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# Verbal fluency as a measure of lexical access and cognitive control in bilingual persons with aphasia

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## Abstract

**Background.—**Lexical access in bilinguals can be influenced by the demands that different interactional contexts pose on cognitive control processes (Green & Abutalebi, 2013: Adaptive Control Hypothesis; Green, 1998: Inhibitory Control Model). However, how varying cognitive control demands impact lexical access in bilingual persons with aphasia (BPWA) remains unclear. Verbal fluency tasks may provide valuable insights into the interplay between cognitive control and lexical access in BPWA by addressing word generation abilities in language contexts that exert varying degrees of cognitive control effort.

**Aims.—**The present study aimed to examine the performance of BPWA on a semantic category generation task that required word retrieval in single and dual-language contexts under varying cognitive control demands and a traditional letter fluency task conducted in single-language contexts. We also examined the associations between verbal fluency performance and (i) bilingual language history, and (ii) performance on standardized language assessments in both BPWA and healthy bilinguals.

**Methods and procedures.—**Thirteen Spanish-English BPWA and twenty-two Spanish-English healthy bilinguals completed a language use questionnaire, verbal fluency testing and standardized language assessments in each language. The semantic category generation task included four conditions: two conditions examined word retrieval in the first-acquired (L1) and second-acquired language (L2) in single language contexts (No Switch-L1 and No Switch-L2) and two conditions elicited word retrieval in dual-language contexts (Self-Switch and Forced-Switch) with low and high cognitive control demands by allowing or restricting switching across languages. The letter fluency task was administered in single language contexts only (F, A, S for English and P, M, R for Spanish). Verbal fluency performance was compared across conditions and groups using multivariate analyses. Further, correlational analyses were used to examine associations between verbal fluency tasks and bilingual language history, language assessments, and cognitive function.

**Outcomes and results.—**Overall, the healthy bilinguals produced a higher proportion of accurate words in both verbal fluency tasks relative to the BPWA. Results indicate that BPWA

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were more sensitive to the effects of increased cognitive control on lexical access relative to healthy bilinguals. BPWA and healthy bilinguals' performance on both verbal fluency tasks was associated with metrics of bilingual language history and standardized language assessments. Additionally, for BPWA, L2 letter fluency performance was associated with cognitive function.

**Conclusions.—**Our findings suggest that verbal fluency tasks can help characterize the impact of cognitive control on lexical access in BPWA in single and mixed language contexts with important clinical implications.

### Keywords

bilingual aphasia; verbal fluency; cognitive control; lexical access; semantic fluency; letter fluency

## Introduction.

Understanding lexical-semantic organization, cross-language lexical activation and the interactions between the language and the cognitive control systems remains a central issue in bilingual research. While these important aspects of bilingual language processing have been extensively studied in healthy bilinguals using multiple methodological approaches, only little research has been conducted to characterize lexical access difficulties in bilingual persons with aphasia (BPWA). Verbal fluency tasks are well known neuropsychological assessments of word retrieval. They are typically employed to examine language and executive functioning in healthy adults (Hughes & Bryan, 2002) and clinical populations with focal brain damage (Henry & Crawford, 2004) and allow examining individual differences in strategy use during lexical access. As such, verbal fluency tasks can provide a comprehensive insight into lexical access difficulties in BPWA while considering both language and cognitive control abilities known to influence language processing in bilingual speakers. In the present study, we sought to examine how varying cognitive control demands in verbal fluency tasks would affect lexical retrieval in healthy bilinguals and BPWA. The verbal fluency tasks employed here allowed to examine word retrieval in (i) single language contexts that elicited word retrieval in each language separately, and in (ii) dual-language contexts which required word retrieval across the first-acquired (L1) and second-acquired (L2) languages, thus engaging varying degrees of cognitive control. In particular, manipulating the cognitive control demands in verbal fluency tasks allows examining how increased cognitive control demands affect lexical access, and how this is further affected in aphasia. In what follows, we review cognitive control and its interaction with lexical retrieval and language production in bilinguals and current evidence of lexical retrieval via verbal fluency tasks in both healthy bilinguals and BPWA.

Language switching and mixing is one of the important aspects of language processing in which bilingual speakers differ from monolinguals. Bilinguals often switch between their two languages during everyday language use depending on the different language contexts they encounter and relative proficiencies in each language (Heredia & Altarriba, 2001). As suggested by Meuter and Allport (1999) even though bilingual speakers are able to frequently switch between their two languages, there may be behavioral costs to switching between languages. Meuter and Allport proposed asymmetric switching costs, such that there is a greater cost of switching when a bilingual speaker switches from their less dominant L2 to their more dominant L1 than vice versa. Similar asymmetric switching costs have been observed in other non-linguistic tasks, and as such, it is suggested that language switching in bilinguals may reflect greater use of underlying cognitive control processes that are not specific to language (Meuter & Allport, 1999).

In their Adaptive Control Hypothesis, Green and Abutalebi (2013) suggest that the increased use of cognitive processes associated with controlling two languages in bilingual speakers may actually lead to enhanced cognitive control skills. In this model, Green and Abutalebi classify three different interactional contexts for bilingual speakers, namely, single-language, dual-language, and dense code-switching contexts. Given that there is evidence to support that both languages are active in bilinguals even when only one language is in use (Bialystok, Craik, Green, & Gollan, 2009; Kroll, Bobb, & Wodniecka, 2006), different contexts require different types of language control, and in turn, varying degrees of cognitive control. In the single-language context, one language is used exclusively, which requires continuous inhibition of the non-target language. In the dual-language context, the speaker may switch between languages frequently (typically when communicating with different speakers in the same environment), which requires control processes such as goal maintenance, conflict monitoring, and interference suppression. In the dense code-switching environment, on the other hand, the speaker may switch between the two languages freely in a less constrained manner, which requires more opportunistic planning and less interference suppression and conflict monitoring. The main assumption made by Green and Abutalebi (2013) is that in both the single- and dual-language contexts the two languages are in a competitive relationship, while in the dense code-switching context the two languages are in a cooperative one. As such, the dual-language context is thought to have highest cognitive demands, and dense code-switching the least. Examining how bilinguals perform across these three different language contexts may provide greater insight into cognitive control in bilingual speakers and its impact on language processing.

Inhibition is one subprocess of cognitive control which is particularly important to consider when discussing bilingual language processing. The Inhibitory Control (IC) model (Green, 1998) attempts to explain the interaction between inhibitory processes and bilingual language processing. This model supposes three levels of language control in bilinguals, the first level contains language task schemas that compete to control output of the lexical-semantic system by altering their levels of activation, the second level specifies properties of a lexical concept which leads to activation of an associated word form, and the third level is reactive and inhibitory where a checking procedure is used to ensure that the correct lexical concept is activated. This model also assumes that lexical concepts in one language activate associated concepts in the other language and therefore supposes that lemmas with incorrect language tags are suppressed once all lemmas related to the active concept have been activated. When considering the application of the IC model, Green (1998) underscores how relative proficiency impacts the amount of inhibitory control required to suppress one language in favor of another. Theoretical models of bilingual language production acknowledge a role of proficiency in lexical access either assuming stronger links between words and concepts for L1 relative to L2 (Kroll & Stewart, 1994: Revised Hierarchical Model - RHM, [although see Altarriba & Mathis, 1997; Brysbeart & Duyck, 2010 for debate on some claims of this model] or lower activation resting levels for L1 relative to L2

(Dijkstra et al., 2018: Multilink model). Given these differences between L1 and L2 proficiency, more inhibitory control would be required to suppress the more dominant L1 in favor of the weaker L2 (Green, 1998) particularly in unbalanced bilinguals with low L2 proficiency. Conversely, bilinguals with increased L2 proficiency would demonstrate a shift from highly controlled to more automatic and less effortful language processing (Abutalebi & Green, 2007). As reviewed here, the IC model, in conjunction with the role of relative language proficiencies posited by theoretical models of bilingual language production is one way of explaining the role that cognitive control plays in bilingual language processing.

Because the abovementioned models of bilingual language processing and cognitive control highlight the role of language proficiency in bilingual lexical access, language switching, and cognitive control, it is crucial to take proficiency into account when evaluating language performance in bilingual populations. As proposed by Heredia (1997) language proficiency and dominance can shift over the lifespan as a bilingual's language use patterns change. Heredia proposed that with increased exposure and use of the L2 over extended periods of time, a speaker's L2 may become the more dominant language, and therefore it is important to consider a speaker's bilingual language history when looking at lexical access performance in bilinguals.

Verbal fluency tasks can help examining the interactions between cognitive control and lexical access in BPWA and how they differ from healthy bilinguals. Verbal fluency is one neuropsychological assessment frequently used to measure cognitive control and lexical-semantic access (Shao, Janse, Visser, & Meyer, 2014). Multiple studies have shown that there are a number of cognitive processes that underly lexical retrieval in verbal fluency tasks (see Mitrushina, Boone, Razini, & D'Elia, 2005 for a review). These include, but are not limited to short-term memory, initiation and maintenance of word production sets, cognitive flexibility, long-term vocabulary storage, and response inhibition. Additionally, performance on these tasks not only depends on vocabulary storage and efficient mental processing, but executive functions as well (Mitrushina et al., 2005). There are two types of traditional verbal fluency tasks: category generation, in which participants have one minute to name items within a given semantic category, and letter fluency, in which participants are given one minute to generate words starting with a given letter. In the category generation task, semantically related items are selected via spreading activations through relevant subcategories (Gruenewald & Lockhead, 1980), whereas the letter fluency task requires a serial search of words based on word onsets (Rende, Ramsberger, & Miyake, 2002). Since different search mechanisms are required for the letter fluency task as compared to the category generation task, the inhibition of semantically related words required in letter fluency could indicate an increased need for cognitive control processes (Perret, 1974).

While verbal fluency tasks commonly measure both lexical access and cognitive control, the category generation task and the letter fluency task may differentially rely on these two processes. Shao et al. (2014) found that vocabulary size, a general measure of lexical knowledge, was positively correlated with performance on category generation tasks but not letter fluency tasks in healthy bilinguals, while performance on an operations span task was significantly correlated with both verbal fluency tasks. This suggests that while both category generation and letter fluency are measures of executive control, the category generation task is more dependent on vocabulary size. Additionally, more recent work by Patra, Bose, and Marinis, (2019) observed an association between performances on the verbal fluency and Stroop tasks in bilinguals, thus implicating the role of inhibition in verbal fluency performance.

While traditional verbal fluency tasks are frequently used to measure lexical access and executive functions (Shao et al., 2014), manipulating the cognitive control demands required for successful lexical retrieval in these tasks may provide greater insight into the interplay between cognitive control and lexical access in bilinguals. Recent work by Jevtovic, Duñabeitia, and de Bruin (2019), examined healthy bilinguals' performance on two picture-naming tasks and a verbal fluency task using voluntary and mandatory language contexts. The category generation task made use of four conditions (two single-language conditions and two dual-language conditions). In the single-language conditions, the participants were instructed to use one language or the other, in the voluntary dual-language condition, they were instructed to switch between languages as desired, and in the mandatory dual-language condition, they were required to switch languages after each response. They found that healthy bilinguals performed comparably in the L1 single-language and the voluntary dual-language conditions, with performance on these conditions being significantly better than performance on the L2 single-language and mandatory dual-language conditions. These results suggest that the higher cognitive control demands required by the L2 single-language and mandatory dual-language condition may negatively impact lexical retrieval and verbal production in healthy bilinguals.

While numerous studies have examined the interaction between cognitive control and lexical access in healthy bilinguals, not many have employed verbal fluency tasks to examine lexical retrieval and its relationship with cognitive control in BPWA. Kiran, Balachandran, and Lucas (2014) demonstrated that although BPWA generate fewer correct words than healthy bilinguals on a category generation task, both groups employed the same semantic clustering strategy to generate words within a given semantic subcategory. In another study, Faroqi-Shah, et al. (2016) examined the associations between cognitive control as measured by a Stroop task and lexical access performance on category generation and picture naming tasks in BPWA. Their findings revealed a strong correlation between picture naming and category generation performance, but neither of these word retrieval tasks were related to performance on the Stroop task. While the evidence reported here is preliminary, the influence of cognitive control processes on lexical retrieval and verbal production in BPWA remains unclear.

The present study aimed to examine how varying degrees of cognitive control demands influence lexical access in BPWA and healthy bilinguals in two verbal fluency tasks where word retrieval is required in single- and dual-language contexts. To this aim, we employed a semantic category generation task that manipulated the degree of cognitive control demands (i.e., low versus high) and the type of lexical-semantic access (i.e., no switch versus switch across languages) required for word generation. Specifically, this task presented different word retrieval requirements in L1 and L2 across four conditions: No-Switch (NS) administered in each language separately (NS-L1 and NS-L2), Self-Switch (SS) and Forced-Switch (FS). The NS condition required producing words within a semantic category in just one language, the SS allowed for switching across languages as desired, and the FS demanded for a forced switch between languages for every new item produced. As such, both the SS and the NS-L1 conditions were expected to require minimal cognitive control resources because unconstrained language choice and highly automatized processes involved in L1 lexical retrieval require less cognitive control than non-automated tasks (Green, 1998; Green & Abutalebi, 2013). In contrast, the NS-L2 condition was expected to require moderate levels of cognitive control in order to inhibit prepotent L1 translations of the intended L2 words (Green & Abutalebi, 2013). Finally, the FS condition was expected to place the highest cognitive control demands since accurate performance would require goal maintenance, conflict monitoring, and interference suppression (Green, 1998; Green & Abutalebi, 2013). We also administered a letter fluency task that required word retrieval in L1 and L2 in a single language context, which is thought to have higher cognitive control demands compared to semantic category generation given that it requires a serial search of words based on phonemic representation, a strategy that is not typically employed in everyday language processing (Luo, Luk, & Bialystok, 2010; Patra et al., 2019; Shao et al., 2014).

Our first aim was to characterize the performance of the BPWA on the semantic category generation task across four different conditions relative to healthy bilinguals. Because lexical retrieval deficits are commonplace across all aphasic syndromes, we expected that the healthy bilinguals would produce a greater proportion of accurate words than BPWA as shown in previous research (Kiran, et al., 2014). Additionally, we expected that healthy bilinguals would outperform the BPWA across all conditions in the semantic category fluency task, although both groups would perform better on the NS-L1 and SS conditions relative to the NS-L2 and FS conditions as shown in past research with healthy bilinguals (Jevtovic et al., 2019). Here we hypothesized that word retrieval would be compromised because of the increased cognitive control demands on the two latter conditions. Additionally, because the SS and FS conditions allow or require switching between languages respectively, both languages are co-activated (Colomé, 2001; Costa, 2005), and thus we also examined whether these conditions elicited direct translations in word generation as a strategy that may facilitate word generation for both groups. Our second aim was to examine performance on the letter fluency task across the two languages (LF-L1 and LF-L2). We hypothesized that, again, healthy bilinguals would produce a greater proportion of accurate words across both languages, but both groups would perform better in the LF-L1 condition relative to the LF-L2 condition, as L1 word retrieval would benefit from stronger links between words and concepts (Kroll & Stewart, 1994) or lower activation resting levels relative to L2 (Dijkstra et al., 2018). Additionally, given these differences between L1 and L2, increased cognitive control is assumed for the LF-L2 condition, because more inhibitory control would be required to suppress the more dominant L1 to favor word retrieval in the weaker L2 (Green, 1998). Our third aim was to determine whether verbal fluency performance was associated with individual bilingual language history and language assessment scores, irrespective of whether participants were healthy or had aphasia. For the semantic category generation task, we hypothesized that bilingual language history factors and performance on formal assessments would better predict performance on the NS and SS conditions compared to the FS condition since the latter posed increased cognitive control demands for lexical retrieval. If supported, these results would indicate the likely presence of a language-switching cost with increased cognitive control (Faroqi-Shah et al., 2016; Meuter & Allport, 1999). For the letter fluency task, we expected that performance on each language condition would be associated with individual bilingual language history and performance on language tests conducted in the same language (English or Spanish).

## 2. Methods.

### 2.1. Participants.

Participants were 13 Spanish-English BPWA (7 female) and 24 Spanish-English healthy bilinguals (20 female) were originally recruited for this study. Two healthy bilinguals were excluded from the final sample due to performance in the semantic category task reflecting a lack of understanding on the semantic category "transportation". Therefore, the final group of healthy bilinguals included 22 participants (19 female). The BPWA presented persistent aphasia secondary to stroke ($n$ = 11), traumatic brain injury ($n$ = 1), or tumor ($n$ = 1) and were at least 6-months post-onset ($M$ = 93.38, $SD$ = 128.20, *range* = 6 – 411 months). Their mean age was 51 ($SD$ = 19, range = 24 – 82), and their mean number of years of education was 15.77 ($SD$ = 2.01, *range* = 12 – 19). Eleven BPWA reported Spanish as their first acquired language L1 (mean L2 age of acquisition = 15, $SD$ = 10, range = 5 – 35) whereas 2 BPWA reported English as their L1 and acquired Spanish at the ages of 5 and 6 respectively. The healthy bilinguals had a mean age of 47 years ($SD$ = 15, range = 21 – 82) and 17.64 years of education on average ($SD$ = 5.15, range = 8 – 27). Of these, 21 bilinguals had Spanish as their first acquired language (mean L2 age of acquisition = 17, $SD$ = 12, range= 3 – 40) and only one healthy bilingual was a L1 English speaker who acquired Spanish at the age of 19. Hence, both groups had mostly Spanish-L1 speakers.

Of the full sample, 9 healthy bilinguals and 1 BPWA reported exposure to additional languages, yet none reported fluency in these languages. All participants reported normal or corrected-to-normal vision and no history of neurological or psychiatric illness (other than those reported for BPWA). BPWA were excluded from participation only if they could not complete a standard verbal fluency task due to their language difficulties. All participants gave their written consent to undergo language testing following procedures approved by the Ethical Committee at Boston University. Tables 1 and 2 summarize the demographic and bilingual language history information of the BPWA and the healthy bilinguals.

### 2.2. Bilingual background assessment.

All healthy bilinguals and BPWA completed an extensive Language Use Questionnaire (LUQ; Kastenbaum et al., 2019) which allowed obtaining information regarding their bilingual language history. The first section of the LUQ allows defining the languages that were acquired first (L1) and second (L2) in life, as well as the *L2 age of acquisition* reflecting the age for L2 learning onset. The following sections request detailed information regarding the participants' background for each language separately as follows. *Language usage* was measured as the percentage of time spent using each language on weekdays and weekends on an hourly basis. *Lifetime exposure* reflected the percentage of time spent hearing, speaking and reading in each language over the lifetime. *Lifetime confidence* represented the percentage of confidence in hearing, speaking and reading in each language over the lifetime. *Family proficiency* summarized the average participant's ratings on their parents and siblings' confidence in each language. *Educational history* was computed as the average frequency each language was used by the participant and peers during elementary school, high school and college. The *language ability rating* reflected an average ability score for each language indicating the participant's ability for speaking, listening, reading and writing in each language. Post-stroke language usage and language ability ratings in each language were also collected for the BPWA to reflect changes in these metrics after aphasia onset.

### 2.3. Verbal fluency tasks.

Each participant completed two verbal fluency tasks: a category generation task and a letter fluency task that required producing as many different words as fast as possible within 60 seconds. In the category generation task participants were to produce words in four semantic categories: *animals*, *clothing, food*, and *modes of transportation*. Each semantic category was administered in one of four conditions of interest: No-Switch (NS) administered in each language separately (NS-L1 and NS-L2), Self-Switch (SS) and Forced-Switch (FS). In the NS conditions, participants were instructed to produce words in the assigned semantic category in just one language (NS-L1 or NS-L2). In the SS condition, participants were to produced words in the assigned semantic category switching across languages as desired. In contrast, the FS condition required participants to switch from one language to the other while producing different words within the assigned semantic category. No restrictions were given for cross-language translations in the FS or SS conditions. The four semantic categories were administered in one language (two semantic categories in the NS condition: NS1 and NS2), one category in the SS condition, and one in the FS condition. The two semantic categories in the NS1 and NS2 condition were administered again in the participant's other language, however, only performance on the NS1 condition in each language was considered for statistical analyses (i.e., NS-L1 and NS-L2). The order of conditions in one language was defined as NS1-NS2-SS-FS to reduce potential carry over effects from the FS to the SS condition. The category-to-condition assignments were counterbalanced across participants to account for the potential impact of semantic category knowledge on condition performance. Participants additionally completed a letter fluency task in each language. They were requested to produce words that start with the letters F, A, and S in English (COWAT; Benton & Hamsher, 1976) and with P, M, and R in Spanish (Peña-Casanova et al., 2009). The order of the letter conditions was randomized across participants.

### 2.4. Additional language assessments.

All participants also completed additional language testing in both English and Spanish. Picture naming ability was evaluated with the Boston Naming Test (BNT; Kaplan, Goodglass & Weintraub, 2001; Kohnert, Hernandez, & Bates, 1998) and a naming screener involving 60 pictures of high-frequency words (hereafter, 60-item naming screener). Lexical-semantic processing was evaluated with selected subtests of the Psycholinguistic Assessment of Language Processing in Aphasia (PALPA; Kay, Coltheart, & Lesser, 1992) and its Spanish translation (EPLA, Valle & Cuetos, 1995) including spoken word to picture matching (PALPA 47/ EPLA 45), written word to picture matching (PALPA 48/ EPLA 46), auditory synonym judgment (PALPA 49/ EPLA 47) and written synonym judgment (PALPA 50/ EPLA 48). Because the four PALPA/EPLA subtests were strongly correlated, a PALPA composite score for L1 and L2 was calculated to represent lexical-semantic processing. Four subtests of the Bilingual Aphasia Test (BAT; Paradis & Libben, 1987) including semantic categories, synonyms, antonyms I, and antonyms II allowed to compute a composite BAT score that also represented lexical-semantic processing in each language. Non-verbal semantic knowledge was evaluated with the Pyramids and Palm Trees (PAPT; Howard & Patterson, 1992). Additionally, non-verbal cognitive function was evaluated only in the BPWA using the Raven's Coloured Progressive Matrices (RCPM) subtest from the Western Aphasia Battery-Revised (WAB-R, Kertesz, 2006).

### 2.5. Procedure.

All participants were tested individually in person or via videoconference using GoToMeeting (LogMeIn, Boston, MA, USA). The LUQ was administered first, followed by the category generation task, the letter fluency task and the additional language assessments. Assessments were administered entirely in one language before switching to the other language. Within each language, the order of the assessments was arranged to minimize potential cross-assessment priming effects. The order of language administration (i.e., English versus Spanish testing first) was counterbalanced across participants.

### 2.6. Data coding and scoring procedures.

All data including bilingual language history metrics, performance on language tests and on the semantic category generation task were coded as being produced in each participants' first-acquired L1 or second-acquired L2 as self-reported in their LUQ. Responses in the verbal fluency tasks were recorded in audio and in written form during the testing session and verified for accuracy afterwards via the audio recording. Additionally, all scores were verified and corrected when necessary by a second researcher. In the semantic category generation task, the total number of produced words and overall accuracy were computed separately for each condition in each language. Proportion accurate responses, in addition to number of correct responses, were computed to control for category effects as some semantic categories tend to elicit a greater number of responses than others (Roberts & Le Dorze, 1997). As in previous research (Kiran et al., 2014), accurate responses for BPWA included unique words in the target category, produced in the target language, that were not a repetition of a previously produced response, and contained no more than one phonemic substitution, omission, or addition. In the SS condition, all unique words produced in either language in the target category counted as correct responses. In the FS condition, words were taken as correct as long as each word was produced in the opposite language relative to the previous one (even when those included direct translations of the previously named item). The number of direct translations (e.g. FS condition: apple, *manzana*) were computed for the SS and FS conditions as these two conditions elicit responses across both languages. A proportion of direct translations was calculated in each condition separately by dividing the number of direct translations by the total number of items produced in that condition.

In the letter fluency task, the total number of accurate words productions were calculated for each target letter in the FAS and the PMR conditions and averaged into a composite score for each language separately, proportion of accurate responses was then calculated from the composite scores. FAS and PMR composite scores were then coded into each participants' L1 and L2 as self-reported in their LUQ, such that if a participant's first-acquired language was Spanish, PMR was coded as LF-L1 and FAS was coded as LF-L2 and vice versa. Items were scored following the same procedure as for category fluency.

## 3. Results.

### 3.1. Performance of BPWA and healthy bilinguals on the semantic category generation task.

Number of correct responses across the four experimental conditions were computed for each group separately, means and standard deviations are reported in Table 3. Paired-samples t-tests were also conducted to compare differences between conditions within groups. For BPWA results revealed no significant differences between any of the conditions: NS-L1 and NS-L2 [$t(1, 12) = .387$, $p = .706$], NS-L1 and SS [$t(1, 12) = .368$, $p = .719$], NS-L1 and FS [$t(1, 12) = 1.492$, $p = .162$], NS-L2 and SS [$t(1, 12) = -.156$, $p = .878$], NS-L2 and FS [$t(1, 12) = .645$, $p = .531$], or SS and FS [$t(1, 12) = .953$, $p = .359$]. For Healthy bilinguals results revealed a significant difference between NS-L1 and FS [$t(1, 21) = 3.679$, $p = .001$], NS-L2 and FS [$t(1, 21) = 2.273$, $p = .034$], and SS and FS [$t(1, 21) = 3.211$, $p = .004$]. Healthy bilinguals did not significantly differ between NS-L1 and NS-L2 [$t(1, 21) = 1.644$, $p = .115$], NS-L1 and SS [$t(1, 21) = .673$, $p = .508$], or NS-L2 and SS [$t(1, 21) = -1.141$, $p = .267$].

A two-way repeated measures ANOVA with Group (BPWA and healthy bilinguals) as the between-subject factor and Condition (SS, NS-L1, NS-L2, and FS) as the within-subject factor was conducted to compare the proportion of accurate responses produced by the two groups across the four experimental conditions. The ANOVA revealed a significant main effect of Group [$F(1, 33) = 29.65$, $p < .001$, $\eta^2_p = .473$] and Condition [$F(3, 31) = 8.062$, $p < .001$, $\eta^2_p = .438$]. The interaction Group × Condition was also significant [$F(3, 31) = 3.462$, $p = .028$, $\eta^2_p = .251$]. Follow-up independent-samples t-tests conducted for each condition revealed significant group differences in the NS- L1 [$t(1, 33) = -3.515$, $p = .001$, $d = 1.100$], NS-L2 [$t(1, 33) = -3.990$, $p < .001$, $d = 1.211$], and FS conditions [$t(1, 33) = -3.888$, $p < .001$, $d = 1.235$] such that the healthy bilinguals produced a higher proportion of accurate words compared to the BPWA in these three conditions. However, the BPWA did not significantly differ from the healthy bilinguals in the SS condition [$t(1, 33) = -1.779$, $p = .085$, $d = 0.552$] (Figure 1). Additional paired-samples t-tests were conducted to compare differences between conditions within groups. For BPWA, results revealed a significant difference between the NS-L2 and SS conditions [$t(1, 12) = -2.244$, $p = .044$, $d = .734$] and the SS and FS conditions [$t(1, 12) = 3.022$, $p = .011$, $d = 1.20$]. BPWA did not significantly differ between the NS-L1 and NS-L2 conditions [$t(1, 12) = .415$, $p = .685$, $d = .152$], the NS-L1 and SS conditions [$t(1, 12) = -1.522$, $p = .154$, $d = .660$], the NS-L2 and FS conditions [$t(1, 12) = .842$, $p = .416$, $d = .284$], or the NS-L1 and FS conditions [$t(1, 12) = 1.814$, $p = .095$, $d = .487$]. For healthy bilinguals, results revealed a significant difference between the NS-L1 and FS conditions [t (1, 21) = 2.926, $p = .008$, $d = .731$], NS-L2 and FS conditions [$t$ (1, 21) = 3.728, $p = .001$, $d = 1.030$], and the SS and FS conditions [$t$ (1, 21) = 3.281, $p = .004$, $d = .089$]. Healthy bilinguals did not significantly differ between the NS-L1 and NS-L2 [$t$ (1, 21) = −.802, $p = .431$, $d = .249$], NS-L1 and SS [$t$ (1, 21) = −.233, $p = .818$, $d = .070$], or NS-L2 and SS [$t$ (1, 21) = .858, p = .401, $d = 0.230$] conditions.

To examine between-group differences in the production of direct translations across conditions, we conducted a repeated-measures ANOVA with Group (BPWA and healthy bilinguals) as the between-subject factor and Condition (SS and FS) as the within-subject factor. The proportion of direct translations over total accurate productions in each condition was defined as the dependent measure. Greenhouse-Geisser corrections were required for violations to sphericity. Results revealed a significant main effect of Condition [$F$ (1, 33) = 12.369 $p = .001$, $\eta^2_p = .273$], although the main effect of Group [$F$(1, 33) = .039, $p = .844$, $\eta^2_p = .001$] and the interaction Group by Condition [$F$(1, 33) = .005, $p = .944$, $\eta^2_p = .000$] were non-significant, indicating that both groups showed similar trends in the usage of direct translations across conditions, although they were more frequently used in the FS condition relative to the SS condition (Figure 2).

### 3.2. Performance of BPWA and healthy bilinguals on the letter fluency task.

Number of correct responses across the two conditions of the letter fluency task were computed for each group separately, means and standard deviations are reported in Table 4. Paired-samples t-tests were also conducted to compare differences between conditions within groups. Results revealed that while BPWA did not significantly differ between LF-L1 and LF-L2 [$t$ (1, 12) = −.128, $p = .900$], healthy bilinguals did significantly differ between LF-L1 and LF-L2 [$t$ (1, 21) = 4.791, $p = .000$].

A repeated-measures ANOVA with Group as the between-subjects factor and Condition (LF-L1 and LF-L2) as the within-subjects factor was conducted to compare the proportion of accurate responses produced across conditions for the two groups. Greenhouse-Geisser corrections were used for violations of sphericity. These results indicated a significant main effect of Group [$F$ (1, 33) = 21.09, $p < .001$, $\eta^2_p = .390$], although the main effect of Condition [$F$ (1, 33) = .889, $p = .353$, $\eta^2_p = .026$], and the Group by Condition interaction were non-significant [$F$ (1, 33) = 0.116, $p = .735$, $\eta^2_p = .004$] (Figure 3). Additional paired-samples t-tests conducted to compare differences between conditions within groups revealed no difference between conditions for either BPWA [$t$ (1, 12) = .501, $p = .626$, $d = .191$] or healthy bilinguals [$t$ (1, 21) = 1.634, $p = .117$, $d = .237$].

### 3.3. Factors that influence verbal fluency performance in BPWA and healthy bilinguals.

The relationship between performance on the semantic category task (i.e., NS-L1, NS-L2, SS, and FS) and the letter fluency task (i.e., LF-L1 and LF-L2), and (i) metrics of bilingual language history, (ii) performance on language measures, and (iii) age in both healthy bilinguals and BPWA was examined using partial correlations controlling for group. The bilingual language history metrics included in these analyses were L2 age of acquisition, L1 and L2 language ability ratings, L1 and L2 usage, L1 and L2 lifetime exposure, and L1 and L2 lifetime confidence. For BPWA, only pre-stroke values were used for both language ability ratings and usage to avoid potential confounds between post-stroke bilingual language history values and language impairment. The language assessments examined in these analyses included the L1 and L2 60-item naming screener, L1 and L2 PALPA composite scores, L1 and L2 BAT composite scores, and the PAPT score. The Benjamini-Hochberg procedure using a false discovery rate of .05 was used to calculate critical thresholds for *p* values.

Table 5 shows a summary of all significant correlations after corrections for multiple comparisons. For the category generation task, we found that performance on the NS-L1 condition was significantly correlated with L1 lifetime confidence and L1 language assessments, whereas performance on the NS-L2 condition was significantly correlated with most of the L2 language assessments and negatively correlated with L2 age of acquisition. Interestingly, performance on the SS condition was negatively correlated with age, but positively correlated with L1 and L2 measures of semantic processing whereas performance on the FS condition was correlated with L2 lifetime confidence and all language assessment measures.

For the letter fluency task, we found that performance on the LF-L1 condition was negatively correlated with L1 usage, but positively correlated with L2 language usage and almost all language assessment measures in both L1 and L2. Performance on the LF-L2 was correlated with almost all language assessment measures in both L1 and L2 and negatively correlated with both age and L2 age of acquisition. Of note L1 and L2 language ability ratings, and L1 and L2 lifetime exposure did not reveal significant correlations after corrections for multiple comparisons (both $p \geq .023$).

Additionally, Pearson correlations were computed for only the BPWA on the RCPM as there was no data available for healthy bilinguals. We found a significant correlation between RCPM scores and performance on the LF-L2 condition of the letter fluency task ($r = .727$, $p = .017$). However, no significant correlations were observed between scores on the RCPM and the LF-L1 condition of the letter fluency task ($r = .329$, $p = .355$) or any of the conditions of the semantic category generation task ($p \geq .066$ in all cases).

## 4. Discussion.

The aim of this study was to examine how varying degrees of cognitive control demands influence lexical access in BPWA and healthy bilinguals in two verbal fluency tasks where word retrieval is required in single- and dual-language contexts. The semantic category generation task included different lexical access requirements in L1 and L2 across four conditions involving varying degrees of cognitive control: two No-Switch conditions that required generating words in a semantic category in the first language (NS-L1) and the second language separately (NS-L2), a Self-Switch condition (SS) that allowed switching across L1 and L2 as desired, and a Forced-Switch (FS) condition that required a forced switch between L1 and L2 for every new word produced. We also employed a letter fluency task that evaluated lexical access in L1 and L2 in single language contexts (i.e., FAS in English and PMR in Spanish). Proportion of accurate responses, as well as number of correct responses, were collected for both verbal fluency tasks to (i) control for category effects as some semantic categories tend to elicit a greater number of responses than others (Roberts & Le Dorze, 1997), and (ii) allow for more nuanced analyses of word production to measure the effects of cognitive control on lexical access that may not be fully captured by number of correct responses alone.

As observed in previous bilingual aphasia research (Kiran et al., 2014) we found that overall, BPWA produced lower proportions of accurate responses in both the semantic and letter fluency tasks relative to the healthy bilinguals, reflecting varying degrees of damage to the bilingual language processing system. Importantly, we found that while the healthy bilinguals outperformed the BPWA in the NS-L1, NS-L2 and FS conditions, the performance of the BPWA in the SS condition was comparable to that of the healthy bilinguals. The SS condition, is thought to place the least cognitive control demands during lexical retrieval, reflecting the dense code-switching context described by the Adaptive Control Hypothesis (Green & Abutalebi, 2013). According to this model, dense code-switching contexts such as the SS condition would require the two languages to operate in a cooperative relationship relying on opportunistic planning for successful lexical retrieval performance. However, the single-language (NS-L1 and NS-L2) and dual-language contexts (FS) involve a competitive relationship between the two languages that requires the continuous inhibition of the non-target language for successful word retrieval. Under this view, our results indicate that when lexical access can bypass the constraints placed by single- and dual-language contexts, BPWA can benefit from their lexical knowledge in either language and use alternative forms of expression to facilitate lexical access, fluency and ultimately communication. Interestingly, both groups produced a greater number of direct translations in the FS condition compared to the SS. This suggests that (i) translations of already-produced words might become more accessible than new concepts and (ii) usage of direct translations is a strategy that both healthy bilinguals and BPWA use to make word retrieval less difficult when cognitive control demands increase in a time-limited context.

Next, several differences emerged between conditions for each of the two groups. The healthy bilinguals showed a comparable performance on the NS-L1, NS-L2, and SS conditions both in terms of number of items produced as well as proportion of accurate responses whereas their performance on the FS condition was significantly lower relative to the other conditions. This indicates that not only did the healthy bilinguals produce fewer words in the FS condition but also produced more errors in this condition as well. For the BPWA, while they performed comparably across all conditions in terms of number of items produced, accuracy in the SS condition was higher than both FS and NS-L2 conditions, indicating that BPWA produced more errors in the latter two conditions as compared to the SS condition. Again, there were no significant differences between NS-L1, NS-L2, FS or between NS-L1 and SS. Relatively lower performance on the FS condition for both groups is reasonable given that this condition (and NS-L2) places higher cognitive control demands during word retrieval (Green & Abutalebi, 2013; Meuter & Allport, 1999). First, these results are similar to recent work by Jevtovic et al. (2019), who found that healthy bilinguals produced higher numbers of correct responses on a category generation task in the L1 single-language and voluntary dual-language conditions, relative to the L2 single-language and mandatory dual-language conditions. Healthy bilinguals in this study performed somewhat similarly as they produced significantly more correct responses in the SS and both

NS-L1 and NS-L2 (NS-L1, NS-L2, and SS) as compared to the FS condition. Second, because both L1 and L2 are co-activated in parallel (Colomé, 2001; Costa, 2005), producing words in a dual language context makes lexical retrieval difficult since switching from the L1 to the L2 requires stronger inhibition of L1 word representations, and in turn, switching back from the L2 to the L1 requires larger amounts of activation to overcome L1 inhibition. Third, lexical retrieval in dual-language contexts that require forced switching between L1 and L2 following a cue, has been shown to (i) increase in reaction times and decrease in accuracy relative to single language conditions and (ii) recruit brain regions of the cognitive control network (Fu et al., 2017). Thus, dual-language conditions with language constraints may require more sustained top-down cognitive control to maintain active unique representations for word retrieval while inhibiting interference from the unintended language (Fu et al., 2017).

Finally, a lack of significant difference between the healthy bilinguals and BPWA on the SS condition and a strong significant difference between the two groups on the FS condition illustrates an interesting dissociation between lexical-semantic access and cognate control. As noted above, SS requires lexical-semantic access but minimal cognitive control whereas FS requires lexical-semantic access and as noted above, high levels of cognitive control. The present results indicate that the BPWA are significantly different from the healthy bilinguals in the conditions that require cognitive control, as highlighted by significant differences between the two groups for the NS-L1, NS-L2 and FS conditions, but no significant difference between the two groups for the SS condition. In other words, when the two languages are in a competitive relationship, BPWA perform significantly worse than healthy controls.

We also examined group differences in L1 and L2 letter fluency. While BPWA did not differ in the number of correct responses produced in either condition, healthy bilinguals produced more correct words in the LF-L1 condition compared to the LF-L2, however neither group differed in terms of proportion of accurate words across the two language conditions. This is consistent with findings of the semantic category generation task, where neither group showed significant differences across the L1 and L2 single-language conditions. The letter fluency task is thought to place higher cognitive control demands since it requires a serial search of words based on phonemic representation, a strategy that is not typically employed in everyday language processing (Luo et al., 2010; Patra et al., 2019; Shao et al., 2014). This again highlights that for BPWA, the increase cognitive control demands of this task, coupled with deficits in lexical access may further hinder performance for this group.

The final research question examined the relationship between verbal fluency tasks, metrics of bilingual language history, performance on language measures, and age in both healthy bilinguals and BPWA. The discussion of these correlations is broken down into further subgroups (i) correlations for the category and letter fluency measures, (ii) correlations for the language proficiency measures, (iii) correlations for the language assessment measures, and (iv) correlations between RCPM and letter fluency tasks. First, when examining category and letter fluency measures as well as language assessment measures, results show that NS-L1 was positively associated with L1 naming and L1 BAT, the latter two indicating that the easier the lexical-semantic access, the higher the performance on this task. NS-L2 was significantly positively correlated with LF-L2, L2 naming, L2 PALPA, L1 BAT and L2 BAT. These results suggest that NS-L2 and LF-L2 likely tapped into similar L2 lexical-semantic access mechanisms that were related to the degree of language and lexical access as measured by standardized language tests. SS was significantly positively correlated with LF-L2, L1 PALPA, L2 PALPA and PAPT, which are all measures of semantic processing. Hence, SS, which engages lexical access in the least constraining fashion seems related to semantic, processing abilities and the ability to link L1 and L2 word forms with concepts within specific semantic categories. Finally, FS was positively correlated with several factors including NS-L1, LF-L1, LF-L2, L2 lifetime confidence, L1 and L2 naming screener, L1 and L2 PALPA, L1 and L2 BAT and PAPT. These correlations suggest that performance in FS is related to other cognitive control measures (LF-L1, LF-L2), language proficiency in L2 and language and lexical-semantic access in both L1 and L2 (i.e., NS-L1 and all the standardized language measures). Similarly, LF-L1 was also related to language proficiency and language performance measures in L1 and L2. LF-L2 was related to other category fluency measures indicating some degree of cognitive control and L1 and L2 language assessment measures. In general, these results indicate that with increased cognitive control demands, better performance on these tasks requires increased lexical-semantic performance, and further validate our premise that performance of BPWA across these fluency conditions illustrates the role of cognitive control further impacting their already impaired lexical-semantic access.

When examining the various language use and proficiency measures, age was negatively correlated with the SS condition of the semantic category generation task and the LF-L2 condition of the letter fluency task, indicating that cognitive control demands become more taxing on lexical access as a function of age. Next, L1 lifetime confidence was significantly correlated with NS-L1, this is not surprising as language confidence may be one measure that contributes to language dominance (Gertken et al., 2014), and greater dominance in L1 would lead to better lexical retrieval in the single-language context. Additionally, L2 lifetime confidence was significantly correlated with FS suggesting that increased L2 dominance would demonstrate a shift from highly controlled to more automatic and less effortful language processing (Abutalebi & Green, 2007), thereby, allowing for increased ability to switch between the two languages. L2 age of acquisition was negatively correlated with NS-L2 and LF-L2, indicating that the later the second language is acquired the worse performance may be on a category generation task administered in the L2. Finally, on the letter fluency task, LF-L1 was negatively correlated with L1 usage, but positively correlated with L2 usage.

Third, language performance measures (L1/L2 naming screener, L1/L2 PALPA, L1/L2 BAT, and PAPT) were found to be significantly intercorrelated. This finding was expected given these are all measures of lexical-semantic processing and language access and further validate these measures as tapping into language access and semantic processing.

Finally, RCPM was significantly positively correlated with L2 LF performance in BPWA. This is consistent with previous research suggesting that greater cognitive control is required in letter fluency compared to semantic fluency tasks (Luo et al., 2010). Because performance on RCPM was correlated with LF-L2 but not LF-L1, greater cognitive effort may be required for L2 word retrieval, presumably reflecting higher inhibition demands on the prepotent L1 (Green, 1998).

A few limitations are worth noting in this study. The aphasia group was a smaller sample compared to the healthy bilingual group, which suggests that more research is needed to ensure the generalizability of our results to the general population of BPWA. Additionally, our LUQ did not gather information regarding code-switching, nor the frequency with which participants operated within the three language contexts outlined in the Adaptive Control Hypothesis (Green & Abutalebi, 2013). Thus, future work could examine how performance on this task is modulated by how often bilinguals operate in these real-life language contexts. Finally, in this study, all data was coded as L1 and L2 to reflect the language that was acquired first and second in life instead of language dominance. While we acknowledge that language dominance may influence language performance, studies with healthy bilinguals have shown no common agreement as how to quantify language dominance (see Köpke & Genevska-Hanke, 2018; Silva-Corvalan, & Treffers-Daller for a review). When considering BPWA, quantifying language dominance after stroke can become even more difficult given that post-stroke language dominance (i.e., metrics of post-stroke bilingual language history, or post-stroke language performance) becomes confounded by language impairment. Hence, coding our data based on first-acquired vs. second-acquired is a more robust and consistent way to analyze the data as this metric (i) remains unchanged after stroke, and (ii) is consistent with the LUQ pre-stroke language ability ratings for the majority of our participants, a metric that has been used in the past as to reflect language dominance in healthy bilinguals (Kohnert, Hernandez, & Bates, 1999). Future research will need to examine the impact of language dominance on verbal fluency tasks in BPWA as better and more reliable methods become available to measure language dominance after brain insult.

## 5. Conclusions.

The present findings demonstrate that verbal fluency tasks that incorporate different demands on word production based on single and dual language use constraints can be sensitive to the effects of cognitive control on lexical retrieval and may reveal both lexical and cognitive control deficits in BPWA. Also, verbal fluency tasks that include an FS condition or the combination of our FS and SS conditions can be employed as a brief and practical method to evaluate both lexical access and cognitive control in BPWA. Our findings may also have important implications for the development of treatment plans for BPWA since deficits in lexical retrieval and cognitive control could be both addressed in rehabilitation.

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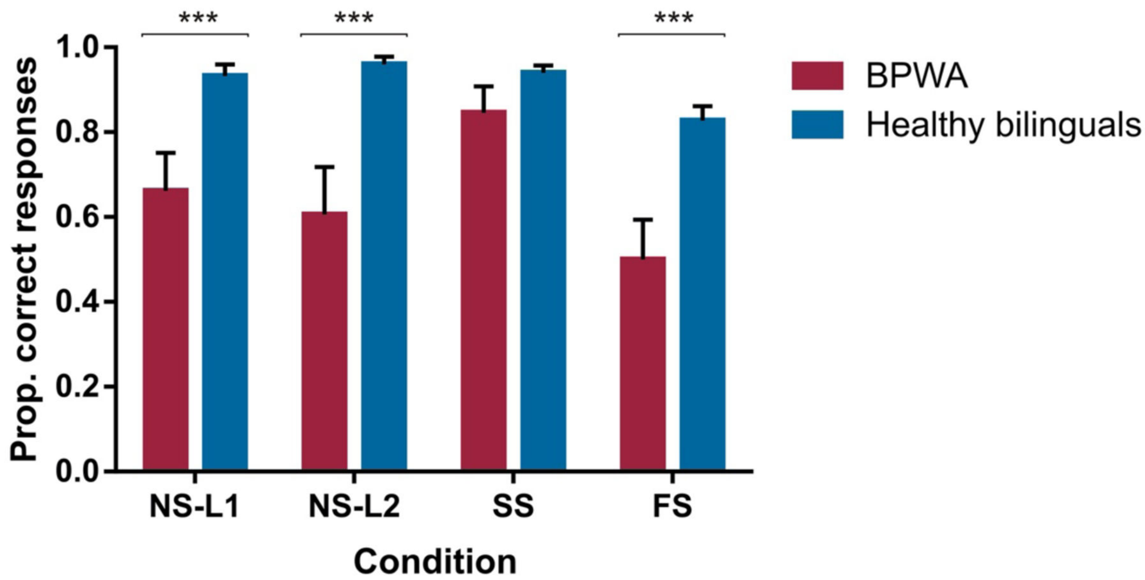


**Figure 1. Proportion of correct responses of the BPWA and the healthy bilinguals on the semantic category generation task across conditions.**

Mean and standard error values are presented separately for each group across all four conditions. Healthy bilinguals showed a significantly higher proportion of accurate responses in all conditions relative to the BPWA, except for the SS condition. *p<.05, **p<.01, ***p<.001.

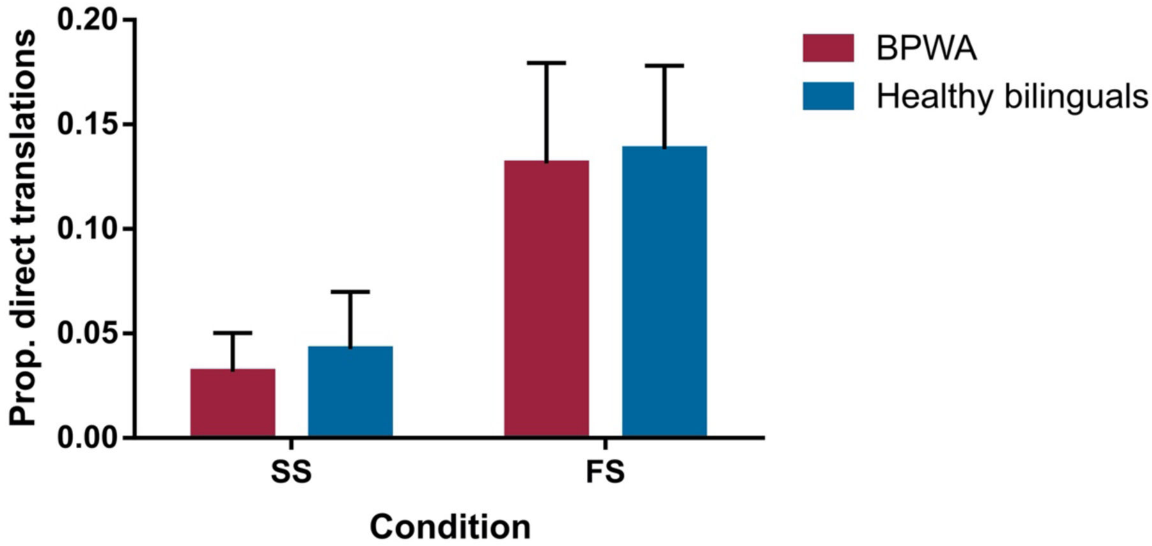


**Figure 2. Proportion of direct translations generated by the BPWA and the healthy bilinguals on the semantic category generation task.**

Mean and standard error values are depicted for each group on the SS and FS conditions. Both the BPWA and the healthy bilinguals produced a higher number of direct translations in the FS condition relative to the SS condition, although both groups performed similarly in each condition.

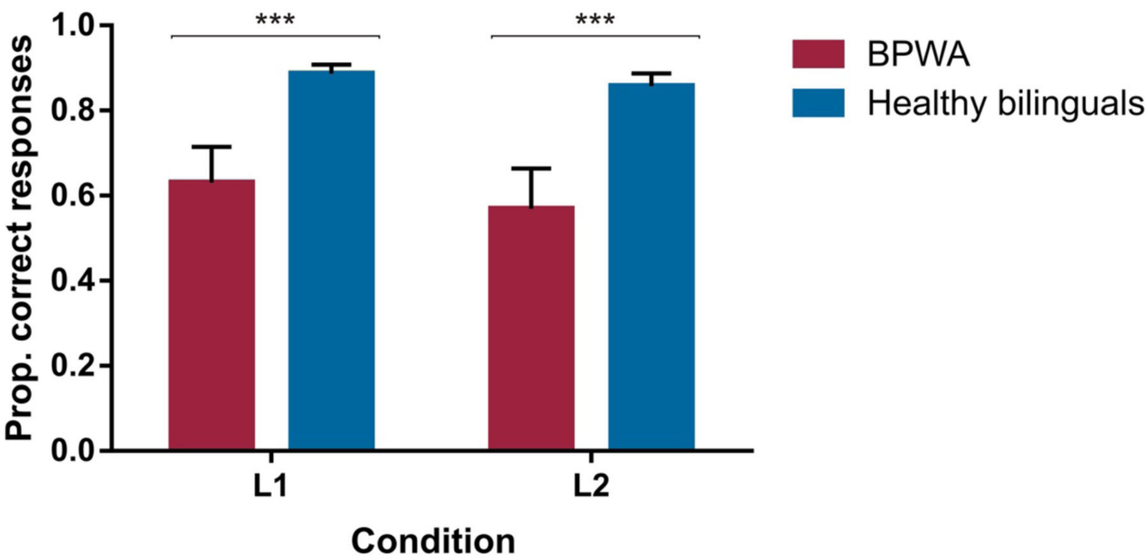


**Figure 3. Proportion of correct responses of the BPWA and the healthy bilinguals on the letter fluency task.**

Mean and standard error values are shown separately for each group across the two letter fluency conditions. Healthy bilinguals showed a significantly higher proportion of accurate responses in both the L1 and the L2 conditions relative to the BPWA. *p<.05, **p<.01, ***p<.001.

**Table 1.**

Demographic Information and Language Use Questionnaire (LUQ) data for the healthy bilinguals.

| Code | Age | Sex | Edu. | L1 | L2 AoA | LAR % | | Language Usage % | | Lifetime Exposure % | | Lifetime Confidence % | | Family Proficiency % | | Educational History % | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Eng | Span | Eng | Span | Eng | Span | Eng | Span | Eng | Span | Eng | Span |
| HB1 | 53 | F | 20 | Span | 6 | 77 | 97 | 87 | 13 | 37 | 63 | 62 | 93 | 50 | 100 | 6 | 94 |
| HB2 | 47 | F | 25 | Span | 28 | 80 | 100 | 83 | 17 | 29 | 71 | 40 | 100 | 33 | 100 | 11 | 89 |
| HB3 | 36 | F | 21 | Span | 26 | 100 | 100 | 53 | 47 | 30 | 70 | 34 | 100 | 25 | 100 | 17 | 83 |
| HB4 | 45 | M | 27 | Span | 12 | 91 | 100 | 100 | 0 | 40 | 60 | 57 | 100 | 25 | 100 | 6 | 94 |
| HB5 | 30 | F | 23 | Span | 7 | 80 | 100 | 72 | 28 | 24 | 76 | 75 | 100 | 33 | 100 | 0 | 100 |
| HB6 | 48 | F | 15 | Span | 15 | 86 | 100 | 91 | 9 | 45 | 55 | 72 | 100 | 25 | 100 | 17 | 83 |
| HB7 | 39 | F | 21 | Span | 36 | 97 | 100 | 78 | 22 | 20 | 80 | 18 | 100 | 92 | 42 | 0 | 100 |
| HB8 | 30 | M | 26 | Span | 7 | 91 | 100 | 79 | 21 | 32 | 68 | 55 | 94 | 25 | 100 | 11 | 89 |
| HB9 | 27 | F | 18 | Span | 6 | 100 | 80 | 81 | 19 | 61 | 39 | 61 | 76 | 67 | 92 | 89 | 11 |
| HB10 | 21 | F | 20 | Span | 7 | 89 | 100 | 18 | 82 | 19 | 81 | 47 | 100 | 42 | 100 | 22 | 78 |
| HB11 | 63 | F | 14 | Span | 7 | 43 | 100 | 3 | 97 | 11 | 89 | 15 | 100 | 58 | 100 | 0 | 100 |
| HB12 | 33 | F | 18 | Eng | 19 | 100 | 83 | 50 | 50 | 81 | 19 | 98 | 67 | 100 | 13 | 94 | 6 |
| HB13 | 82 | F | 12 | Span | 40 | 49 | 100 | 0 | 100 | 11 | 89 | 0 | 100 | 33 | 100 | 0 | 100 |
| HB14 | 54 | F | 14 | Span | 5 | 100 | 80 | 63 | 38 | 55 | 45 | 98 | 94 | 92 | 100 | 67 | 33 |
| HB15 | 38 | F | 18 | Span | 21 | 86 | 100 | 93 | 7 | 36 | 64 | 37 | 100 | 13 | 100 | 22 | 78 |
| HB16 | 45 | F | 14 | Span | 26 | 97 | 100 | 28 | 73 | 35 | 65 | 48 | 93 | 100 | 100 | 6 | 94 |
| HB17 | 55 | F | 16 | Span | 12 | 100 | 100 | 93 | 7 | 74 | 26 | 77 | 100 | 42 | 100 | 72 | 28 |
| HB18 | 52 | F | 12 | Span | 3 | 100 | 100 | 39 | 61 | 71 | 29 | 89 | 100 | 42 | 100 | 33 | 67 |
| HB19 | 76 | F | 8 | Span | 22 | 77 | 100 | 28 | 72 | 28 | 72 | 32 | 100 | 17 | 100 | 0 | 100 |
| HB20 | 60 | M | 9 | Span | 27 | 60 | 100 | 14 | 86 | 26 | 74 | 26 | 100 | 33 | 100 | 0 | 100 |
| HB21 | 61 | F | 19 | Span | 3 | 74 | 100 | 4 | 96 | 31 | 69 | 80 | 100 | 58 | 100 | 11 | 89 |
| HB22 | 43 | F | 18 | Span | 38 | 69 | 100 | 43 | 57 | 100 | 0 | 0 | 100 | 0 | 100 | 11 | 89 |

HB = healthy bilingual; Edu. = years of education; L1 = first-acquired language; L2 = second-acquired language; AoA= age of acquisition; LAR= language ability rating; Eng = English; Span= Spanish.

**Table 2.**

Demographic Information and Language Use Questionnaire (LUQ) data for the bilingual persons with aphasia (BPWA).

| Code | Age | Sex | Edu. | L1 | L2 AoA | Pre-Stroke LAR % | | Post-Stroke LAR % | | Pre-Stroke Language Usage % | | Post-Stroke Language Usage % | | Lifetime Exposure % | | Lifetime Confidence % | | Family Proficiency % | | Educational History % | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Eng | Span | Eng. | Span | Eng | Span | Eng. | Span. | Eng | Span | Eng | Span | Eng | Span | Eng | Span |
| BPWA1 | 82 | M | 16 | Span | 35 | 80 | 100 | N/A | N/A | 38 | 62 | N/A | N/A | 20 | 80 | 36 | 100 | 17 | 100 | 11 | 89 |
| BPWA2 | 54 | F | 17 | Span | 6 | 54 | 100 | 31 | 57 | 46 | 55 | 90 | 10 | 55 | 45 | 28 | 100 | 67 | 100 | 11 | 89 |
| BPWA3 | 25 | F | 13 | Eng | 5 | 100 | 74 | 66 | 46 | 71 | 29 | 50 | 50 | 46 | 54 | 100 | 67 | 50 | 100 | 100 | 0 |
| BPWA4 | 44 | M | 16 | Eng | 6 | 86 | 66 | 60 | 57 | 99 | 1 | 98 | 2 | 74 | 26 | 95 | 65 | 100 | 100 | 50 | 50 |
| BPWA5 | 63 | F | 12 | Span | 25 | 60 | 60 | 40 | 40 | 24 | 76 | 22 | 78 | 50 | 50 | 50 | 50 | 42 | 100 | 0 | 100 |
| BPWA6 | 24 | F | 16 | Span | 5 | 100 | 89 | 46 | 31 | 86 | 14 | 58 | 42 | 53 | 47 | 70 | 65 | 58 | 58 | 72 | 28 |
| BPWA7 | 24 | F | 13 | Span | 5 | 60 | 80 | 60 | 80 | 4 | 96 | 91 | 9 | 43 | 57 | 85 | 93 | 75 | 92 | 56 | 44 |
| BPWA8 | 58 | F | 18 | Span | 10 | 100 | 70 | N/A | N/A | 87 | 13 | N/A | N/A | 67 | 33 | 26 | 90 | 100 | 100 | 50 | 50 |
| BPWA9 | 48 | M | 16 | Span | 5 | 91 | 67 | 63 | 46 | 65 | 35 | 68 | 32 | 78 | 22 | 92 | 79 | 33 | 92 | 83 | 17 |
| BPWA10 | 66 | M | 16 | Span | 25 | 100 | 100 | 33 | 60 | 96 | 4 | 45 | 55 | 59 | 41 | 61 | 100 | 25 | 100 | 17 | 83 |
| BPWA11 | 47 | F | 19 | Span | 18 | 91 | 100 | 37 | 100 | 91 | 9 | 35 | 65 | 40 | 60 | 45 | 100 | 17 | 100 | 0 | 100 |
| BPWA12 | 53 | M | 17 | Span | 12 | 100 | 100 | 86 | 94 | 98 | 2 | 31 | 69 | 32 | 68 | 46 | 100 | 8 | 100 | 0 | 100 |
| BPWA13 | 77 | M | 16 | Span | 18 | 100 | 97 | 69 | 69 | 76 | 24 | 59 | 41 | 57 | 43 | 36 | 100 | 42 | 100 | 17 | 83 |

BPWA = bilingual person with aphasia; Edu. = years of education; L1 = first-acquired language; L2 = second-acquired language; AoA= age of acquisition; LAR= language ability rating; Eng = English; Span= Spanish. N/A = data not available.

**Table 3.**

Number of correct responses produced in each condition of the category generation task.

| Condition | BPWA | | HB | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| NS-L1 | 7.31 | 5.35 | 18.45 | 7.94 |
| NS-L2 | 6.69 | 5.99 | 16.09 | 5.62 |
| SS | 7.00 | 6.61 | 17.64 | 6.34 |
| FS | 5.62 | 4.81 | 12.64 | 5.84 |

BPWA = bilingual persons with aphasia; HB = healthy bilinguals; NS-L1 = No Switch, L1; NS-L2 = No Switch, L2; SS = Self-Switch; FS = Forced Switch.

**Table 4.**

Number of correct responses produced in each condition of the letter fluency task.

| Condition | BPWA | | HB | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| LF-L1 | 3.08 | 3.40 | 13.09 | 3.98 |
| LF-L2 | 3.15 | 3.76 | 10.50 | 3.22 |

BPWA = bilingual persons with aphasia; HB = healthy bilinguals; LF-L1 = Letter Fluency, L1; LF-L2 = Letter Fluency, L2.

## Table 5.

Significant partial correlations between verbal fluency tasks, age, bilingual language history, and language assessments including both healthy bilinguals and BPWA after controlling for group.

| Measures | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Age | 1.00 | 0.38 | 0.10 | −0.37 | **0.55**$^{**}$ | −0.40 | −0.34 | **−0.69**$^{***}$ | 0.39 | −0.39 | 0.29 | −0.32 | −0.09 | −0.25 | −0.41 | **−0.45**$^{*}$ | **−0.43**$^{**}$ | −0.25 | **−0.45**$^{*}$ |
| 2. L2 AoA | | 1.00 | −0.12 | **−0.47**$^{**}$ | −0.33 | −0.40 | −0.27 | **−0.51**$^{**}$ | 0.16 | −0.16 | 0.16 | **−0.77**$^{***}$ | −0.07 | −0.36 | −0.35 | **−0.54**$^{**}$ | −0.39 | −0.28 | −0.43 |
| 3. NS-L1 | | | 1.00 | 0.04 | −0.27 | **0.61**$^{***}$ | 0.39 | 0.13 | −0.16 | 0.16 | **0.62**$^{***}$ | 0.12 | **0.54**$^{**}$ | 0.33 | 0.30 | 0.26 | **0.43**$^{*}$ | 0.30 | −0.06 |
| 4. NS-L2 | | | | 1.00 | 0.33 | 0.36 | 0.08 | **0.75**$^{***}$ | −0.14 | 0.14 | −0.02 | 0.31 | −0.02 | **0.51**$^{**}$ | 0.27 | **0.65**$^{***}$ | **0.45**$^{*}$ | 0.30 | 0.43 |
| 5.SS | | | | | 1.00 | 0.06 | 0.33 | **0.46**$^{*}$ | −0.11 | 0.11 | −0.31 | 0.18 | 0.09 | 0.30 | **0.56**$^{**}$ | **0.51**$^{**}$ | 0.33 | 0.05 | **0.73**$^{***}$ |
| 6. FS | | | | | | 1.00 | **0.54**$^{**}$ | **0.58**$^{***}$ | −0.34 | 0.34 | 0.23 | **0.53**$^{**}$ | **0.52**$^{**}$ | **0.73**$^{***}$ | **0.50**$^{**}$ | **0.65**$^{***}$ | **0.78**$^{***}$ | **0.53**$^{**}$ | **0.44**$^{*}$ |
| 7. LF-L1 | | | | | | | 1.00 | 0.34 | **−0.48**$^{**}$ | **0.48**$^{**}$ | 0.17 | 0.25 | **0.49**$^{**}$ | **0.49**$^{**}$ | **0.64**$^{***}$ | **0.58**$^{***}$ | **0.54**$^{**}$ | 0.28 | **0.63**$^{***}$ |
| 8. LF-L2 | | | | | | | | 1.00 | −0.31 | 0.31 | 0.04 | 0.39 | 0.29 | **0.61**$^{***}$ | **0.54**$^{**}$ | **0.76**$^{***}$ | **0.73**$^{***}$ | **0.51**$^{**}$ | **0.57**$^{***}$ |
| 9. L1 Usage | | | | | | | | | 1.00 | **−1.00**$^{***}$ | −0.02 | −0.27 | −0.07 | −0.32 | −0.28 | **−0.47**$^{*}$ | −0.21 | −0.28 | −0.31 |
| 10. L2 Usage | | | | | | | | | | 1.00 | 0.02 | 0.27 | 0.07 | 0.32 | 0.28 | **0.47**$^{*}$ | 0.21 | 0.28 | 0.31 |
| 11. L1 Lifetime Confidence | | | | | | | | | | | 1.00 | −0.23 | **0.53**$^{**}$ | 0.02 | 0.26 | 0.03 | 0.32 | 0.21 | −0.11 |
| 12. L2 Lifetime Confidence | | | | | | | | | | | | 1.00 | 0.00 | **0.46**$^{*}$ | 0.17 | **0.53**$^{**}$ | 0.31 | 0.38 | 0.37 |

| Measures | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13. L1 Naming Screener | | | | | | | | | | | | | 1.00 | 0.41 | **0.68** *** | 0.42 | **0.76** *** | **0.57** *** | 0.38 |
| 14. L2 Naming Screener | | | | | | | | | | | | | | 1.00 | **0.44** * | **0.80** *** | **0.68** *** | **0.59** *** | **0.57** *** |
| 15. L1 PALPA | | | | | | | | | | | | | | | 1.00 | **0.70** *** | **0.75** *** | 0.41 | **0.74** *** |
| 16. L2 PALPA | | | | | | | | | | | | | | | | 1.00 | **0.77** *** | **0.59** *** | **0.79** *** |
| 17. L1 BAT | | | | | | | | | | | | | | | | | 1.00 | **0.65** *** | **0.63** *** |
| 18.L2 BAT | | | | | | | | | | | | | | | | | | 1.00 | 0.34 |
| 19.PAPT | | | | | | | | | | | | | | | | | | | 1.00 |

Significant partial correlations are marked in bold with *p* value significance threshold defined as ≤ .020 after correcting for multiple comparisons using the Benjamini-Hochberg procedure:

* $p<.02$;

** $p<.01$;

*** $p<.001$.

Variables of interest are been color-coded as follows: LUQ measures in yellow, category and letter fluency tasks in green, and language assessments in orange.

L2 AoA = L2 Age of Acquisition; NS-L1 = No Switch, L1; NS-L2 = No Switch, L2; SS = Self-Switch; FS = Forced Switch; LF-L1 = L1 letter fluency composite score; LF-L2 = L2 letter fluency composite score; L1 PALPA = PALPA composite score, L1; L2 PALPA = PALPA composite score, L2; L1 BAT = BAT composite score, L1; L2 BAT = BAT composite score, L2; PAPT: Pyramids and Palm Trees test.