or written word) was presented in the middle of the cue frame. The cue and the stimulus remained on the screen until a response (key press or vocal response) was given. The interval between the response of the participant and the next cue was 600 ms.

The experiment consisted of eight blocks with 90 trials each. That is, for each task there were two successive blocks and the sequence of the four tasks was counterbalanced across participants. Participants were told to start the next block by pressing the space bar after a self-paced pause. The sequence of trials was controlled for an equal number of each language, picture/word, and language sequence (AB*A* vs. CB*A*) in each of the four tasks. Immediate repetitions of a language were excluded, because such an immediate repetition is known to affect the size of inhibitory effects (Philipp & Koch, 2006). Furthermore, immediate repetitions of stimuli, either in the next trial or the one following it, were also excluded.

Design

Each of the four tasks were analyzed separately, since they are not comparable: production (naming/reading) and comprehension (categorization) require different response modalities (vocal response vs. manual key press). Furthermore, pictures can elicit a response in both languages (bivalent), whereas written words refer to only one language (univalent). Because bivalency differences are known to affect n-2 repetition costs (see Koch et al., 2010) we could not compare these different stimulus types directly.

The four tasks all had two independent variables: language (German vs. English vs. French) and language transition (AB*A* vs. CB*A* trial). The dependent variables of all four contrasts were reaction time (RT) and error rate.

Results

RTs that were larger or smaller than two standard deviations from the mean (per participant and per task) were discarded as outliers, which resulted in the exclusion of 5.3% of the picture naming data, 3.2% of the reading aloud data, 4.5% of the picture categorization data, and 4.7% of the written word categorization data. The first two trials, error trials (i.e., processing the concept wrong and/or processing in the wrong language), and trials following errors were also excluded from RT analyses, which resulted in the exclusion of 8.6% of the picture naming data, 0.3% of the reading aloud data, 9.6% of the picture categorization data, and 5.4% of the written word categorization data.

Picture naming. An analysis of variance (ANOVA) of the RT data revealed a significant effect of language, $F(2, 46) = 5.20$, $p = .017$, $\eta_p^2 = .184$, with slower responses during French trials (1441 ms; SE: 61), $t(23) = 3.59$, $p = .002$, and English trials (1435 ms; SE: 47), $t(23) = 2.16$, $p = .041$, than in German trials (1341 ms; SE: 54; see Table 1). Performance in French and English trials was similar, $t(23) = 0.01$, $p = .990$. Importantly, the effect of language transition was significant, $F(1, 23) = 48.51$, $p = .000$, $\eta_p^2 = .678$, with slower responses during AB*A* trials (1465 ms; SE: 50) than during CB*A* trials (1346 ms; SE: 52), indicating overall n-2 language repetition costs of 119 ms. The interaction was not significant, $F(2, 46) = 2.11$, $p = .134$, $\eta_p^2 = .084$.

An ANOVA of the error data revealed no significant effect of language, $F < 1$, language transition, $F(1, 23) = 1.16$, $p = .293$, $\eta_p^2 = .048$, or the interaction, $F(2, 46) = 1.07$, $p = .345$, $\eta_p^2 = .044$.

--Table 1--

Reading aloud. An ANOVA of the RT data revealed no significant effect of language, $F < 1$, but did show a significant effect of language transition, $F(1, 23) = 4.36$, $p = .048$, $\eta_p^2 = .159$, with slower responses during AB*A* trials (536 ms; SE: 15) than during CB*A* trials (530 ms; SE: 14; see Table 1), indicating overall n-2 language repetition costs of 6 ms. The interaction was not significant, $F(2, 46) = 1.25$, $p = .295$, $\eta_p^2 = .052$.

No analysis was performed on the error data due to the extremely low amount of errors (4 errors in AB*A* trials and 5 errors in CB*A* trials across all participants).

Picture categorization. An ANOVA of the RT data revealed a significant effect of language, $F(2, 46) = 6.85$, $p = .006$, $\eta_p^2 = .229$, with slower responses during French trials (2161 ms; SE: 135), $t(23) = 4.95$, $p = .000$, and English trials (2146 ms; SE: 103), $t(23) = 3.05$, $p = .006$, than in German trials (1962 ms; SE: 102; see Table 1). Performance in French and English trials was similar, $t(23) = 0.125$, $p = .902$. The effect of language transition, $F(1, 23) = 2.63$, $p = .118$, $\eta_p^2 = .103$, and the interaction were not significant, $F(2, 46) = 1.04$, $p = .353$, $\eta_p^2 = .043$.

An ANOVA of the error data revealed no significant effect of language, $F < 1$, and language transition, $F(1, 23) = 1.32$, $p = .263$, $\eta_p^2 = .054$. The interaction, on the other hand, was significant, $F(2, 46) = 4.73$, $p = .014$, $\eta_p^2 = .171$, with larger French n-2 language repetition costs (3.4%; $t(23) = 3.00$, $p = .006$) than in English (-1.7%; $t(23) = 1.55$, $p = .134$), $t(23) = 2.85$, *p* = .009, or German (0.0%; *t* < 1), *t*(23) = 2.12, *p* = .045. Though, there was no difference between German or English n-2 language repetition costs, *t*(23) = 1.01, *p* = .326.

Written word categorization. An ANOVA of the RT data revealed a significant effect of language, *F*(2, 46) = 19.39, *p* = .000, η_p^2 = .457, with slower responses during French trials (657 ms; SE: 30), *t*(24) = 6.41, *p* = .000, and English trials (631 ms; SE: 28), *t*(24) = 4.46, *p* = .000, than in German trials (625 ms; SE: 32; see Table 1). Performance in French and English trials was similar, *t*(23) = 1.84, *p* = .079. The effect of language transition, *F*(1, 23) = 1.92, *p* = .179, η_p^2 = .077, and the interaction were not significant, *F*(2, 46) = 2.11, *p* = .134, η_p^2 = .084.

An ANOVA of the error data revealed a significant effect of language, *F*(2, 46) = 5.04, *p* = .014, η_p^2 = .180, with more errors during French trials (4.2%; SE: 1.1), than in German trials (2.4%; SE: 0.6), *t*(23) = 2.51, *p* = .020, and English trials (2.6%; SE: 0.8), *t*(23) = 2.86, *p* = .009. There was no difference in error rates between German and English trials, *t*(23) = 0.44, *p* = .667. The effect of language transition, *F* < 1, and the interaction, *F*(2, 46) = 1.86, *p* = .180, η_p^2 = .075, were not significant.

Discussion

Whereas several studies have investigated bilingual inhibition through n-2 language repetition costs, most of these studies examined digit naming. In the present study, we aimed to investigate whether n-2 language repetition costs, and thus inhibition, could be elicited with other stimulus types (i.e., pictures and written words) in both a production and comprehension task. The results showed that n-2 language repetition costs could be observed with both stimulus types when the task required the bilinguals to name/read them (i.e., production). Yet, n-2 language repetition costs were only found with pictures, but not with written words, in the comprehension task in the least dominant language (cf. French).

Bilingual language production

From the production tasks, we can deduce that n-2 language repetition costs can be found regardless of the stimulus type, and thus that inhibition is implemented during bilingual language production. More specifically, this shows that there is persisting inhibitory control during bilingual language production, since n-2 language repetition costs reflect persisting inhibition: The persisting inhibition of switching to another language will be stronger when producing in the same language as two trials prior to the current trial (AB*A*), in comparison to having produced in that language with a longer interval (CB*A*). This is in line with models that assume language control to rely on persisting inhibitory control (e.g., Declerck et al., 2015; Green, 1998; Schwieter & Sunderman, 2008). According to Green (1998), for example, inhibitory control will occur for non-target languages. In turn, this inhibition will persist into the following word(s), making it harder to produce in the inhibited language.

Yet, it should be addressed that the n-2 language repetition costs observed during reading aloud were very small (6 ms). It might very well be that, due to reading aloud requiring less thorough lexical-semantic processing than during picture naming (e.g., Belke, 2008; Carr et al., 1982; Damian et al., 2001; Glaser & Glaser, 1989; Herrera & Macizo, 2011; Roelofs, 2007; Smith & Magee, 1980), little inhibition is required during reading aloud, and thus small n-2 language repetition costs were found. This would be in line with inhibition-based models of language control that propose language control to mainly occur during lexical-semantic processing (Declerck et al., 2015; Green, 1998; Schwieter & Sunderman, 2008).

In addition, it might be that the presence of the language cue prior to the word benefited reading aloud to a large degree. More precisely, it might be that showing the language cue prior to the word lead to enhanced language preparation, which helped with selecting the phonological code faster, thus allowing to start reading aloud faster, before lexical-semantic processing taking place. This, in turn would leave less inhibitory control during reading aloud. However, the literature on preparation effects and n-2 repetition costs seems inconclusive, with some studies showing no preparation effect on n-2 repetition costs (e.g., Philipp & Koch, 2006; Mayr & Keele, 2000), whereas other studies did find a preparation effect on n-2 repetition costs (e.g., Philipp et al., 2007; Gade & Koch, 2014). Moreover, since the cue presentation prior to the stimulus was only 100 ms, we suppose that this preparation effect will be small at best.

A more surprising effect was that there was no difference between n-2 language repetition costs across languages during both picture naming and reading aloud. According to the model of Green (1998), larger n-2 language repetition costs should have been observed with the more dominant language, as this language should have a higher overall activation and thus requires more inhibition (cf. reactive inhibition). Yet, such a pattern has rarely been observed in prior n-2 language repetition studies that investigated bilingual language production (Babcock & Vallesi, 2015; Guo et al, 2013a, 2013b; Philipp et al., 2007; Philipp & Koch, 2009; however, see Declerck et al., 2015). According to Declerck and Philipp (2015), this complex pattern across production studies occurs due to multiple influences of language activation in mixed language blocks, such as language dominance and recency of language use, and its relation to inhibition.

Bilingual language comprehension

Turning to the comprehension tasks, there was little evidence for n-2 language repetition costs, and thus persisting inhibition. More specifically, no n-2 language repetition costs were observed with the written word categorization task, and n-2 language repetition costs were solely observed in the error data of the picture categorization task in the least dominant language (cf. French). Because of this scares evidence for n-2 language repetition costs in a comprehension task, we asked 18 new participants (German-English-French trilinguals) from the same participant pool to perform a n-2 language repetition task in which they had to perform a parity task (odd vs. even) with auditorily presented numbers (1-8; for a more comprehensive description of the methodology, see Appendix), which are known to elicit lexical-semantic processing (e.g., Holcomb & Neville, 1990). The results showed that n-2 language repetition costs could be found with this setup. However, similar to the picture categorization task in the main experiment, n-2 language repetition costs were only observed with the least dominant language (i.e., French).[1]

The fact that n-2 language repetition costs were only observed for the least dominant language in this control experiment and with the picture categorization task, could be accounted for by the BIA and BIA-d. According to these models, activation of a word results in activation of its language node and in turn results in inhibition of all words that are not part of this language. Since the more dominant languages have a higher overall activation, the least dominant language will be inhibited most. Hence, it is not surprising that if any of the three languages shows n-2 language repetition costs, that it is observed with the least dominant language. This, however, provides a critical difference to inhibitory mechanisms in bilingual language production models. More specifically, while the amount of inhibition is related to the activation of the non-target languages in language production models (i.e., reactive inhibition; Green, 1998), it is related to the activation of the target language in language comprehension. Nevertheless, the models still converge in the assumption that inhibitory control is exerted via language nodes.

With respect to the written word categorization task, it could be that no n-2 language repetition costs were observed with written words because participants did not focus on the words, but on the individual letters to perform the task. However, we know from studies that use the stroop task (Stroop, 1935) or the word flanker task (Shaffer & LaBerge, 1979) that written words are automatically comprehended, even when participants do not pay attention to them. In turn, the BIA and BIA-d assume that a word automatically activates its language node. Evidence along these lines has been observed in a recent study by Declerck, Snell, and Grainger (2017), who let French-English bilinguals perform a novel bilingual flanker task, which consisted of a centrally presented word that could either be in the same or a different language than its unrelated flanker words. The central word and its flankers were only presented for 170 ms, so that only the central word could be fully attended. The results showed that performance was better when the centrally presented word was in the same language as the flanker words, which indicates that the language of the flankers was automatically perceived, and influenced the central word. Hence, we assume that even in the word comprehension task, there was the possibility for inhibitory control of the non-target languages.

The lack of n-2 language repetition costs with the written word categorization task could be explained in a similar way as the very small n-2 language repetition costs during reading aloud. More specifically, less thorough lexical-semantic processing was required when processing written words when searching for letter, which in turn resulted in little inhibition and thus little to no n-2 language repetition costs. In the control experiment (i.e., semantic categorization) and the picture categorization task (i.e., letter search task based on pictures, which should activate the lexical-semantic information when accessing the word representation) on the other hand, deep lexical-semantic processing is required. In turn, in these tasks some evidence was observed for n-2 language repetition costs, and thus inhibition, during bilingual language comprehension. Hence, similar to the bilingual language production data, our bilingual language comprehension data could be explained with a lexical-semantic locus for inhibitory control.

Finding n-2 language repetition costs solely with the least dominant language (picture categorization task and control experiment) or not at all (written word categorization task) during bilingual language comprehension does raise some questions. These findings could be explained by assuming that inhibition of languages during bilingual language comprehension is only implemented under certain restrictions, depending on such characteristics as task complexity and language proficiency. Put differently, these findings indicate that inhibition, as observed with n-2 language repetition costs, can play a role during comprehension-based language control, but it is not a necessity.

Similar inhibitory control during bilingual language production and comprehension?

Since clear evidence is found for inhibitory control with language production tasks and only partial evidence with language comprehension tasks, one could assume that the overlap in language control between these two modalities is quite limited. On first glance, this is not entirely in line with the BIA-d, a model that proposed that language control relies on the activation of language nodes, which in turn inhibit all non-target language words, during both language production and comprehension. The difference across these modalities with respect to language control would then depend on how the language nodes are activated. During bilingual language production, this activation is considered to be exogenous, in which the goal to speak a language activates the language nodes. During bilingual language comprehension, on the other hand, it is assumed that the language nodes are activated through the language of the words (i.e., endogenous). Hence, the difference in n-2 language repetition cost pattern could also be explained by the BIA-d: it might be that the goal to speak a certain language (i.e. endogenous language activation) results in a higher activation of the corresponding language node, relative to the presented language of a word (i.e. exogenous, bottom up activation). In turn, one would expect more pronounced n-2 language repetition costs with a production task than a comprehension task, which is what our data show.

Taken together, the current results indicate that inhibition, measured by n-2 language repetition costs, can be observed with a variety of stimulus types during bilingual language production. On the other hand, during bilingual language comprehension n-2 language repetition costs were not found in all contexts. This indicates that inhibition can be implemented during bilingual comprehension, but this is not always the case.

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Footnotes

[1] An ANOVA of the RT data revealed a significant effect of language, $F(2, 34) = 47.03$, $p = .000$, $\eta_p^2 = .734$, with slower responses during French trials (1071 ms; SE: 15), $t(17) = 7.81$, $p = .000$, and English trials (1003 ms; SE: 17), $t(17) = 5.41$, $p = .000$, than in German trials (979 ms; SE: 15). Responses were also slower during English than German trials, $t(17) = 5.74$, $p = .000$. The effect of language transition was significant, $F(1, 17) = 24.03$, $p = .000$, $\eta_p^2 = .586$, with slower responses during AB*A* trials (1026 ms; SE: 15) than during CB*A* trials (1011 ms; SE: 15), indicating n-2 language repetition costs of 15 ms. The interaction was also significant, $F(2, 34) = 6.25$, $p = .005$, $\eta_p^2 = .269$, with larger n-2 language repetition costs observed in French trials (30 ms; $t(17) = 7.42$, $p = .000$) than in English (8 ms; $t(17) = 1.2$, $p = .240$), $t(17) = 3.04$, $p = .007$, or German trials (7 ms; $t(17) = 1.47$, $p = .159$), $t(17) = 3.18$, $p = .005$. Though, there was no difference in n-2 language repetition costs in German and English, $t < 1$.

An ANOVA of the error data revealed a significant effect of language, $F(2, 34) = 6.92$, $p = .009$, $\eta_p^2 = .289$, with more errors during French trials (3.9%; SE: 0.8) than in English (2.4%; SE: 0.4), $t(17) = 2.27$, $p = .036$, or German trials (1.9%; SE: 0.4), $t(17) = 3.16$, $p = .006$. Though, there was no significant difference in error rates between German and English trials, $t(17) = 1.53$, $p = .143$. The effect of language transition, $F < 1$, and the interaction were not significant, $F(2, 34) = 1.47$, $p = .245$, $\eta_p^2 = .079$.

Table 1. Overall mean reaction time in ms (RT) and error rates (PE) in percentages (SE in parenthesis) of the picture naming contrast (A), written word naming contrast (B), picture categorization contrast (C), and written word categorization (D) as a function of language (German vs. French vs. English) and language transition (AB*A* vs. CB*A* trial), and for n-2 language repetition costs.

		Languages	AB*A*	CB*A*	n-2 language repetition costs
A	RT	German	1397 (53)	1284 (56)	113
		English	1480 (48)	1389 (49)	91
		French	1516 (65)	1366 (61)	150
	PE	German	3.6 (0.8)	2.7 (1.0)	0.9
		English	3.4 (0.8)	2.3 (0.6)	1.1
		French	2.3 (0.6)	2.7 (0.9)	-0.4
B	RT	German	534 (16)	535 (15)	-1
		English	539 (17)	529 (15)	10
		French	535 (14)	525 (14)	10
	PE	German	0.0 (0.0)	0.0 (0.0)	0.0
		English	0.0 (0.0)	0.0 (0.0)	0.0
		French	0.0 (0.0)	0.0 (0.0)	0.0
C	RT	German	1973 (102)	1951 (106)	22
		English	2191 (103)	2102 (107)	89
		French	2165 (147)	2158 (125)	7
	PE	German	5.5 (1.3)	5.5 (1.4)	0.0
		English	4.5 (0.9)	6.2 (1.4)	-1.7
		French	7.5 (1.6)	4.1 (1.2)	3.4
D	RT	German	634 (33)	614 (30)	20
		English	636 (30)	627 (27)	9
		French	655 (31)	659 (31)	-4
	PE	German	2.7 (0.8)	2.1 (0.5)	0.6
		English	2.5 (0.9)	2.8 (0.8)	-0.3
		French	3.4 (0.9)	5.0 (1.5)	-1.6

Appendix

List of stimuli used in the experiment. The critical letters for the categorization task (S and L) are highlighted in the Table but were not highlighted in the experiment.

German	English	French
VOGE**L**	BIRD	OI**S**EAU
WO**L**KE	C**L**OUD	NUAGE
PFERD	HOR**S**E	CHEVA**L**
AFFE	MONKEY	**S**INGE
BLEI**S**TIFT	PENCI**L**	CRAYON
BAUM	TREE	ARBRE

Summary of methodology of auditory control experiment.

The methodology was similar to that of the written word categorization task in the original experiment. The main differences are: The stimuli were auditory numbers 1-8 spoken by a man in all three languages. The task of the participants consisted of categorizing the numbers in odd or even by pressing the “ALT” or “ALT Gr” key, respectively. The language cues consisted of a diamond shape to indicate that a German word was coming up, a square shape to indicate that an English word was coming up, and a triangle to indicate that a French word was coming up. These cues were presented for 500 ms prior to stimulus presentation. Following the reaction of the participants, there was 600 ms until the next cue would be presented.