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Asymmetric inhibitory treatment effects in multilingual aphasia

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Abstract

Findings from recent psycholinguistic studies of bilingual processing support the hypothesis that both languages of a bilingual are always active and that bilinguals continually engage in processes of language selection. This view aligns with the convergence hypothesis of bilingual language representation (Abutalebi & Green, 2008). Furthermore, it is hypothesized that when bilinguals perform a task in one language they need to inhibit their other, non-target language(s) (e.g., Costa, Miozzo, & Caramazza, 1999) and that stronger inhibition is required when the task is performed in the weaker language than in the stronger one (e.g., Costa & Santesteban, 2004). The study of multilingual individuals who acquire aphasia resulting from a focal brain lesion offers a unique opportunity to test the convergence hypothesis and the inhibition asymmetry. We report on a trilingual person with chronic non-fluent aphasia who at the time of testing demonstrated greater impairment in her first acquired language (Persian) than in her third, later-learned language (English). She received treatment in English followed by treatment in Persian. An examination of her connected language production revealed improvement in her grammatical skills in each language following intervention in that language, but decreased grammatical accuracy in English following treatment in Persian. The increased error rate was evident in structures that are not shared by the two languages (e.g., use of auxiliary verbs). The results support the prediction that greater inhibition is applied to the stronger language than to the weaker language, regardless of their age of acquisition. We interpret the findings as consistent with convergence theories that posit overlapping neuronal representation and simultaneous activation of multiple languages, and with proficiency-dependent asymmetric inhibition in multilinguals.

Introduction

People who use two or more languages are typically very good at selecting the right language at the right time, especially when communicating with an interlocutor who speaks only one language. This ability to select the target word in a target language and inhibit potential competitors, including words in the other, non-target languages, has been the subject of extensive study by psycholinguists and neurolinguists. Early suggestions posited that bilinguals may operate in a “bilingual mode”, when both their languages are highly active, or in a “monolingual mode”, during which only the relevant language is active (Grosjean, 2001). However, recent evidence supports the hypothesis that a pure monolingual mode is unlikely. Rather, the assumption is that both (or all) languages of bilinguals and multilinguals are always active and that bilinguals continually engage in processes of selection (e.g., Kroll, Bobb, & Wodniecka, 2006; Misra, Guo, Bobb, & Kroll, 2012). For example, when bilinguals wish to produce a word in one language, both languages are active; the non-target language needs to be inhibited for the target word to be selected. Furthermore, it appears that stronger inhibition is required when the word is produced in the

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weaker language than when it is produced in the stronger one (e.g., Costa & Santesteban, 2004). This view of bilingual processing is in line with the convergence hypothesis put forward by Green and colleagues, postulating largely overlapping neural networks for all languages in a multilingual's brain, and separate neural networks that support processes of selection, activation and inhibition (Abutalebi & Green, 2008; Green & Abutalebi, 2008).

When either the language system or the selection system is impaired due to acquired brain damage, difficulty with appropriate language selection may arise. Speakers of multiple languages who acquire aphasia resulting from a focal brain lesion offer a unique opportunity to test the convergence hypothesis and the postulated inhibition asymmetry. We review below the psycholinguistic evidence that demonstrates the inhibition asymmetry and summarize previous findings from treatment and recovery in bilingual aphasia, before presenting evidence for inhibition processes in language production of a trilingual person with aphasia.

Experimental research has shown that when bilinguals process or produce words in one of their languages, performance is influenced by the other languages they know. In language processing tasks (such as lexical decision), cognates – words that share form and meaning in two languages – facilitate recognition, whereas inter-lingual homographs – words that share written form but diverge in meaning across two languages – slow performance down (e.g., Dijkstra, Miwa, Brummelhuis, Sappelli, & Baayen, 2010; Ko, Wang, & Kim, 2011; Van Heuven, Dijkstra, & Grainger, 1998). Similarly, in word production tasks, such as picture naming, bilinguals produce cognate words faster than non-cognates (e.g., Costa, Caramazza, & Sebastian-Galles, 2000) and demonstrate activation of lexical forms from the non-target language (Colomé, 2001). The exact locus of the selection/inhibition in the process of production (e.g., response selection vs. lexical selection) has been a subject of debate (e.g., Costa, Miozzo, & Caramazza, 1999; Kroll, Bobb, Misra, & Guo, 2008; La Heij, Kuipers, & Starreveld, 2006; Finkbeiner, Gollan, & Caramazza, 2006; Finkbeiner & Caramazza, 2006).

When language selection is embedded in the experimental task, as in a picture-naming task that compares blocked- and mixed-language conditions (e.g., participants are instructed to name a list of pictures in one language vs. participants are cued to name a picture in language A or language B within the same list) or in a reading aloud task, findings have demonstrated the existence of a "switching cost". That is, bilinguals display longer response latencies in the mixed-language conditions than the blocked-language conditions, and longer latencies within the mixed-language condition for items that follow a language switch than for items that are named in the same language as the previous item (Hernandez, Martinez, & Kohnert, 2000; Kolers, 1966; Meuter & Allport, 1999).

Furthermore, Meuter and Allport (1999) reported the counter-intuitive finding of longer response time in the stronger L1 than the weaker L2 in bilinguals who are instructed to name pictures, in one or the other of their languages, following a cue. The authors interpreted their findings as evidence for the need to strongly inhibit the better language when attempting production in a weaker one, resulting in longer re-activation latency when naming in the stronger language follows. However, corroborating evidence for proficiency-related inhibition asymmetry has been somewhat tenuous. Costa and his colleagues have demonstrated that whether an asymmetry is obtained is dependent on relative language proficiency. That is, bilinguals who are highly proficient in both their L1 and L2 show little asymmetry in the switching cost, whereas those who are dominant in one language show clearly longer response time when switching back to their stronger one (Costa & Santesteban, 2004). However, when trilinguals performed a picture-naming task in a mixed-language block, there was an asymmetry of switching cost between their L1 and weaker L2 and L3, but not between a stronger L2 and a weaker L3. In a subsequent experiment, the

authors found the expected asymmetry between the third and fourth languages of quadrilinguals (Costa, Santesteban, & Ivanova, 2006), and Philipp and colleague found the asymmetry for each language pairs in another group of trilingual speakers (Philipp, Gade, & Koch, 2007).

Another source of evidence for overlap in the representation of a bilingual's languages comes from comparable impairment in the multiple languages of bilingual individuals who acquire aphasia. If one focal brain lesion affects both languages, the parsimonious interpretation is that the damaged area was part of a circuit responsible for processing both languages. In contrast, patterns of non-parallel impairment, such as when one language is impaired while another is preserved, may cast doubt on a completely overlapping representation of the languages. Nevertheless, under the convergence hypothesis, non-parallel patterns of impairment among the languages as well as patterns of trade-off selection – when one language demonstrates recovery while another regresses – are interpreted as evidence for an impaired selection mechanism resulting from brain damage in the network responsible for activation and inhibition (Green & Abutalebi, 2008).

Taking this logic a step further, successful treatment in one language of a multilingual speaker with aphasia would be expected to carry-over to the untreated languages if all languages are processed in overlapping brain networks (and improvement is associated with brain change). Here, too, it can be expected that if two languages compete for activation and one needs to be inhibited for the other to be activated, trade-off patterns should be observed whereby following treatment in one language, the other languages may be inhibited. In addition, a proficiency-related asymmetry of inhibition can be predicted. However, recent reviews of findings from aphasia treatment studies with speakers of multiple languages portray mixed results (Faroqi-Shah, Frymark, Mullen, & Wang, 2010; Kohnert & Peterson, 2012; Obler & Park, 2012).

In the lexical domain, positive generalization has been reported from the language that was weaker prior to the stroke to the stronger (pre-stroke) language, whereas training in the stronger pre-stroke language did not generalize to the weaker one (Edmonds & Kiran, 2006). Other studies have reported greater generalization for cognate words, those words that are assumed to have shared representations, than for non-cognates (Kiran & Roberts, 2010; Kohnert, 2004). Additional studies have pointed out the findings of overall cross-language generalization from the treated language to an untreated language but not to the untreated first-acquired language (Miertsch, Meisel, & Isel, 2009). Consistently, a recent study found no evidence of improvement in the untreated L1 following treatment in the participant's L2 (Miller Amberber, 2012) and one study reported lower performance in the stronger L1 following treatment in L2 (Abutalebi, Rosa, Tettamanti, Green, & Cappa, 2009). Few studies have systematically examined change in syntactic production following treatment (Goral, Levy, & Kastl, 2010).

We hypothesized that if proficiency-dependent inhibition processes occur at the language selection level of language production (rather than at the item level), evidence for proficiency-related inhibition can be detected following treatment in multilingual speakers with aphasia. Specifically, we predicted that aphasia treatment in a weaker language may result in the inhibition of language production in a stronger language in the same way that naming in a weaker language results in inhibition of the stronger one in healthy individuals, but that treatment in a stronger language will have small or no inhibitory effect on an untreated weaker language. Furthermore, we predicted that because the inhibition processes are dynamic and are associated with activation levels, the determinant proficiency levels would be those observed following the stroke, even if they do not reflect pre-stroke

proficiency levels. We report here data from a trilingual speaker who is an ideal case for testing these predictions.

Methods

Participant

PGE, a 41-year-old right-handed woman, participated in the study. She was born in Iran, acquiring Persian as her first language. When she was six years old, her family moved to Germany, where she acquired German and completed all her schooling, including a college degree in German. Upon moving to the United States at age 27, she began using English primarily, attaining high proficiency. She maintained high proficiency and frequent use in her three languages. At age 28, she sustained a cerebral-vascular accident affecting large portions of her left hemisphere, including frontal regions. Her language production at the time of the study, 13 years post stroke, was characterized by anomia, agrammatism including incomplete sentences and difficulty with grammatical morphemes and with function words, and frequent rephrasing. Her language processing abilities were superior to her expression, with mild auditory and reading comprehension impairment. Her English abilities were superior to her abilities in Persian, her L1, and German, her L2. An administration of the Western Aphasia Battery (WAB, Kertesz, 1982) in English revealed an Aphasia Quotient of 78.3.

In the years following the stroke and before the current study, PGE used virtually only English to communicate. She had received speech-language therapy in English in individual and group setting. She reported hearing Persian regularly from her mother and other family members, and German, less frequently, from her siblings but not attempting to produce Persian or German since her CVA.

Treatment

PGE received two consecutive treatment blocks, the first in English and the second in Persian. Treatment targeted spoken language production and was adjusted to the level of ability in each language. The treatment incorporated principles from the constraint-induced aphasia treatment described by Pulvermüller and colleagues (CIAT, Difrancesco, Pulvermüller, & Mohr, 2013; Pulvermüller et al., 2001) in that verbal production was required and the exchange of new information between the participant and the clinician was encouraged. As well, a relatively intense treatment schedule was employed (seven hours of therapy per week over five weeks). Unlike traditional CIAT, treatment sessions were conducted in a one-on-one format.

English treatment was administered by a native speaker of English; Persian treatment was administered by a bilingual English-Persian graduate student who acquired Persian at home (a heritage speaker). Treatment activities included language games that aimed to facilitate production of complete sentences in English and short subject-object-verb (the unmarked word order in Persian) sentences in Persian. Picture stimuli included color picture cards each depicting an action. The clinician and participant took turns producing sentences to describe the action in the picture. There were no target items that were specifically trained; rather, the clinician and the participant each took turns producing sentences that could be appropriate to describe the pictures. When the participant was unsuccessful, the clinician elicited the verb if missing, clarified the participant's intended response, and modeled the correct sentence if needed. Further details about the treatment activities and conceptualization can be found in Kempler and Goral (2011, Generative protocol). Treatment fidelity was assured by following a written protocol and by periodic observation by a certified clinician followed by discussions.

Pre- and post-treatment assessment

Three connected language production tasks were selected as measures of treatment effects. Because we did not – by design – train specific words or sentences, our outcome assessment tasks can be considered measures of generalization. The first, an action description task, resembles most the language production practiced during treatment (but the pictures or actions used in testing were not specifically targeted during treatment). Two additional tasks, the picture-sequence description subtest (Description) from the Bilingual Aphasia Test (BAT, Paradis & Libben, 1987) and a personal narrative production task, neither directly practiced during treatment, were also included.

In the Action Naming task, the participant was presented with 12 action pictures and was instructed to describe the action depicted in the picture using a complete sentence. In the Description task, the participant was presented with a panel of six drawings and was instructed to tell the story depicted in the sequence of pictures. In the Narrative Production task, the participant was instructed to talk about one of three topics (a recent vacation, a happy moment, or a recent book she read or movie she watched).

Performance was assessed over three testing days for repeated measures at each testing time. The testing times we report here are: Pre-English treatment, post-English treatment/Pre-Persian treatment, and Post-Persian treatment. (As part of a larger study, PGE enrolled in three consecutive treatment phases, one in each of her three languages. The German treatment and testing, administered after the study in English and Persian was completed, is not included in this paper.)

Analysis

We focused on PGE's sentence-level production, as this level was targeted during treatment. For the Action Naming task, we focused on PGE's production of the target verbs and the completeness of the sentences produced; for the two connected language production tasks, we report change in number of utterances produced, whether the sentences were complete and grammatical, and whether PGE code-switched to another language to complete her utterances. We counted the nouns and verbs and examined noun-verb agreement and other morphosyntactic errors. Tables 1–3 present the mean numbers (and standard deviations) produced over the three days of testing in each language in each of the three testing times.

Change from pre- to post-treatment was determined using effect size estimations, employing Cohen's d statistic, that is, by dividing the change score (post-treatment minus pre-treatment) by the pre-treatment variability (standard deviation). The effect size estimation has been used for within-subject, pre-post treatment studies (Beeson & Robey, 2006). Effect size of greater than 1.0 was considered meaningful. For several specific measures we employed, such as numbers of code-switched words, proportions rather than raw numbers were calculated; for those, percentage of change was calculated and increases of above 10% were considered meaningful (e.g., Holland & Crinion, 2012).

Results

We report the results for each language on each of the three production tasks. The corresponding values are presented in Tables 1–3.

Action naming

Production in English—On average, PGE responded to 11 of the 12 pictures by producing the target or an appropriate verb, and these numbers did not change following treatment in English, nor following treatment in Persian. She produced more grammatical

sentences post English treatment (effect size 2.6) and this number did not change following the Persian treatment. The number of noun-verb agreement errors did not change following treatment in English but increased following treatment in Persian (effect size 1.7). There were no instances of code switched words while attempting English production.

Production in Persian—In Persian, PGE successfully produced a target or appropriate verb to only two of the 12 pictures prior to treatment. The number of target/appropriate verbs she produced in response to the action pictures did not change following treatment in English. In contrast, there was a significant increase post-Persian treatment in the number of target/appropriate verbs (effect size 5.2) and a significant decrease in the number of wrong verbs produced (effect size 3.3). In addition, the percentage of code-switched words (of the total words produced) decreased by 29% post-English treatment, and decreased dramatically – by 92% – post-Persian treatment.

The number of grammatical sentences produced post-English treatment decreased (effect size 1.3); in contrast, PGE produced significantly more grammatical sentences (effect size 5.2) post-Persian treatment, and her noun-verb agreement errors (of the verbs produced) decreased (effect size 2.0).

Description

Production in English—PGE produced more sentences (effect size 2.9) following treatment in English and a greater number of grammatical sentences (effect size 4.6). There was a significantly greater number of auxiliary verbs (effect size 8.7) and of prepositions (effect size 2.7) produced. The number of complete sentences produced increased (effect size 7.0). In addition, the noun-verb agreement errors decreased (effect size 2.1).

A different pattern was observed in her English production following treatment in Persian: PGE produced a few more sentences (effect size 1.4), but omitted a greater number of auxiliary verbs (effect size 3.5), and omitted more main verbs (effect size 1.7) as well produced more noun-verb agreement errors (effect size 2.1). The number of complete sentences produced increased (effect size 1.8) but so did the number of incomplete sentences (effect size 1.4).

Production in Persian—The number of utterances produced in the Description task post-English treatment increased (effect size 2.0), as did, however, the proportion of code-switched words (a 15% increase). There was no change in the grammaticality or completeness of the sentences.

Post Persian treatment, the number of sentences produced by PGE increased (effect size 2.0) as did the total number of words (effect size 6.0). The number of incomplete sentences did not change from pre-Persian treatment to post-Persian treatment, but the number of complete simple sentences produced increased (effect size 3.2). The number of noun-verb agreement errors increased post Persian treatment (effect size could not be calculated due to 0 SD), as she produced more verbs in Persian (effect size 5.2). The number of omitted verbs did not change (effect size 0.2).

Narratives

Production in English—There were no significant differences in the narrative production in English following English treatment, possibly due to variability across the three testing sessions.

Following treatment in Persian, PGE produced more sentences in her English narratives (effect size 2.8) but omitted more obligatory auxiliary verbs than before Persian treatment (effect size 2.3). She produced no incomplete sentences following treatment in English but three following treatment in Persian. She omitted more verbs and more auxiliary verbs in English post treatment in Persian (effect sizes 1.2 and 2.3, respectively).

Production in Persian—Overall, few changes were observed in PGE's Persian production following treatment in English, whereas significant improvement was noted following treatment in Persian. There was no significant increase in the number of sentences produced post-English treatment (effect size 0.6), nor in the number of words in the best response. As well, the number of complete simple sentences produced did not change following treatment in English (effect size 0.2).

In contrast, the number of sentences produced post-Persian treatment increased significantly (effect size 8.7) as did the number of words (effect size 4.9). Moreover, the proportion of code switched words decreased by 50% following Persian treatment. As well, the number of complete simple sentences PGE produced increased following treatment in Persian (effect size could not be calculated due to a standard deviation of 0), and the proportions of grammatical sentences increased by 56%. There was no significant change in her omission of main verbs but the increase in verb production (effect size 5.2) was accompanied by increase number of noun-verb agreement errors (effects size 2.0).

Discussion

We contrasted treatment effects within-language and between-languages in a trilingual individual with aphasia to examine patterns of proficiency-dependent inhibition in language production. The participant received constrained language treatment targeting sentence production first in her late-learned, better-recovered English and then in her more-impaired first-acquired Persian. Overall, PGE demonstrated parallel within-language treatment effects, in that she improved her production in English following treatment in English and her production in Persian following treatment in Persian, and divergent cross-language treatment effects (see Figures 1 & 2). Specifically, PGE's weaker (post-stroke) language, Persian, was not generally affected – positively or negatively – by treatment in the stronger (post-stroke) English, with the exception of an increase in the number of sentences produced in one of the outcome measures (the Description task) and a decrease in the number of grammatical sentences in another (Action naming). In contrast, and consistent with our prediction, performance in English appeared to be negatively affected by the treatment that focused on Persian. For example, PGE produced more noun-verb agreement errors, omitted more auxiliary verbs, and produced fewer complete sentences in English following treatment in Persian than she did prior to the treatment in Persian. This decrease in the quality of the sentences produced in English was noted in the three language production tasks measured, albeit to different degrees. We address aspects of our results within the context of the convergence hypothesis of bilingual representation and psycholinguistics findings of asymmetric language inhibition.

Convergence, recovery, and plasticity

The result of any cross-language treatment effects in multilingual aphasia can be interpreted as supporting the convergence hypothesis (Abutalebi & Green, 2007), under the assumption that cross-language treatment effects would be expected only if the mechanisms that improve following treatment support all languages of multilingual speakers. To the extent that shared neuronal networks facilitate processing in any language, any cross-language treatment effects, regardless of language proficiency and other variables (language

similarity), would be expected. Previous findings from treatment studies support this prediction by demonstrating improvement in bilinguals' untreated languages following treatment in one language (e.g., Edmonds & Kiran, 2006; Goral et al., 2010; Kohnert, 2004). However, other studies have reported minimal or no cross-language treatment effects (e.g., Meinzer, Obleser, Flaisch, Eulitz, & Rockstroh, 2007; Miller Amberber, 2012). The presence of mixed results in the literature points to the potential influence of individual variables, such as language proficiency and age of language acquisition as well as to the potential role of language control.

The convergence hypothesis would account for treatment-related changes in multiple languages under the assumption that treatment affects brain networks that support processing in all languages of multilingual speakers. Treatment-related brain changes have been recently demonstrated in studies that employed neuroimaging techniques to track brain activation prior to and following treatment in monolingual individuals with aphasia (Meinzer, Harnish, Conway, & Crosson, 2011; Saur et al., 2006). Such changes could underline behavior changes in all languages in the case of multilingual individuals, a prediction that is yet to be supported by research evidence. Two existing studies that employed neuroimaging in the study of treatment in bilingual aphasia may represent such potential evidence, although in both cases only the treated language showed improvement following treatment.

Meinzer and colleagues reported on a German-French bilingual individual who improved his German, but not French, production following treatment in German. Consistently, the fMRI results showed changes during performance in German but not in French (Meinzer, Obleser, Flaisch, Eulitz, & Rockstroh, 2007). Similarly, Abutalebi and colleagues showed that improvement in the treated language was associated with increased activation in language areas as measured by fMRI, whereas no such brain changes were detected for the untreated language (Abutalebi et al., 2009). An increased number of intrusion errors while naming pictures in the untreated L1 was interpreted as impairment in control; consistently, changes in brain activation were interpreted as changes in the control networks.

Proficiency-dependent inhibition

Our findings are consistent with our prediction outlined above and with the findings of Abutalebi et al. (2009) in that our participant experienced negative effects in her stronger language following treatment in her weaker language. In the Abutalebi et al. study, the treated language (yielding negative effects in the untreated language) was the participant's second language whereas here the weaker, treated language was the participant's first acquired language. Thus, the results of the two studies differ in the effect of L1 status or age of acquisition, but are similar regarding the relative level of proficiency.

Taken together, evidence of an inhibitory effect of treatment for the participant's weaker language on her production in her stronger language is consistent with the inhibitory effect reported for lexical retrieval in healthy bilinguals. Of interest, whereas the effect reported in the psycholinguistic literature concerned single-word production, the inhibition in the present study was observed at the sentence level, involving grammatical production. The asymmetric inhibition here resembles the one found for healthy bilinguals in that it appears to be proficiency-dependent. In both sets of findings, the likely interpretation is that while producing a word or a sentence in the weaker language, the stronger language needs to be inhibited, resulting in a lingering effect when production switches back to the stronger language. In the psycholinguistic switching cost data, inhibition is typically found in both directions – when the word has to be retrieved in either L1 or L2 following a switch – with greater costs observed in one direction (switching to L1); in the present set of data we found evidence for inhibition only in one direction, namely, following treatment in the weaker

language. Future studies could further explore the existence of uni- or bi-directional inhibition in cross-language treatment effects.

Alternatively, the unidirectional inhibition found here could be interpreted, instead, as increased interference from the now more active Persian. That is, it may be the case that the change in English performance observed following treatment in Persian is the result of greater interference between the two languages (e.g., Colomé & Miozzo, 2010; Kurland & Falcon, 2011) due to the relatively increased activation of the previously inactive Persian. This may be the case particularly considering the specific language aspects in English that appeared affected following the Persian treatment (e.g., greater omission of auxiliary verbs), although we did not observe overt interference from Persian to English at the lexical level.

We note that in the aphasia case reported here, the relative proficiency that appears relevant is the measured (and self-reported) levels post-stroke, not the original, pre-stroke levels of proficiency. This distinction may explain apparent inconsistencies between the findings reported here and those reported in previous studies (e.g., Edmonds & Kiran, 2006). It remains to be examined whether facilitation vs. inhibition effects following treatment in aphasia are explained by proficiency, as in the case presented here, by additional variables, such as language use and language domains (e.g., lexical vs. grammatical output), or a combination of variables (Abutalebi et al., 2009; Goral, Rosas, Conner, Maul, & Obler, 2012).

Local or global inhibition

One additional question emerges from the current findings, regarding the time frame of the inhibition. In the psycholinguistics literature, inhibition effects associated with switching cost are typically short-lived. That is, elevated response times have been observed for words in the stronger language during performance in language-mixed conditions. It is possible that the inhibition effects could linger beyond the immediate effect of naming in a mixed language condition. Evidence for somewhat more long-term effects has been reported by Kroll and her colleagues, in studies of bilinguals' L1 performance while immersed in their L2 environment (Linck, Kroll, & Sunderman, 2009). The inhibitory effects we found here were obtained during the testing of each language in a monolingual condition, during three days immediately following the end of the treatment. Follow-up data, when available, may shed light on the time frame of such effects.

Moreover, our results suggest that the inhibitory effect is global, affecting language production generally, rather than a more local effect of inhibition, such as when one lexical item interferes with the retrieval of its translation equivalent. This kind of a local lexical inhibition has been found in conjunction with the opposite, facilitation effect, for people with aphasia who speak multiple languages (Ansaldo, Marcotte, Scherer, & Raboyeau, 2008; Goral, Levy, Obler, & Cohen, 2006). The question of local vs. global inhibition is of theoretical interest in the context of the recent discussion about mechanisms of cognitive control (e.g., Bialystok, Fergus, Craik, Green, & Gollan, 2009; Buchweitz & Prat, 2013; Hervais-Adelman, Moser-Mercer, & Golestani, 2011).

Implications, caveats and future directions

The findings we report here extend previous findings reported only at the lexical domain and with healthy individuals and may aid the interpretation of previously reported findings from bilinguals and multilinguals with aphasia. Theoretically, the findings of this study can be interpreted as evidence for the dynamic nature of language activation. In addition to corroborating evidence for asymmetric inhibition of the stronger language following a period of activation of the weaker one, our data extend the domain of such inhibition

processes. Areas in which inhibition was observed in the stronger language in the case presented here include morphosyntactic processing, such as use of auxiliary verbs and noun-verb agreement. These domains add to previous findings of inhibition, which focused on lexical processing. Moreover, increased errors appear to be evident in those linguistic aspects that differed across the two languages examined here (for example, increased numbers of errors on auxiliary verbs in English following treatment in Persian, a language that does not have a comparable sentence structure). This observation is consistent with previous studies that have ascribed importance to the relationship between the languages for cross-language treatment effects (Faroqi & Chengappa, 1996; Kohnert, 2004).

Clinically, if the findings of negative effects on the dominant language, even if in the form of temporary inhibition, hold for other multilinguals with aphasia, they can inform clinicians in their decisions regarding the choice of language of treatment. This could be particularly critical for immigrant and speakers of minority languages who may have access to therapy only in their non-dominant, weaker language. Increasing resources for treatment in these individuals' stronger language may be therefore advisable.

Conclusions from one individual case should, of course, be drawn with caution. Additional examples of proficiency-dependent cross-language inhibition are needed. Converging evidence from a variety of languages and learning circumstances would help dissociate the effects of age of acquisition, levels of proficiency, and the linguistic similarities among the languages. As well, additional single-subject studies could address treatment order effects (here, English treatment was administered prior to treatment in Persian). Two additional differences between the participants' languages may have contributed to the asymmetry of cross-language results; one pertains to the fact that the participant was literate in English and not in Persian (e.g., Tsegaye, de Bleser, & Iribarren, 2011); the other is the possible effect of the long-term disuse of Persian prior to the participant's enrollment in this study. She reported attempting to produce little in her Persian in the years since her stroke, suggesting the possibility of language attrition or long term inhibition (e.g., Schmid & Köpke, 2011).

We acknowledge that some of the effects reported here are relatively small and attribute this, in part, to our attempt to examine connected language production and tasks and sentences that were not trained during treatment; larger effect sizes are typically obtained for direct treatment effects. Furthermore, the changes we report pertain to the language domain of interest here. The degree to which improved sentence structure and grammaticality improves the overall communication effectiveness of people with aphasia and their quality of life needs to be demonstrated. Yet, we argue, individuals with non-fluent aphasia can improve their communication when their syntactic abilities improve by reducing efforts associated with sentence generation and decreasing instances of self-correction and reformulations.

In conclusion, we interpret our findings as pointing to global inhibition processes in the stronger language of bilinguals, that transcend local interference of single lexical items, the main kind of interference treated in the literature to date.

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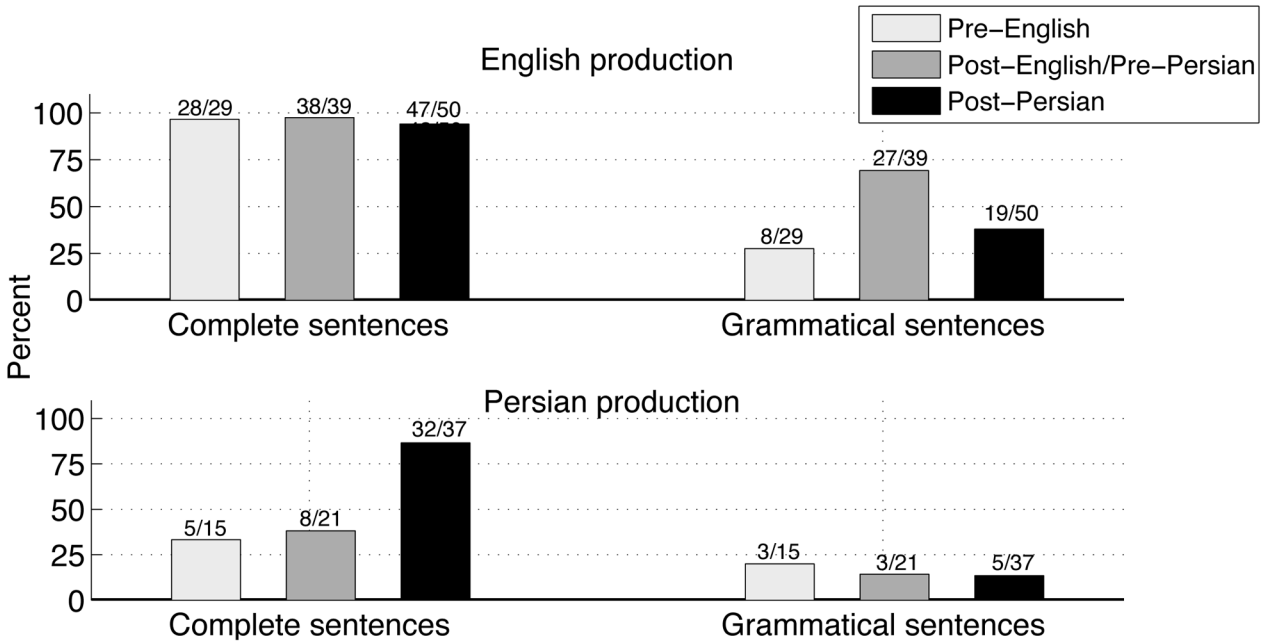

Figure 1.
English and Persian Sentence Production in the Description Task

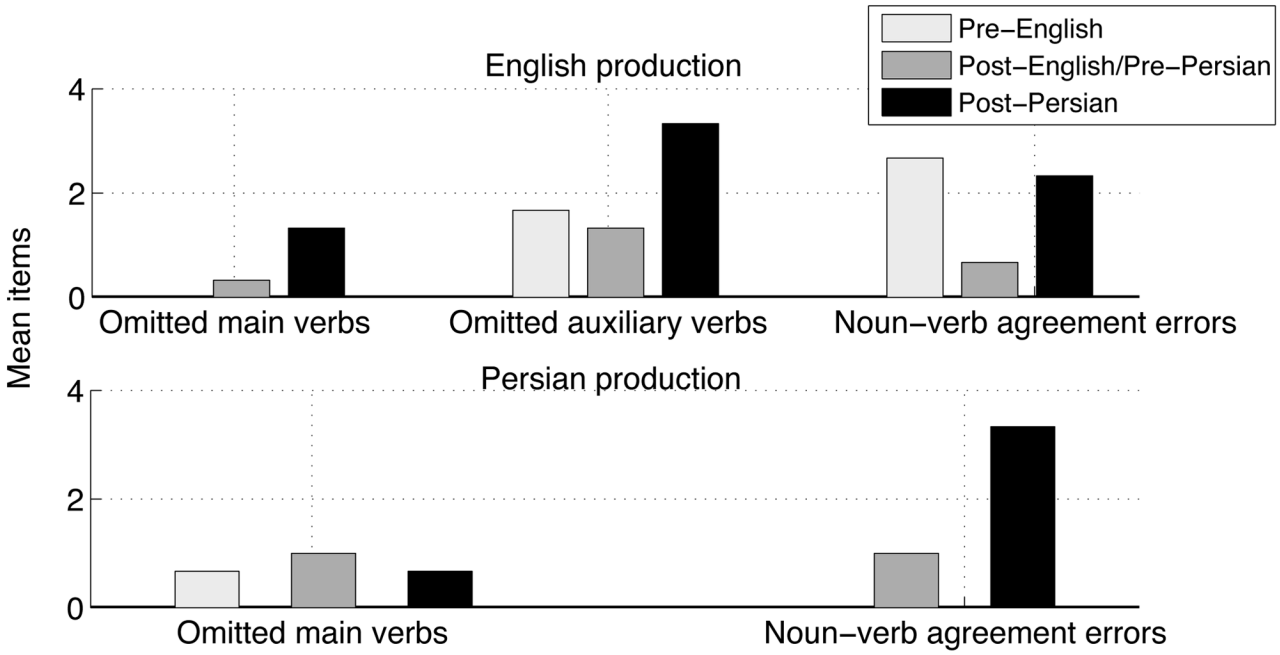

Figure 2.
English and Persian Error Production in the Description Task

Table 1

Action naming: Means (and SDs)

Action Naming (n=12)	Complete sentences	Grammatical sentences	Target/appropriate verbs	Noun-verb agreement errors
English Production				
Pre-English	11.7 (0.6)	3.7 (1.5)	10.7 (0.6)	3.0 (2.0)
Post-English	11.0 (0)	5.0 (1.0)	11.0 (1.0)	1.7 (0.6)
Post-Persian	12.0 (0)	5.0 (1.0)	10.7 (0.6)	2.7 (2.1)
Persian Production				
Pre-English	3.0 (1.7)	2.0 (1.0)	2.3 (2.3)	0
Pre-Persian	4.7 (3.5)	0.7 (0.6)	2.7 (1.2)	2 (1.0)
Post-Persian	11.0 (0)	3.7 (0.6)	8.7 (1.2)	0

Table 2

Description: Means (and SDs)

Description	Sentences	Complete sentences	Grammatical sentences	Omitted verbs	Omitted auxiliary verbs	Noun-verb agreement errors
English Production						
Pre-English	9.7 (1.2)	9.3 (0.6)	3.7 (1.2)	0	1.7 (1.5)	3.3 (0.9)
Post-English	13 (2.7)	12.7 (2.1)	9 (2.7)	0.3 (0.6)	1.3 (0.6)	1.3 (0.5)
Post-Persian	16.7 (2.1)	15.7 (1.5)	6.3 (1.5)	1.3 (0.6)	3.3 (0.6)	2.3 (1.7)
Persian Production						
Pre-English	5.0 (1.0)	1.7 (1.2)	1.0 (0)	0.7 (0.6)	n/a	0
Pre-Persian	7.0 (2.7)	2.7 (2.5)	1.0 (1.7)	1.0 (1.7)	n/a	1.0 (0)
Post-Persian	12.3 (1.5)	10.7 (0.6)	1.7 (0.6)	0.7 (0.6)	n/a	3.3 (0.6)

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Table 3

Narratives: Means (and SDs)

Narratives	Sentences	Complete sentences	Grammatical sentences	Omitted verbs	Omitted auxiliary verbs	Noun-verb agreement errors
English Production						
Pre-English	10.0 (3.5)	6.3 (2.1)	5.3 (2.1)	2.3 (1.5)	2.0 (2.0)	0.7 (1.2)
Post-English	7.7 (1.5)	6.3 (2.3)	3.7 (1.5)	0.7 (1.2)	0.3 (0.6)	0.7 (0.6)
Post-Persian	12.0 (1.7)	9.0 (1.0)	5.3 (1.2)	2 (2.7)	1.7 (1.5)	0
Persian Production						
Pre-English	3.7 (0.6)	1.3 (1.5)	0.3 (0.6)	0.7 (0.6)	n/a	0
Pre-Persian	3.3 (0.6)	1.0 (0)	0.3 (0.6)	0.3 (0.6)	n/a	1.0 (1.0)
Post-Persian	5.0 (1.0)	3.0 (0)	0.7 (0.6)	0.7 (0.6)	n/a	2.3 (0.6)

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