Highly proficient bilinguals implement inhibition - Evidence from n-2 language repetition costs.

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Abstract

Several, but not all, models of language control assume that highly proficient bilinguals implement little to no inhibition during bilingual language production. In the current study, we tested this assumption with a less equivocal marker of inhibition (i.e., n-2 language repetition costs) than previous language switching studies have. N-2 language repetition costs denote worse performance when switching back to a recently abandoned language (i.e., worse performance in AB*A* language sequences than CB*A* sequences, where A, B, and C refer to different languages). Whereas this marker has solely been used to investigate second language learners in prior studies, we examined highly proficient bilinguals. The results showed that substantial n-2 language repetition costs can be observed with highly proficient bilinguals. Moreover, this inhibition effect was substantial for all three languages but larger for the two dominant languages (Turkish and German) relative to the less proficient language (English). These findings indicate that even highly proficient bilinguals implement inhibition to restrict language production to the target language.

(words:163)

Bilingual language control is an important process that restricts bilingual speech production to the currently relevant language in order to avoid any intrusions from the non-target language(s), since activation and selection of words of the non-target language can occur (e.g., Gollan, Schotter, Gomez, Murillo, & Rayner, 2014; Poulisse & Bongaerts, 1994). A prominent model to account for bilingual language control is the inhibitory control model (ICM; Green, 1998). According to this model, language control mainly consists of persisting, reactive inhibition. Reactive inhibition means that a larger activation of a non-target language will lead to more inhibition of this language, whereas the persistence of inhibition entails that this inhibition will continue into the following word(s). Yet, several later models have assumed that this inhibitory process only applies for second language learners but not for highly proficient bilinguals (e.g., Costa & Santesteban, 2004; Schwieter & Sunderman, 2008, 2009). Schwieter and Sunderman (2008, 2009), for example, proposed a language cue at the conceptual level, which facilitates the subsequent activation and selection of the representation in the target language, thus rendering inhibition obsolete for highly proficient bilinguals (see also La Heij, 2005).

Evidence that highly proficient bilinguals do not implement inhibition, whereas second language learners do implement it is founded on studies that observed differences in language control between these two types of bilinguals (e.g., Garbin et al., 2011; Martin et al., 2013) and studies that found no evidence for inhibitory processes with highly proficient bilinguals (e.g., Branzi, Martin, Abutalebi, & Costa, 2014; Costa & Santesteban, 2004; Costa, Santesteban, & Ivanova, 2006; Runnqvist, Strijkers, Alario, & Costa, 2012). Costa and Santesteban (2004), for example, observed in a picture naming task that when highly proficient Catalan-Spanish bilinguals switch from one language to another, which incurs a cost relative to staying in the same language (“switch costs”; e.g., Meuter & Allport, 1999), the switch costs are generally similar for both languages even when they switch between languages other than their highly proficient languages (see also Calabria, Hernández, Branzi,

& Costa, 2011; Costa et al., 2006; Christoffels, Firk, & Schiller, 2007; Martin et al., 2013; yet see Experiments 3 and 4 of Costa et al., 2006). With second language learners, on the other hand, switch costs are typically, but not always (e.g., Declerck, Koch, & Philipp, 2012; Verhoef, Roelofs, & Chwilla, 2010), larger when switching from the less dominant language to the more dominant language (e.g., Meuter & Allport, 1999; Peeters, Runnqvist, Bertrand, & Grainger, 2014; Philipp, Gade, & Koch, 2007).

These “asymmetrical switch costs”, observed with second language learners, can be explained by the ICM: Due to more experience with the first language (L1) than the second language (L2), L1 has a larger activation than L2. In turn, more inhibition will be needed to suppress L1 during L2 production than vice versa (cf. reactive inhibition), which will lead to larger persisting inhibition on L1 than on L2 during switch trials. Hence, switch costs should be larger when switching (back) to L1 than to L2 (Green, 1998; Meuter & Allport, 1999).

As we mentioned earlier, no such asymmetry has been observed with highly proficient bilinguals, even when implementing a third language. Since a third, less proficient language should have less activation than the two highly proficient languages, smaller switch costs are expected according to the ICM, similar to the pattern observed with second language learners. Costa and Santesteban (2004) suggested that this is evidence that highly proficient bilinguals and second language learners have fundamentally different language control processes, with little to no inhibitory language control for highly proficient bilinguals.

Yet, the interpretation of asymmetrical switch costs in terms of inhibition has recently been put into question (for reviews on asymmetrical switch costs, see Bobb & Wodniecka, 2013; Koch, Gade, Schuch & Philipp, 2010). It has been proposed that asymmetrical switch costs can, next to persisting inhibition, also be explained with persisting activation (i.e., positive language priming; Philipp et al., 2007). This account relies on a similar idea as that proposed by the ICM. The only difference is that the target language gets activated, instead of the non-target language getting inhibited, and that it is this increased activation that persists into the next trial. In that scenario, L2 is weaker and thus needs stronger activation, which renders L2 a stronger competitor when switching (back) to L1, and thus should result in larger L1 than L2 switch costs (see Koch et al., 2010). Other interpretations have proposed that solely L1 repetition trials are not encumbered by language interference, and thus increase L1 switch costs by affecting the baseline (i.e., repetition trials; Verhoef, Roelofs, & Chwilla, 2009). Finally, Finkbeiner, Almeida, Janssen, and Caramazza (2006) have proposed that asymmetrical switch costs are due to switch trials being difficult. To prevent any errors in this difficult situation, participants would reject initial responses that are too fast. In turn, since L1 is typically faster than L2, it follows that more L1 responses will be rejected than L2, and thus larger switch costs should be found with L1.

More recently, Runnqvist and colleagues (2012) also investigated whether highly proficient Spanish-Catalan bilinguals implement inhibition. Yet, unlike prior research, they focused on inhibition at the lexical level. To investigate bilingual lexical processing, they implemented semantically-related pictures after every second trial, which is known to decrease performance linearly after production of every semantically-related picture due to increased lexical competition (e.g., Howard, Nickels, Coltheart, & Cole-Virtue, 2006). The presentation of semantically-related pictures coincided also with switching to another language. They reasoned that if inhibition would occur when switching between languages, as the ICM assumes, then no performance decrease should be observed due to naming semantically-related pictures, since the competitors would be inhibited. However, they did observe such a performance decrease, indicating that highly proficient bilinguals do not necessarily implement inhibition.

In the current study, we aimed to further investigate inhibitory processes in highly proficient bilinguals by examining n-2 language repetition costs, which has previously only been used to investigate second language learners, who were also third language learners (Guo, Liu, Chen, & Li, 2013; Guo, Ma, & Liu, 2013; Philipp et al., 2007; Philipp & Koch, 2009). In prior n-2 language repetition experiments, participants were presented with digits, which had to be named in one of three languages. The production in one of these three languages was indicated by a language cue (e.g., different geometric shapes). It was regularly found that performance is better during the production of language "A" when bilinguals responded in a CB*A* sequence, with "A", "B" and "C" being trials with different languages, than when they had to respond in an AB*A* sequence. These n-2 language repetition costs are explained by assuming that non-target languages become inhibited to produce in the target language. The amount of inhibition depends on the activation of a non-target language (cf. reactive inhibition), which is based on language proficiency (Green, 1998) and recency of language use (i.e., the language used in the preceding trial is activated to a relatively high degree and, thus, inhibited to a high degree; that is, producing language B in an AB*A* sequence leads to a strong inhibition of language A). 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 produced in that language with a longer interval (CB*A*; e.g., Koch et al., 2010; Philipp et al., 2007). Notably, persisting activation would predict just the opposite result (i.e., n-2 repetition benefits), so that finding n-2 language repetition costs, unlike the switch cost asymmetry, can be more unequivocally attributed to the existence of relative differences in persisting inhibition.

In the present study we set out to investigate whether n-2 language repetition costs can also be observed with highly proficient bilinguals, who were language learners with respect to a third language. According to the ICM (Green, 1998), we should find n-2 language repetition costs with highly proficient bilinguals, since inhibition is the main feature of language control in this model, regardless of language proficiency. Furthermore, since this model assumes reactive inhibition, larger n-2 language repetition costs were expected for the dominant languages (i.e., the two languages in which they are highly proficient) than the less dominant language. According to Costa and Santesteban (2004) and Schwieter and Sunderman (2008, 2009), on the other hand, no inhibition and thus no n-2 language repetition costs should be observed, since they assume that highly proficient bilinguals do not require inhibition to restrict their language production to the target language – even with respect to a third language (Costa et al., 2006).

Method

Participants

Eighteen Turkish-German bilingual participants (eight male; average age: 23.9), who all grew up in Germany with both parents being Turkish and spoke English as their third language after Turkish and German, took part. The average English age of acquisition, years of formal English education, and self-rated scores of English speaking, writing, and reading indicate that they are not proficient in English (see Table 1). The average age of acquisition for Turkish and German and the amount of time they typically spoke Turkish relative to German indicates that these participants are highly proficient in Turkish and German (see Table 2). Moreover, all participants indicated that they considered both Turkish and German to be their L1.

--Table 1--

--Table 2--

To further test the apparent status of our participants as proficient Turkish-German bilinguals empirically, we let the participants perform a Turkish-German language switching task after the main experiment. A similar pattern was observed (see below, *Language switch cost contrast*) as in prior studies that investigated highly proficient bilinguals (Calabria et al., 2011; Costa & Santesteban, 2004; Costa et al., 2006; Christoffels et al., 2007; Meuter & Allport, 1999).

Apparatus and stimuli

Arabic numerals 1-9 (1 cm x 0.5 cm) were used in the current experiment, which subjects had to name in Turkish, German, or English depending on the language cue. The language cues could be a square (3.8 cm x 3.8 cm), to indicate Turkish, a diamond (5.3 x 5.3 cm), to indicate German, or a triangle (4.5 cm x 4.0 cm), to indicate English. These cues and their relation to each language were kept constant for all participants, since there is arguably no preferential mapping of the arbitrarily chosen language cues to the specific languages. Furthermore, Philipp and Koch (2009) used two alternate cues for each of the three languages and showed that priming effects at the level of cue encoding (i.e., n-2 cue repetitions vs. non-repetitions) have only a minor effect on n-2 language repetition costs (which could be demonstrated even with n-2 cue non-repetitions).

Speech onset of vocal responses was recorded with a voice-key. Errors were coded during the experiment by the experimenter in a separate file.

Procedure

Prior to the experiment, the instructions were presented in German both orally and visually, with an emphasis on both speed and accuracy. This was followed by a practice block of 27 trials and six experimental blocks of 108 trials each. The trials within each experimental block were controlled for an equal amount of each language, digit, and language transition (AB*A* vs. CB*A* trials), which resulted in approximately 107 trials of AB*A* and CB*A* trials in each language for each participant. Furthermore, immediate repetitions of digit or language were not admitted.

Each trial started with a language cue (100 ms) and was followed by a digit in the middle of the cue frame that stayed visible until a response was registered. After the onset of word production, a pause of 1000 ms was initiated, after which the subsequent trial would be presented.

After the main experiment, a typical Turkish-German language switching task was implemented. The post-experimental task and the main experiment only differed in few characteristics: the reduction of trials (i.e., there were three blocks of 72 trials each), languages were restricted to Turkish and German, and that immediate language repetitions were possible.

Design

In the *n-2 language repetition cost contrast*, the independent variables were language (Turkish vs. German vs. English) and language transition (AB*A* vs. CB*A* trial). In the *language switch cost contrast*, the independent variables were language (Turkish vs. German) and language transition (switch vs. repetition trials). The dependent variables in both contrasts were reaction time (RT) and error rate.

Results

RTs in all trials were z-transformed per participant, and trials with a z-score of -2/+2 were discarded as outliers. The first two trials and error trials, which constituted the production of a wrong number and/or production in the wrong language, were also excluded from RT analyses. Taken together, this resulted in the exclusion of 10.4% of the data.

--Table 3--

N-2 language repetition cost contrast. An analysis of variance (ANOVA) of the RT data revealed a significant effect of language, $F(2, 34) = 12.37$, $p < .001$, $\eta_p^2 = .421$, indicating slower responses during German trials (994 ms) than during Turkish (891 ms) or English trials (894 ms; see Table 3). Importantly, the effect of language transition was significant, $F(1, 17) = 53.33$, $p < .001$, $\eta_p^2 = .758$, with slower responses during AB*A* trials (949 ms) than during CB*A* trials (903 ms), indicating overall n-2 language repetition costs of 46 ms.

Moreover, the interaction was also significant, $F(2, 34) = 5.48$, $p < .01$, $\eta_p^2 = .244$. There were n-2 language repetition costs for English (17 ms, $t(17) = 2.09$, $p = .052$), German (67 ms, $t(17) = 4.94$, $p < .001$), and Turkish (55 ms, $t(17) = 4.86$, $p < .001$). Post hoc *t*-tests with a Bonferroni adjustment indicated that n-2 language repetition costs for English were significantly smaller than for Turkish, $t(17) = 2.69$, $p < .05$, or German, $t(17) = 2.70$, $p < .05$, whereas the effect did not differ for Turkish and German, $t < 1$.

An ANOVA of the error data revealed a significant effect of language, $F(2, 34) = 10.65$, $p < .001$, $\eta_p^2 = .385$, with more errors during German trials (2.1%), followed by Turkish trials (1.8%) and English trials (1.2%). The effects of language transition, $F < 1$, and of the interaction, $F(2, 34) = 2.44$, ns., $\eta_p^2 = .125$, were not significant.

Language switch cost contrast. An ANOVA of the RT data revealed no effect of language, $F < 1$. There was a significant effect of language transition, $F(17) = 4.98$, $p < .05$, $\eta_p^2 = .227$, with slower responses in switch trials (721 ms) than repetition trials (688 ms; see Table 4). The interaction was not significant, $F(17) = 1.06$, ns., $\eta_p^2 = .059$, and thus showed symmetrical switch costs.

An ANOVA of the error data revealed no effect of language, $F < 1$. There was a significant effect of language transition, $F(17) = 31.51$, $p < .001$, $\eta_p^2 = .650$, with more errors in switch trials (5.6%) than repetition trials (1.6%). The interaction was not significant, $F(17) = 1.48$, ns., $\eta_p^2 = .080$, again showing symmetrical switch costs.

--Table 4--

Discussion

The present study set out to investigate whether inhibition, measured by n-2 language repetition costs, could be observed with highly proficient bilinguals. The results showed that highly proficient bilinguals instigate n-2 language repetition costs and that these costs are similar for both highly proficient languages (Turkish and German). Yet, smaller n-2 language repetition costs were observed for the less proficient language (English).

N-2 language repetition costs

Since n-2 language repetition costs are considered a marker for inhibition (Guo et al., 2013; Philipp et al., 2007; Philipp & Koch, 2009; for a review see Koch et al., 2010), these results provide a strong indication that inhibition can occur during language control of highly proficient bilinguals. This finding is not in line with models that assume that only second language learners, but not highly proficient bilinguals, implement inhibition during language control (e.g., Costa & Santesteban, 2004; Schwieter & Sunderman, 2008, 2009). Our results are, however, in line with the ICM (Green, 1998), which assumes that inhibition occurs to restrict production to the target language, regardless of whether participants are highly proficient or not.

Another finding that is in line with the ICM is that the dominant languages, according to the demographic information and the history of language learning (see Tables 1 and 2), were inhibited more strongly than the less dominant language (see also Guo et al., 2013; Philipp et al., 2007). This is consistent with the reactive inhibition assumption, which states that languages that incur a larger activation (i.e., more dominant languages) will need to be inhibited to a larger extent. The increase of inhibition should also persist more strongly in ensuing trials (cf. persisting inhibition) and thus result in higher n-2 language repetition costs, which is consistent with our data.

It should be noted that, whereas our findings indicate that inhibition plays an integral role during language control of highly proficient bilinguals, this does not preclude other processes, such as activation (cf. Branzi et al., 2014; Philipp et al., 2007), to be implemented as well, since both processes are not mutually exclusive. Such a combination of processes seems to be in line with the literature (e.g., Branzi et al., 2014).

(A)symmetrical switch costs

Next to the n-2 language repetition costs, we also observed symmetrical switch costs when switching between Turkish and German in the post-experimental language switching task. As we discussed in the introduction, switch costs can be accounted for by other mechanisms than language inhibition (cf. Finkbeiner at al., 2006; Philipp et al., 2007; Verhoef et al., 2009). Consequently, symmetrical switch costs do not necessarily indicate that no inhibition occurs with highly proficient bilinguals. This is even further reinforced by the finding of n-2 language repetition costs in the same highly proficient bilinguals, since this finding is an indication that inhibition was implemented. Additional converging evidence for such a claim comes from studies that found symmetrical switch costs with second language learners (e.g., Declerck et al., 2012, 2015; Gollan & Ferreira, 2009), even though second language learners are generally assumed to implement inhibitory processes during language control (e.g., Guo et al., 2013; Philipp et al., 2007; Philipp & Koch, 2009). Hence, it is doubtful whether an (a)symmetry of switch costs across languages should be referred to as a measure of inhibition (for reviews on this matter, see Bobb & Wodniecka, 2013; Koch et al., 2010).

Response speed and error rates reversed to language dominance

One remarkable observation of the present experiment is that, overall, German performance was worse than Turkish performance. In turn, Turkish was worse than English.

Based on the demographic information of the participants, one would assume that English performance would be worse than Turkish and German, since English was obviously the least proficient of the three languages. Yet, in line with our observation, several language switching studies also found a performance pattern in mixed language blocks that is opposite to the language dominance (e.g., Christoffels et al., 2007; Costa & Santesteban, 2004; Declerck et al., 2013; Gollan & Ferreira, 2009; Verhoef et al., 2009).

This reversal may reflect a sustained, global competitive bias against L1 in order to avoid premature responses in the dominant language(s). We assume two different processes that could explain the observed data pattern. First, we suppose that the less dominant language was activated to a larger degree throughout the experiment by the language control process, causing a relative disadvantage of the more dominant languages. Such an increase in activation might have been caused by relatively large practice effects in the less dominant language. Probably, words in the third language are produced less frequently in daily life so that the experimental situation led to a large increase of word activation for those words, specifically speeding up their RT and decreasing error rates (cf. Francis & Sáenz, 2007). Additionally, we suggest a global inhibition of the more dominant languages (e.g., Christoffels et al., 2007; Gollan et al., 2014; Gollan & Ferreira, 2009; Verhoef et al., 2009).

In the current context we assume that, while participants indicated to be highly proficient in both Turkish and German, German was activated to a higher degree because the participants were in a German environment (i.e., German university, where the participants would be addressed in German; cf. Green, 2011; Green & Abutalebi, 2013; Grosjean, 2001). This German context would also lead to practice effects on German (i.e., by conversing in German), and thus also increase German activation. Converging evidence for the impact of practice on the language difference was observed in the n-2 language repetition task, where the language difference between Turkish and German decreased with 40 ms from the first to the last block. In turn, due to similar practice of Turkish and German during the main experiment, no substantial language difference was observed anymore between Turkish and German in the post-experimental language switching task, thus reducing the impact of the environment. Hence, German was activated more than Turkish and English in the main experiment due to the environment and practice effects, which led to a decrease of German performance because of global inhibition of the dominant language and/or increased activation of the less dominant languages.

However, it is important to note that global inhibition is fundamentally different from the reactive and persisting inhibition that caused n-2 language repetition costs in the present experiment. Whereas reactive, persisting inhibition differs on a trial-to-trial basis, thus causing n-2 language repetition costs, the global inhibition is assumed to be relatively constant throughout the experiment. Yet, one might wonder whether the size of the reactive, persisting inhibition is caused by the language dominance (as indicated by demographic measures) or by the response speed/error rates of each language in the experiment, which is modified by global inhibition, leading to an RT and error rate pattern reversed to the language dominance. In the present study, the asymmetrical n-2 language repetition cost pattern is in line with the ICM based on the language dominance deduced from the demographic language information, but it is not in line with the language dominance based on the RT and error rates. Such a discrepancy has also been observed in prior n-2 language repetition studies (e.g., Philipp et al., 2007; Guo et al., 2013). To reconcile the asymmetrical n-2 language repetition cost pattern and the response speed/error rate pattern, we propose that the functional locus of these effects is different. More specifically, we suggest that the inhibition process, observable with n-2 language repetition costs, occurs earlier in the bilingual language process than the global inhibition, which might influence relatively late processes such as phonological processes or articulation. Converging evidence for this claim can be found in Gollan et al. (2014), where accent errors (i.e., producing a word with the accent of another language) also showed a reversed dominance effect, thus providing some evidence for a late locus of dominance effects. This global language control process could thus be implemented to avoid phonology-based errors. On the other hand, it could also be that the inhibition process, observable with n-2 language repetition costs, occurs outside the bilingual language process between language schemas, which are mental devices that are implemented to achieve task-specific goals that occur early on during bilingual language processing (cf. Green, 1998). Regardless of the specific functional loci of these two effects, the idea that language control can occur at several processing stages of the bilingual language process is in line with current theories (e.g., Declerck et al., 2015; Gollan et al., 2014).

Conclusion

In summary, substantial n-2 language repetition costs were observed with highly proficient bilinguals. This finding provides evidence that inhibitory processes occur during language production of highly proficient bilinguals.

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Table 1. Overview of English demographic information of the participants. The information consists of the average of English age of acquisition (AoA), the average years of formal English education, and how high the participants rated their English spoken level, writing level, and reading level (with 1 being very bad and 7 being very good).

	Average	Standard deviation
English AoA	10.1	0.9
Formal English education	9.1	1.9
English speaking	4.7	1.2
English writing	4.4	1.3
English reading	5.7	1.0

Table 2. Overview of Turkish and German demographic information of the participants. The information consists of the average of Turkish and German age of acquisition (AoA) and the average percentage of time the participants speak Turkish at home, school/work, and with friends, relative to German.

	Average	Standard deviation
Turkish AoA	0.3	1.0
German AoA	2.1	2.3
% of Turkish at home	70%	17.7
% of Turkish at school/work	9.3%	15.3
% of Turkish with friends	38.9%	25.4

Table 3. Overall mean reaction time in ms (RT) and error rates (PE) in percentages (SD in parenthesis) as a function of language (Turkish vs. German 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
RT	Turkish	919 (217)	864 (207)	55
	German	1027 (213)	960 (210)	67
	English	902 (234)	885 (241)	17
PE	Turkish	1.7 (0.2)	1.8 (0.1)	-0.1
	German	2.4 (0.2)	1.9 (0.1)	0.5
	English	1.1 (0.1)	1.3 (0.1)	-0.2

Table 4. Overall mean reaction time of the post-experimental language switching task in ms (RT) and error rates (PE) in percentages (SD in parenthesis) as a function of language (Turkish vs. German) and language transition (switch vs. repetition trial), and for switch costs.

	Languages	AB*A*	CB*A*	Switch costs
RT	Turkish	728 (134)	687 (138)	41
	German	713 (133)	689 (125)	24
PE	Turkish	4.9 (4.2)	1.8 (1.8)	3.1
	German	6.3 (5.0)	1.5 (1.4)	4.8