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The Differential Role of Executive Functions in the Cognitive Control of Language Switching

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Abstract: Studies of bilingual speech production suggest that different executive functions (EFs) contribute to the cognitive control of language production. However, no study has simultaneously examined the relationship between different EFs and language control during online speech production. The current study examined individual differences in three EFs (working memory updating, inhibitory control, and task-set switching) and their relationship with performance in a trilingual language-switching task for a group of forty-seven native English (L1) speakers learning French (L2) and Spanish (L3). Analyses indicate complex interactions between EFs and language switching: better inhibitory control was related to smaller L1 switch costs, whereas better working memory was related to larger L1 switch costs. Working memory was also related to larger L2 switch costs, but only when switching from L1. These results support theories of cognitive control that implicate both global and local control mechanisms, and suggest unique contributions of each EF to both global and local cognitive control during language switching. Finally, we discuss the implications for theories of multilingual language control.

Keywords: language control; trilingualism; inhibitory control; working memory; individual differences; language switching

1. Introduction

Speech production is inherently guided by top-down control processes—the speech act is initiated by the speaker's intention to communicate, and speakers monitor their output to ensure alignment with their interlocutors (Levelt 1989).[1] However, during speech, numerous possibilities arise for conflict between competing representations, both within a language (Andrews 1997) and, in the case of multilinguals, between languages (Costa et al. 1999; Hermans 2000; Hermans et al. 1998; Kroll et al. 2006; Schwieter and Sunderman 2009). Thus, at multiple levels within the language system, there is a need for cognitive control mechanisms to support multilingual speech production. The extent to which language control for bilinguals overlaps with other non-linguistic processing has been debated for years (e.g., Branzi et al. 2016; Calabria et al. 2019; Declerck et al. 2017; Segal et al. 2019).

[1] For further reading on speech acts, the reader may wish to consult Austin (1975); Jakobson (1960); Searle (1969); Lotman (1990); Vygotsky (1962), for foundational linguistic, philosophical, and semiotic perspectives; and Levinson (2017, 2018) for cognitive and neurophysiological perspectives.

Although behavioral studies of multilingual language control have separately examined the importance of different executive functions (EFs), including inhibitory control (IC; Linck et al. 2012; Koch et al. 2010; see also Antoniou 2019; Bialystok 2017), working memory (WM; e.g., Christoffels et al. 2003; see also a meta-analysis by Grundy and Timmer 2017), and task-switching (Prior and Gollan 2011; Timmer et al. 2019; Wiseheart et al. 2016), little is known about the joint contributions of the collection of EFs. In this study, these three EFs were examined simultaneously to estimate their roles during a language-switching task that placed specific demands on language control functions.

Cognitive control has been argued to operate by various mechanisms. On the one hand, global or sustained control guides behavior by keeping active the current goal of the system (Braver et al. 2003). Such global control is necessary to ensure the goal-appropriate response is selected, particularly when multiple task-relevant responses are available for response selection. However, even with a clear goal in place, competition occurs in many forms, such as between distractor and target representations, between competing responses, or between different dimensions of the target representation (see the Dimensional Overlap Model, Kornblum et al. 1990). With language tasks, even more opportunities for conflict appear throughout the system at the phonological, orthographic, and morphosyntactic levels (Kroll et al. 2006). Some additional local control process(es) must be engaged to facilitate the selection and execution of the correct task-relevant response.

This distinction between global and local control processes has been discussed in the literature on bilingual language control (e.g., De Groot and Christoffels 2006) and fits well with models of bilingual language processing. In Green's (1998) IC Model, language task schemas provide sustained control by orienting the system towards performing the goal-relevant task, and potential responses that conflict with the current goals of the system are inhibited to prevent errors. The top-down control of the language task schemas and the reactive inhibitory mechanism work together to resolve cross-language conflict between representations in the two languages. The revised Bilingual Interactive Activation (BIA+) model of word recognition (Dijkstra and Van Heuven 2002) also includes task schema and inhibitory mechanisms. Neurophysiologically motivated models have postulated the importance of the frontal regions—including the anterior cingulate cortex and dorsolateral prefrontal cortex—to language control (Abutalebi and Green 2008), implicating domain-general EFs that support cognition more broadly (see also Levy and Anderson 2002).

Individual differences in global/sustained and local control likely contribute to multilingual speech production in different ways. In Green's (1998) IC Model, sustained control may be supported by the maintenance of goal representations in WM—a critical component to the control of a range of goal-directed behaviors (e.g., Engle 2002). Thus, individuals with larger WM capacity may better engage global control. In contrast, local control may be enacted by engaging inhibitory mechanisms, such as the reactive inhibition of representations that are competing with the target representation, as has also been posited by models of memory retrieval (e.g., Levy and Anderson 2002). Green's IC Model focused on reactive inhibition that is triggered by the activation of non-target representations. Colzato et al. (2008) identified a two-component model of cognitive control that included both a global control mechanism and a separate IC component.[2] We build upon these theoretical frameworks to examine the contributions of different EFs to language control during a trilingual speech production task.

Recent studies have also shown a link between bilingual language control and domain-general executive control by assessing the effect of language-switching training (Liu et al. 2019; Prior and Gollan 2013; Timmer et al. 2019). Although Timmer et al. found that training in language switching transfers to the non-linguistic domain for certain sub-mechanisms (i.e., switch cost) but not for others (mixing cost), Prior and Gollan reported no transfer effects, neither for switch cost nor mixing cost. Liu et al.'s study found that training in language switching reduced mixing costs and the anti-saccade

[2] Colzato et al. (2008) also examined both reactive and proactive inhibitory mechanisms, which are likely to support bilingual language processes in different contexts.

effect among bilinguals. They argue that extensive training in monitoring and inhibitory control enhances the corresponding components of cognitive control.

IC and WM seem particularly relevant to language control during language switching. A recent study (Kaushanskaya and Crespo 2019) found that the effects of exposure to code-switching input were modulated by WM. For children with high WM, being exposed to code-switching input did not negatively affect their language skills. However, in both receptive and expressive language skills, children with low WM were negatively affected if they were exposed to code-switching input. Thus, WM can and may have a modulating effect on IC. Linck et al. (2012) found that better inhibitors showed smaller switch costs in a trilingual language-switching task. In other words, more efficient IC skills resulted in smaller switch costs into a non-target/irrelevant language. Moreover, previous work has shown that language switching led to increased activation of the DLPFC—specifically in areas previously linked to IC mechanisms responsible for resolving conflict (Hernandez et al. 2000, 2001; for a review, see Abutalebi and Green 2008). Additional work has demonstrated enhanced general executive functioning among bilinguals exhibiting better language control on a range of cognitive control tasks requiring attentional control (Festman et al. 2010) and conflict resolution (Festman and Münte 2012). Other works (e.g., Abutalebi et al. 2001; Hernandez 2009; Price et al. 1999) have used neuroimaging studies to examine the broader basis of language switching. What is still unclear, however, is how WM can interact with EFs and IC.

Asymmetries in language dominance will also constrain the effect of IC on switch cost. We should see the largest effects when switching from the least dominant language (L3) to the most dominant language (L1) (Green 1998). This would be consistent with Meuter and Allport (1999) as well as Linck et al.'s (2012) findings that there is a cost to re-engage the previously irrelevant L1. Differences in dominance also have neural consequences. Recent work (Garbin et al. 2011) found that language switching is constrained with proficiency; early and high-proficient bilinguals implement different brain networks than low proficient bilinguals. For low-proficient or unbalanced multilinguals, naming in the least dominant language is expected to place the largest demands on working memory. In order to produce in the weak L3, or even the weak second language (L2) in the case of this study, the individuals must suppress the dominant L1 and focus their attention on the weaker languages.

Our research question in the current study is: Is there a relationship between certain EFs—specifically working memory updating, inhibitory control, and task-set switching—and language control? Given the findings above, one might expect the abbreviated answer to this question to be "yes". If IC is engaged to reduce cross-language representational conflict during speech production in a mixed language context, then IC should be most relevant to performance in conditions where the greatest amount of cross-language interference is expected, namely when switching into or out of L1. Specifically, we predicted that better IC abilities should allow more efficient deployment of inhibition in the face of conflict that arises when switching into a previously irrelevant language, and thus should be related to smaller switch costs, due to faster latencies in switch trials (Linck et al. 2012). In contrast, because L1 is the dominant response language, there should be greater demands on WM resources to activate and maintain the task schema for L2 or L3 naming relative to L1 naming, and thus WM should be most relevant when naming in the less dominant languages. Specifically, more efficient activation and sustainment of the L2 naming and L3 naming task schemas should facilitate switching into L2 and L3, leading to reduced switch costs. Furthermore, following Prior and Gollan (2011), we expect that better task switchers (i.e., those exhibiting smaller switch costs on a monolingual task-switching task) will be better language switchers in mixed language contexts due to the presumed shared cognitive processes.

2. Materials and Methods

2.1. Participants

A unique group of 51 participants were recruited from the same population as that reported by Linck et al. (2012): native English (L1) speakers learning French (L2) and Spanish (L3) at a large public university in an English-speaking region of Ontario, Canada. All participants were currently enrolled in French and Spanish language courses at the time of the study. The average age of the participants was 20.7 years. Although the participants reported a fairly early L2 age of acquisition, data from the proficiency self-ratings[3] and verbal fluency measures indicated a relatively weak L2 and L3 (see Table 1). Data from two participants were excluded from analysis for having incomplete task-switching data due to technical malfunctions, and two additional participants were excluded as univariate outliers on the task-switching or Simon task ($zs < -2.5$), making a final sample of 47 participants.

Table 1. Means (SDs) of participant characteristics and self-ratings.

	L1		L2		L3	
Age of Acquisition	0.49	(1.58)	6.67	(3.97)	16.7	(2.92)
Self-ratings of Ability						
Reading	9.88	(0.33)	7.66	(1.89)	5.86	(1.90)
Writing	9.76	(0.52)	6.78	(1.88)	5.28	(2.15)
Speaking	9.84	(0.47)	6.65	(2.10)	5.16	(2.11)
Listening	9.92	(0.34)	7.53	(2.00)	6.02	(2.37)
Overall	9.94	(0.25)	6.74	(1.85)	4.84	(2.08)
Lexical robustness	132.43	(24.45)	67.18	(22.83)	44.31	(17.24)
% Daily use	76.15	(12.56)	11.71	(7.69)	7.05	(4.63)

Notes. The native language (L1) refers to English; the second language (L2) is French; and the third language (L3) is Spanish. Self-ratings were given on a ten-point Likert scale ranging from one (not fluent) to 10 (very fluent). Lexical robustness is indicated by the total number of category exemplars produced in the verbal fluency task. Scores for each language were computed as the sum across ten categories. Planned contrasts indicated significant differences between all three languages for each measure (all $ps < 0.01$ after Bonferroni correction).

2.2. Procedure

The participants first completed the informed consent and a language questionnaire. They then completed the following tasks in this order (following Linck et al. 2012): (1) verbal fluency measure; (2) picture-naming task; (3) Simon task; (4) running memory span task; and (5) task-switching task. We discuss each experimental task in detail below, which collectively lasted approximately 75 min.

2.2.1. Verbal Fluency Measure

A verbal fluency measure was conducted to estimate global language proficiency in all three languages (Costa et al. 2006; Schwieter and Sunderman 2011). In this task, participants were presented with categories (five semantic and five first-letter) individually on a computer screen. For each category, participants were asked to verbalize as many related words as possible within thirty seconds. A total score for each language was calculated by adding all of the exemplars produced for all ten categories. The verbal fluency scores revealed significant differences in the participants' language abilities (see Table 1). The task can be completed within 10 min.

[3] Relying on self-ratings of proficiency is less ideal than on data from standardized measures such as the Common European Framework of Reference for Languages (Andrews 2014; De Bot 2008; Schwieter 2019). When possible, future studies should use these types of measures to avoid this potential limitation.

2.2.2. Picture-Naming Task

In this task, twenty standardized black and white line drawings (Snodgrass and Vanderwart 1980) of a book, car, bear, chair, cat, dog, house, heart, pencil, table, apple, window, nose, lips, leaf, eyes, donkey, bed, watch, and sun were presented individually on a computer screen in 48 lists ranging from five to 14 pictures in length. Trials within the lists were either non-switch trials (the immediately preceding trial was named in the same language) or switch trials (the previous trial was named in a different language). All pictures appeared 60 times, such that, of the 480 total trials, 312 (65%) were non-switch trials and 168 (35%) were switch trials. There was equal production of all three languages in the experiment (i.e., 160 responses were elicited in each language). Switch trials were equally distributed across the six possible language pairings (e.g., L1 to L2, L1 to L3, etc.). The lists were constructed so that each included between zero and four switch trials, and for lists between five and 10 pictures in length, no picture appeared twice; in lists 11–14 pictures in length, repeated pictures were placed at least three trials away from their first presentation. This design was similar in a number of previous studies (e.g., Costa and Santesteban 2004; Costa et al. 1999; Schwieter and Sunderman 2008; among others).

The language of naming was cued by the color of the background screen (blue, red, or yellow; see example list in Figure 1). Before the 48 experimental lists, the participants practiced the task on six practice lists that were identical in design and procedure as the experimental lists. A break was given between the practice and experimental lists and after every 10 experimental lists (approximately every 5 min) to avoid fatigue. The task can be completed within 30 min.

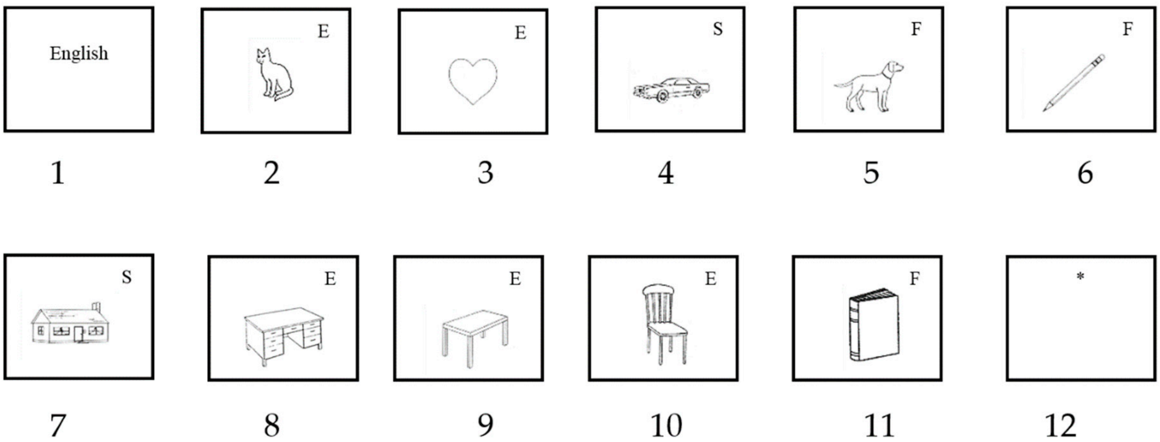

Figure 1. Example of picture naming task with language switches. Note: The letters E, F, and S represent whether the pictures were to be named in English (blue background), French (red background) or Spanish (yellow background), respectively. Pictures appeared for 2000 ms or a until response was recorded through the microphone, with an inter-stimulus interval of 800 ms.

Response times (RTs) were measured by the computer, and productions were digitally recorded and later coded for accuracy by the researchers. Prior to analysis, inaccurate trials and trials with RTs faster than 250 ms or slower than 2500 ms were excluded. RTs were then log-transformed to obtain a more normal distribution.

2.2.3. Simon Task

The Simon task (Simon and Rudell 1967) was used to measure IC (Bialystok et al. 2004; Bialystok et al. 2005). This non-linguistic measure assesses IC without linguistic materials and better examines domain-general rather than language-oriented IC. The design followed Linck et al. (2012), containing three experimental blocks of 42 trials (14 congruent, 14 incongruent, and 14 neutral).

A Simon effect score was computed as the difference in latencies between incongruent and congruent trials. The task can be completed within 10 min.

2.2.4. Running Memory Span Task

The running memory span task (Bunting et al. 2006) was used to measure the updating component of executive functioning. Participants used headphones to listen to pseudo-randomly ordered strings of 12–20 letters from a set of 12 consonants (C, F, H, J, L, N, P, R, T, V, X, and Z) at the rate of three letters per second. Immediately afterward, they were instructed to recall the last six letters in the string, in the same order presented, beginning with the sixth to last and ending with the last letter. The 12 letters were displayed on the recall screen, and participants indicated their choices with mouse clicks. Participants received one point per letter recalled in the correct serial position; points were summed by string, and the final task score was the mean proportion correct across the 20 presented strings. The maximum possible score on the Running Memory Span task was six. The task can be completed within 10 min.

2.2.5. Task-Switching Numbers Task

In the task-switching task, participants viewed the digits one through nine (excluding five) presented within either a gray or a white square in the center of the screen. The color of the square indicated the current task: when the square was white, the participant indicated on the response box whether the presented digit was odd or even ("odd/even task"); when the square was gray, the participant indicated on the response box whether the digit was lower than five or higher than five ("low/high task"). The task cue (i.e., colored background) was presented simultaneously with the digit. Participants completed a series of blocks with each task separately ("Pure" trials), before completing two combined blocks of 72 trials each, presented in predictable alternating runs (three repetitions per task). The task can be completed within 10 min.

A switch cost latency score was computed as the difference between switch trial and non-switch trial reaction times, and was employed as a measure of the shifting component of executive functioning.

2.3. Data Analyses

To simultaneously model the relationships that all three EFs have with language-switching performance, linear mixed effects models were fit to the trial-level data (e.g., Linck et al. 2012). We fit a series of progressively more complex mixed effects models. Chi-square tests of model improvement and examinations of model parameters led to the final model containing the categorical factors of 'current language' and 'switch condition', their interactions, simple effects (i.e., slopes) of the three EFs, and the two- and three-way interactions involving each EF and one or both categorical factors. Mixed effects models were implemented using the lme4 package (Bates and Maechler 2010) within the R statistical computing environment, version 2.13.2 (R development core team 2010).

3. Results

Descriptive statistics for the EF tasks are reported in Table 2. Prior to analysis, all three EF scores were standardized to z-scores to facilitate model interpretation (e.g., Gelman and Hill 2007).[4] IC and task-switching scores were also reverse scaled (i.e., multiplied by −1) so that higher z-scores indicated better ability for all three EFs.

[4] Preliminary analyses indicated that the standard Simon effect scores (incongruent trial mean response times (RTs) minus congruent trial mean RTs) and task-switching switch cost scores (switch trial mean RTs minus non-switch trial mean RTs) were not normally distributed for this sample. Trial-level RTs were log-transformed prior to computing the condition means, resulting in more normally distributed scores. All mixed effects models were refit using standard Simon and task-switching scores (based on raw RTs), and the overall pattern of results remained the same.

Table 2. Means (SDs) of performance on the executive function (EF) tasks.

	Mean	SD
Simon task		
Central	380	(55)
Congruent	365	(65)
Incongruent	393	(58)
Simon effect	28	(22)
Running memory span task	2.89	(0.75)
Task-switching task		
Pure	505	(63)
Non-switch	1107	(235)
Switch	680	(142)
Mix cost	174	(115)
Switch cost	427	(200)

Notes. The Simon effect was calculated by subtracting mean reaction times of congruent trials from mean reaction times of incongruent trials; the mix cost was calculated by subtracting mean reaction times of pure trials from mean reaction times of non-switch trials; the switch cost was calculated by subtracting mean reaction times of non-switch trials from mean reaction times of switch trials.

Reaction times and percent accuracy for the picture-naming task are presented in Table 3. Mean RTs for the nine conditions suggest that prior language affected the magnitude of the switch cost. The L1 switch costs were larger when switching from the less dominant L3 (248 ms) than L2 (182 ms). Switch costs in L2 were larger when switching from the dominant L1 (225 ms) than from the less dominant L3 (184 ms). Switch costs in L3 were larger when switching from L2 (134 ms) than L1 (68 ms).

Table 3. Reaction times (in ms) and accuracy (in percent) for the picture-naming task, by language of preceding and current trials.

	Current Trial					
Preceding Trial	**L1**		**L2**		**L3**	
			Reaction times			
L1	866	(131)	1284	(212)	1134	(176)
L2	1048	(184)	1059	(160)	1200	(205)
L3	1114	(190)	1243	(196)	1066	(167)
			Accuracy			
L1	97.4	(2.8)	92.9	(5.4)	93.1	(6.2)
L2	94.3	(5.8)	92.3	(5.2)	94.8	(7.6)
L3	93.4	(6.0)	92.9	(7.2)	93.5	(6.4)

Notes. Reaction times are reported as raw means to ease interpretation, but analyses were conducted on log-transformed reaction times. Standard deviations are reported in parentheses. The native language (L1) refers to English; the second language (L2) is French; and the third language (L3) is Spanish.

3.1. Executive Functions Differentially Predict Switch Costs

In the final, best-fitting model, all three EFs were modeled simultaneously,[5] and therefore the simple effects and interactions involving each EF represent its relationship with picture naming performance while controlling for differences in the other two EFs. With L1 as the baseline for the 'current language' factor, three parameters are of interest for each EF: the simple slope, and its two interactions with the 'switch cost' parameters (one for each prior language). To extract and assess the statistical significance of the EF slopes in the L2 and L3 naming conditions, the model was refit with L2 as the reference level for 'current language,' then again with L3 as the reference level. See Table 4

[5] The inclusion of all three EFs significantly improved the fit of the model over simpler models, based on chi-square tests of model likelihoods. See Appendix A for coefficients and model fit statistics.

for the simple slopes and interactions of theoretical interest from the three model fits. To facilitate an interpretation of the final model, we plot the EF slopes predicting switch costs in each language, directly extracted from the final model. We consider the three EFs in turn.

Table 4. Model parameters and standard errors (SEs) for EF predictors in non-switch and switch conditions for the three languages of production.

Parameter	Current Language of Naming					
	L1		L2		L3	
IC (non-switch)	**0.052** *	(0.024)	0.028	(0.024)	0.001	(0.024)
IC × Switch-from-L1	–	–	0.003	(0.011)	−0.001	(0.011)
IC × Switch-from-L2	0.001	(0.010)	–	–	−0.002	(0.010)
IC × Switch-from-L3	**−0.024** *	(0.011)	−0.015	(0.011)	–	–
WM (non-switch)	−0.028	(0.023)	−0.042	(0.023)	−0.002	(0.023)
WM × Switch-from-L1	–	–	**0.028** *	(0.010)	0.014	(0.010)
WM × Switch-from-L2	0.011	(0.009)	–	–	0.015	(0.010)
WM × Switch-from-L3	**0.028** *	(0.011)	0.013	(0.010)	–	–
TS (non-switch)	−0.011	(0.020)	**−0.046** *	(0.021)	−0.015	(0.020)
TS × Switch-from-L1	–	–	0.016	(0.009)	−0.002	(0.009)
TS × Switch-from-L2	−0.002	(0.008)	–	–	−0.002	(0.009)
TS × Switch-from-L3	−0.013	(0.010)	0.012	(0.009)	–	–

Notes. L1 parameters are those from the full best-fitting model, with L1 as the baseline level of the 'current language' factor (see the Appendix A for the complete list of model parameter estimates and descriptions of the model-fitting procedures). To estimate the EF simple slopes and simple slope × switch condition interaction parameters for the L2 and L3 naming conditions, the 'current language' factor was reparameterized and the model was refit, first with L2 as the baseline, then with L3 as the baseline. Note that this reparameterization changes the interpretation of the model parameters to allow a direct test of the hypotheses motivating this study, without altering the model fits (Gelman and Hill 2007). * $p < 0.05$.

3.1.1. Inhibitory Control

Better inhibitors had reduced switch costs when switching into L1 from the least dominant L3, replicating one of the effects reported by Linck et al. (2012). This effect is depicted in Figure 2. No effects of IC were found when naming in L2 or L3 (see Table 4). To better understand the L1 switch cost effect, Figure 3 displays the relationship between IC and naming latencies (not switch costs) within each condition. Participants with better IC were overall slower when naming in L1, but when switching into the dominant L1 from L3, they demonstrated better strategic control as evidenced by the reduced IC slope for that particular switch condition.

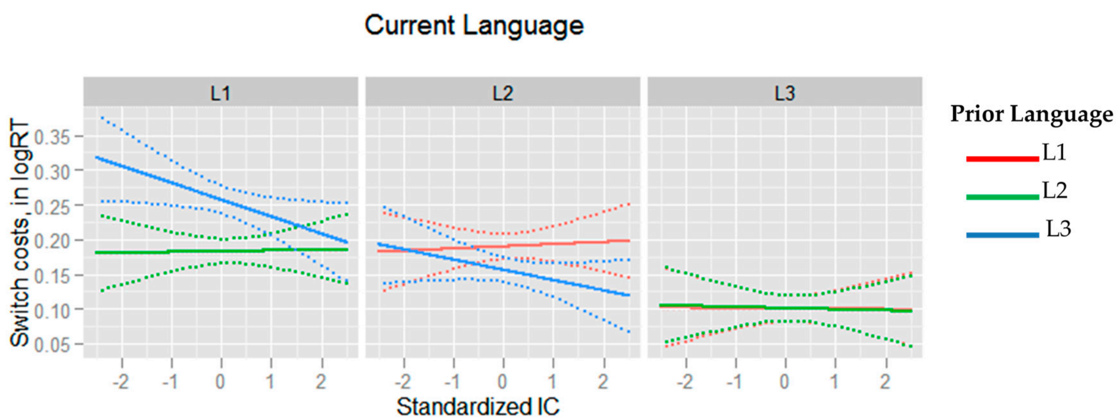

Figure 2. Relationship between inhibitory control and language switch costs (in log RT) by the language on the current trial. A larger standardized inhibitory control (IC) score indicates better inhibitory control abilities. Dotted lines indicate 95% confidence bands.

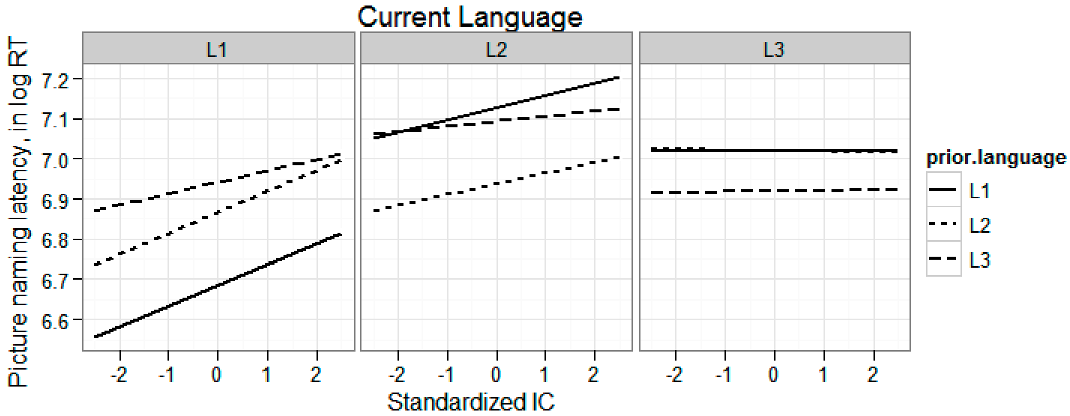

Figure 3. The relationship between inhibitory control and picture naming latencies (in log RT) within each current language and prior language condition. A larger standardized inhibitory control (IC) score indicates better inhibitory control abilities.

3.1.2. Working Memory

Better WM updating was related to larger switch costs when switching into or out of the dominant L1, as depicted in Figure 4. Specifically, larger switch costs occurred when switching into the dominant L1 from the least dominant L3. Better WM updating was also related to larger L2-from-L1 switch costs (see Table 4), with better updaters showing larger switch costs. In both cases, it seems that better WM updating was related to faster latencies in non-switch trials, but no differences appeared on those particular switch trials (see Figure 5). During L3 naming, WM showed no consistent relationship with latencies or switch costs.

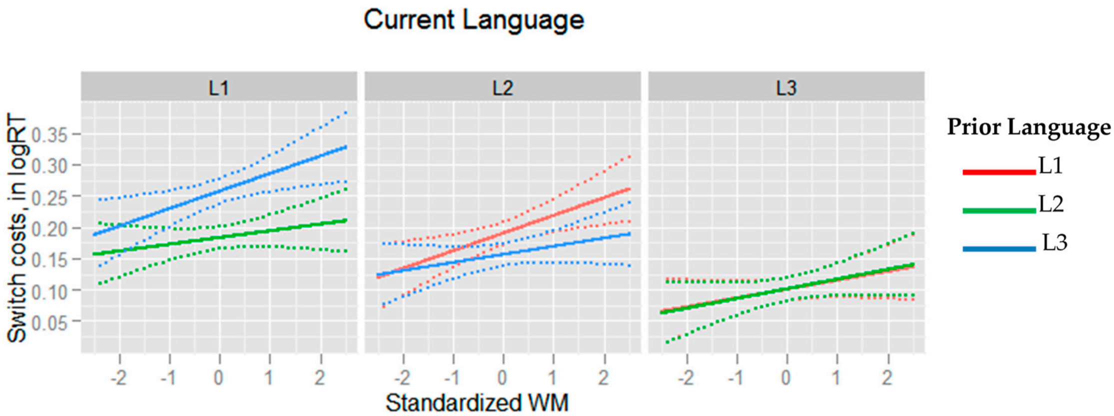

Figure 4. Relationship between working memory and language switch costs (in log RT) by the language on the current trial. A larger standardized working memory (WM) score indicates better working memory updating abilities. Dotted lines indicate 95% confidence bands.

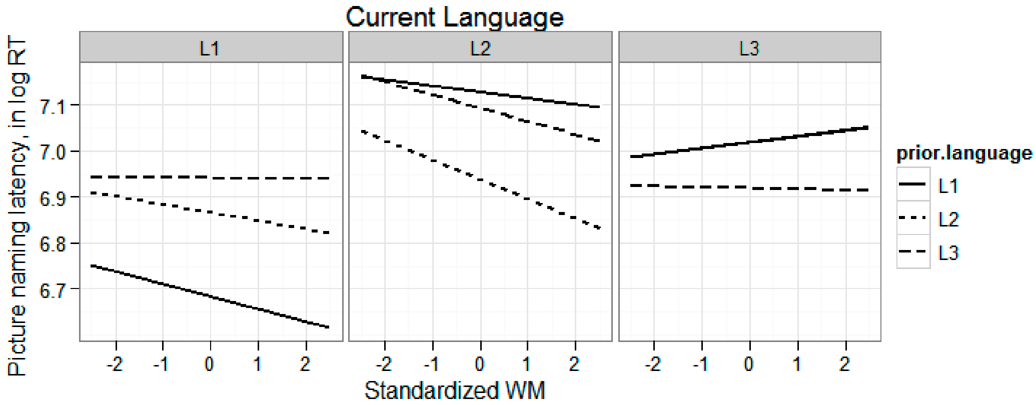

Figure 5. Relationship between working memory and picture naming latencies (in log RT) within each current language and prior language condition. A larger standardized working memory (WM) score indicates better working memory updating abilities.

3.1.3. Task-Switching

Task-switching ability was not related to switch costs in any language (see Figure 6). However, results indicate that better task switchers were faster to name pictures in L2 within this mixed language context (see Table 4).

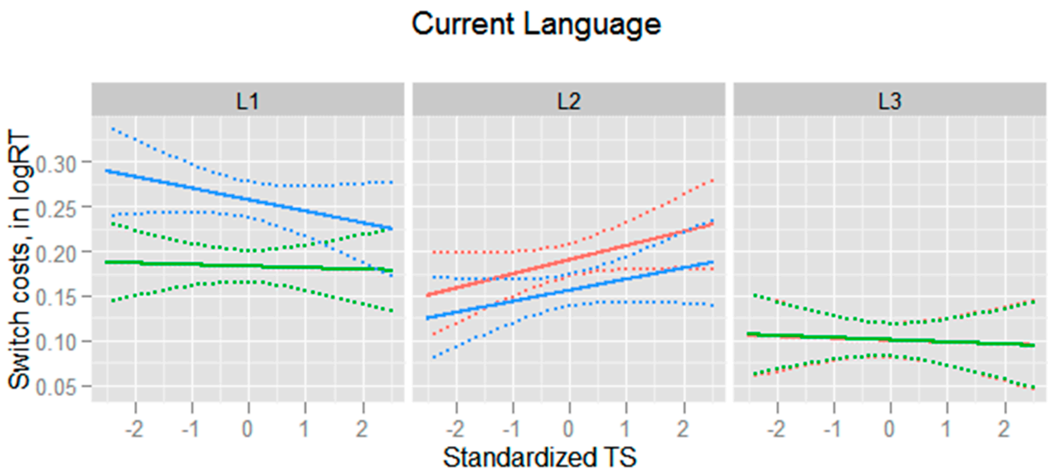

Figure 6. Relationship between task-switching switch costs and language switch costs (in log RT) by the language on the current trial. A larger standardized task-switching (TS) score indicates better task-switching abilities (as indicated by smaller switch costs). Dotted lines indicate 95% confidence bands.

4. Discussion

This study was designed to examine the relationship between different EFs and language control during trilingual speech production. We measured three EFs—inhibitory control, working memory updating, and task-set switching—that are related but separable subcomponents of the executive control system (Friedman and Miyake 2004) and have been linked to bilingual language processing and implicated in studies on the cognitive benefits of bilingualism. Although previous research on multilingual speech production has studied the individual role of these EFs in isolation, this is the first study to simultaneously assess their relative contributions to language control.

The effect of IC on switch costs was constrained to precisely the condition where the asymmetry in language dominance should induce the largest effects of lingering inhibition—when switching from the least dominant L3 to the most dominant L1 (Green 1998). These results are consistent with recent claims that better inhibitors can more efficiently re-engage the previously irrelevant L1 (Linck et al. 2012), although the within-condition slopes suggest a further specification of this account. The switch cost-IC effect appears to have been driven by overall slower access to L1, combined with an increase in control on switches. Slowed L1 lexical access following naming in a less dominant language has been found even after a delay of 10–15 min (see Levy et al. 2007). In their study, Levy et al. similarly asked bilingual learners to switch between languages when naming pictures, but later cued the retrieval of the L1 names of those pictures with a novel phonological rhyme cue (e.g., "break—s___" to cue the retrieval of snake). For pictures that had repeatedly been named in L2, participants were less likely to successfully retrieve the L1 name in response to this rhyme cue. Based on the extensive literature on retrieval-induced forgetting that has implicated inhibitory mechanisms in the control of memory retrieval (see Anderson 2003, for a review), Levy et al. concluded that the forgetting effects indicated that L1 lexical access had been impaired by the lingering inhibition of the L1 picture names.[6] In the present study, perhaps better inhibitors were able to more efficiently engage IC mechanisms to support retrieval in the weaker L3, manifesting as slowed re-engagement of L1 in switch trials relative to non-switch trials (in which the activation of L1 has rebounded).

For unbalanced multilinguals, naming in the least dominant language is expected to place the largest demands on working memory, since the speaker must focus attention on the weakest language in the face of distracting interference from the dominant L1 (and in the case of the present study, another weak language). One useful strategy could be to always prepare not to use L1. This strategy would clearly benefit L3 naming, where L1 is most likely to interfere. Yet this strategy would potentially impair L1 naming trials. This may have the unexpected consequence of increasing demands on working memory to engage the L1 naming schema, despite the relative dominance of L1.

Indeed, this is where WM updating effects were found: better WM updating was related to larger switch costs when switching into or out of the dominant L1. This is a somewhat counterintuitive finding—better WM is typically related to better, not worse, performance. However, the WM effects were driven by a relationship between better WM and faster latencies in non-switch trials (when the same task set must be maintained across trials) but no differences appeared in switch trials. Perhaps in this mixed language naming task, the better updaters were able to engage a top-down strategy of globally biasing against responding in L1 during L3 naming, and this global bias spilled over momentarily upon switching into L1. However, then, the better updaters were able to quickly re-engage L1 and disengage the "inhibit L1" task schema, leading to faster responses on L1 non-switches. In the same vein, Kroll et al. (2002) found a counterintuitive WM result—individuals with better WM resources showed smaller cognate facilitation effects. This finding suggests that the participants were able to focus their attention on L2 to avoid any potential interference from L1, which, for cognates, prevented them from benefiting from the L1 overlap (in orthographic and phonological form). In a parallel manner, the present data suggest that better WM resources may have allowed participants to focus attention away from L1 when using L3, and the effects of this strategy of pushing L1 out of the focus of attention lingered when switching back into L1.

Taken together, the WM and IC results of the current study suggest that language switching may reflect at least two components: a repetition benefit (modulated by available attentional resources), and a switch cost (modulated by IC abilities). Our WM results suggest that individuals with greater WM resources benefit more from task repetitions, since better working predicted faster latencies in non-switch trials. This is consistent with recent claims that switching effects in (monolingual) task-switching reflect a repetition-induced benefit to performance, rather than a switch-induced cost to performance (De Baene et al. 2012). However, the IC results seem to fit with an inhibition-based account of task-switching (Mayr and Keele 2000). In our study, better inhibitors benefited less from

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[6] Morales et al. (2011) found similar results extending to a word's grammatical gender, suggesting that such inhibitory effects may span across levels within the bilingual language system. For a counterargument, see Runnqvist and Costa (2012), who found that repeated production of words in a non-dominant language enhanced lexical retrieval in the dominant language.

task repetitions and, critically, showed reduced costs due to switching. That is, across participants, there was a cost to performance in switch trials, but more efficient inhibitors suffered less of a cost. Moreover, this IC effect was independent of any WM effects, suggesting that inhibitory mechanisms also support language switching. To our knowledge, this study is the first to simultaneously model and examine the effects of multiple EFs on language and task-switching performance.

These accounts are both congruent with existing claims that the relative dominance of the two languages determines the extent to which cognitive control is required for successful language selection (Green 1998; Meuter and Allport 1999). Indeed, when these participants switched between less asymmetric language pairs (e.g., between L2 and L3), no reliable effects of the EFs were found, replicating our previous pattern of results (Linck et al. 2012). That is, cognitive control effects are constrained to conditions in which the greatest amount of competition or response conflict is expected, much as the cognitive benefits of bilingualism most reliably emerge in conditions high in conflict and/or cognitive load (Bialystok and Craik 2010; Hilchey and Klein 2011).

Finally, in terms of task-switching, our results indicated that this was not related to switch costs in any language, but we did find that better task switchers were faster to name pictures in L2. Given the mixed language context of the task and the demands to shift quickly between languages, we find this result to be in line with Festman and Münte (2012) who found that the individuals they had classified as 'non-switchers' (individuals who are able to avoid unintentional language switches) outperformed 'switchers' (those individuals who are less able to avoid unintentional language switches) in terms of speed and accuracy on a series of EF tasks. Festman and Münte cite this as evidence for a relationship between bilingual switching behavior and general cognitive control, a claim our data support as well.

Integrating Models of General Cognitive Control and Multilingual Language Control

Research on the cognitive control of attention and memory systems has generated a theoretical framework that implicates both global/sustained control mechanisms and local control mechanisms (Braver et al. 2003). This framework has broad application to a range of cognitive tasks involving distractor or response conflict (e.g., Flanker task, Stroop task) and ambiguity resolution (e.g., during sentence comprehension), and also can be easily incorporated into existing models of bilingual language processing. Green's (1998) IC Model posits global control via task schemas, which are activated based on the current goals of the speaker. This global control mechanism provides top-down 'supervisory' control over the system through the task schemas. When non-target language representations that conflict with the active task schema are activated, their production is prevented by localized inhibition that is applied to the specific representations based on their degree of competition with the target representation and/or task schema. Inhibition might also be applied globally to an entire language, and indeed evidence of both global and local inhibition effects has been reported (Guo et al. 2011). In the current study, WM effects on switch costs were constrained to non-switch trials, where successful performance depends on maintaining active the current response set/task schema, whereas IC effects on switch costs were found to impact both non-switch and switch trials, with good inhibitors being faster in general, but even more so in switch trials. This suggests that IC supported performance across the board, and especially in switch trials. WM was also important, particularly in non-switch trials when needing to maintain the current response set.

The finding that WM and IC independently accounted for variability in switching performance leads us to speculate that the IC Model could be further specified to incorporate these two EFs at different levels. WM updating effects might operate at the level of the language task schemas to provide top-down guidance of the selection process. In contrast, IC effects might be localized to the level of individual lexicosemantic representations, as currently suggested by the IC Model (see also Levy et al. 2007, for similar claims motivated by the retrieval-induced forgetting literature). These two levels are necessarily interrelated: the inhibition of specific representations is motivated/cued, at least in part, by the top-down guidance from the language task schemas, whose job it is to bias production towards the target language (Green 1998).

These modifications to the IC Model would incorporate theoretical claims from the literature on cognitive control, while also extending the IC Model to make predictions about the impact of individual differences in EFs. This approach provides a unified account of results from this study and other recent examinations of individual differences in language control (Festman and Münte 2012; Festman et al. 2010; Prior and Gollan 2011). Our results build on these findings to provide more specified links between executive functioning and online language processing.

5. Conclusions

The current study examined the relative contributions of EFs to multilingual language control during online speech production. The most striking result was that WM and IC were differentially related to performance in a trilingual language-switching task. Our results inform models of bilingual language control, and provide motivation to expand Green's (1998) IC model to specify that these EFs may operate at different levels to support language control. Critically, these results bridge models of bilingual language processing with an existing theoretical framework within the broader literature on cognitive control implicating a distinction between global and local control mechanisms (Braver et al. 2003). These results highlight the potential for these related studies to inform the development of more sophisticated theoretical models in both domains.

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Appendix A

Table A1 lists maximum likelihood estimates for five mixed effects models considered during the model fitting process. For all models, the 'current language' factor was dummy coded with L1 as the reference level, creating two simple contrasts (L2 and L3), and the 'switch cost' factor was dummy coded with non-switch as the reference level and two contrasts to capture the two possible switch costs ('switch-from-high' = cost of switching from the higher proficiency prior language, and 'switch-from-low' = cost of switching from the lower proficiency prior language). The EF measures were standardized by centering at the sample mean and dividing by the sample standard deviation, to ease interpretation of the model parameters (Gelman and Hill 2007; Raudenbush and Bryk 2002). Thus, the intercept estimates the mean log RT on L1 non-switch trials for a participant with the sample-average inhibitory control, working memory, and/or task-switching abilities, when included in the model. See text for details on the interpretation of critical interaction parameters.

The results reported in the text are based on the final best-fitting model. Our model building process began with the simple, no-covariates model, followed by separate models for each EF, containing its full factorial combination with the prior language and switch cost factors, and finally the union of all predictors from those three factorial models. The most complex model produced the best fit to the data and allowed a direct test of our motivating hypotheses—namely that the three EFs would contribute differentially to language control on this task when examined simultaneously. Model improvement was assessed by the difference in −2*loglikelihood for each model; this statistic is distributed as a chi-square distribution with degrees of freedom equal to the number of additional parameters in the more complex model (e.g., Gelman and Hill 2007). Although both the Akaike information criterion (AIC) and the Bayesian information criterion (BIC) increased in the final model, we concluded that the final, complex model provided the best characterization of the data given the significant chi-square model comparison test statistic and the a priori theoretical motivation for the analysis. In Table A1, we report the maximum likelihood estimates for all five fitted models to allow a direct comparison of the resulting inferences.

Table A1. Estimated coefficients from the best-fitting mixed effects model.

	Final Best-Fitting Model			IC-Only Covariate Model			WM-Only Covariate Model			TS-Only Covariate Model			No Covariate Model		
Predictor	**Coefficient**		***SE***	**Coefficient**		***SE***	**Coefficient**		***SE***	**Coefficient**		***SE***	**Coefficient**		***SE***
Fixed (non-varying) effects															
Intercept	6.684	*	0.024	6.684	*	0.024	6.691	*	0.024	6.691	*	0.024	6.702	*	0.024
L2	0.252	*	0.016	0.254	*	0.016	0.249	*	0.016	0.247	*	0.016	0.236	*	0.016
L3	0.232	*	0.022	0.234	*	0.022	0.225	*	0.022	0.226	*	0.022	0.217	*	0.022
Switch-from-higher	0.183	*	0.009	0.183	*	0.009	0.183	*	0.009	0.184	*	0.009	0.183	*	0.009
Switch-from-lower	0.257	*	0.01	0.258	*	0.01	0.254	*	0.01	0.255	*	0.01	0.252	*	0.01
IC	0.052	*	0.024	0.043	+	0.023	-		-	-		-	-		-
WM	−0.028		0.023	-		-	−0.014		0.022	-		-	-		-
TS	−0.011		0.02	-		-	-		-	−0.002		0.02	-		-
L2 × Switch-from-higher	0.007		0.013	0.006		0.013	0.007		0.013	0.008		0.013	0.016		0.013
L3 × Switch-from-higher	−0.082	*	0.013	−0.082	*	0.013	−0.083	*	0.013	−0.083	*	0.013	−0.078	*	0.013
L2 × Switch-from-lower	−0.101	*	0.014	−0.103	*	0.014	−0.101	*	0.013	−0.1	*	0.013	−0.093	*	0.013
L3 × Switch-from-lower	−0.156	*	0.014	−0.156	*	0.014	−0.153	*	0.014	−0.153	*	0.014	−0.148	*	0.014
L2 × IC	−0.024	*	0.007	−0.033	*	0.007	-		-	-		-	-		-
L3 × IC	−0.051	*	0.007	−0.045	*	0.006	-		-	-		-	-		-
L2 × WM	−0.014	*	0.006	-		-	−0.015	*	0.006	-		-	-		-
L3 × WM	0.026	*	0.006	-		-	0.015	*	0.006	-		-	-		-
L2 × TS	−0.035	*	0.006	-		-	-		-	−0.036	*	0.006	-		-
L3 × TS	−0.004		0.006	-		-	-		-	−0.013	*	0.006	-		-
Switch-from-higher × IC	0.001		0.01	0.004		0.01	-		-	-		-	-		-
Switch-from-lower × IC	−0.024	*	0.011	−0.019	+	0.011	-		-	-		-	-		-
Switch-from-higher × WM	0.011		0.009	-		-	0.011		0.009	-		-	-		-
Switch-from-lower × WM	0.028	*	0.011	-		-	0.024	*	0.01	-		-	-		-
Switch-from-higher × TS	−0.002		0.008	-		-	-		-	−0.003		0.008	-		-
Switch-from-lower × TS	−0.013		0.01	-		-	-		-	−0.019	*	0.009	-		-
L2 × Switch-from-higher × IC	0.002		0.015	0.009		0.014	-		-	-		-	-		-
L3 × Switch-from-higher × IC	−0.002		0.015	−0.0012		0.014	-		-	-		-	-		-
L2 × Switch-from-lower × IC	0.01		0.015	0.009		0.015	-		-	-		-	-		-
L3 × Switch-from-lower × IC	0.023		0.015	0.02		0.015	-		-	-		-	-		-
L2 × Switch-from-higher × WM	0.018		0.014	-		-	0.016		0.013	-		-	-		-
L3 × Switch-from-higher × WM	0.003		0.014	-		-	0.003		0.013	-		-	-		-
L2 × Switch-from-lower × WM	−0.015		0.014	-		-	−0.016		0.014	-		-	-		-
L3 × Switch-from-lower × WM	−0.013		0.014	-		-	−0.009		0.014	-		-	-		-

Table A1. *Cont.*

Predictor	Final Best-Fitting Model		IC-Only Covariate Model		WM-Only Covariate Model		TS-Only Covariate Model		No Covariate Model	
	Coefficient	***SE***	**Coefficient**	***SE***	**Coefficient**	***SE***	**Coefficient**	***SE***	**Coefficient**	***SE***
L2 × Switch-from-higher × TS	0.018	0.012	-	-	-	-	0.016	0.012	-	-
L3 × Switch-from-higher × TS	0	0.012	-	-	-	-	−0.0008	0.012	-	-
L2 × Switch-from-lower × TS	0.025 +	0.013	-	-	-	-	0.028 *	0.013	-	-
L3 × Switch-from-lower × TS	0.01	0.013	-	-	-	-	0.014	0.013	-	-
Random (varying intercept) components										
Subjects	0.018		0.017		0.02		0.018		0.017	
Items	0.005		0.005		0.01		0.005		0.005	
Residual	0.265		0.071		0.07		0.071		0.071	
Fit statistics										
ML deviance (# of parameters)	4182 (40)		4301 (22)		4455 (22)		4323 (22)		4377 (12)	
AIC; BIC	4530; 4840		4474; 4641		4497; 4664		4497; 4664		4465; 4560	

Note: Inhibitory control (IC). Working memory (WM). Task-switching (TS). *t*-ratio = coefficient/SE, with *t*-ratio values over 2.0 indicating the coefficient is significantly different from zero (Gelman and Hill 2007). Akaike information criterion (AIC). Bayesian information criterion (BIC). * $p < 0.05$. + $p < 0.10$.

References

Abutalebi, Jubin, and David Green. 2008. Control mechanisms in bilingual language production: Neural evidence from language switching studies. *Language and Cognitive Processes* 23: 557–82. [CrossRef]

Abutalebi, Jubin, Stefano Cappa, and Daniela Perani. 2001. The bilingual brain as revealed by functional neuroimaging. *Bilingualism: Language and Cognition* 4: 179–90. [CrossRef]

Anderson, Michael. 2003. Rethinking interference theory: Executive control and the mechanisms of forgetting. *Journal of Memory and Language* 49: 415–45. [CrossRef]

Andrews, Sally. 1997. The effect of orthographic similarity on lexical retrieval: Resolving neighborhood conflicts. *Psychonomic Bulletin and Review* 4: 439–61. [CrossRef]

Andrews, Edna. 2014. *Neuroscience and Multilingualism*. Cambridge: Cambridge University Press.

Antoniou, Mark. 2019. The advantages of bilingualism debate. *Annual Review of Linguistics* 5: 395–415. [CrossRef]

Austin, John. 1975. *How to Do Things with Words*. Oxford: Oxford University Press.

Bates, Douglas, and Martin Maechler. 2010. lme4: Linear Mixed-Effects Models Using S4 Classes. R Package Version 0.999375-36. Available online: http://CRAN.R-project.org/package=lme4 (accessed on 20 December 2019).

Bialystok, Ellen. 2017. The bilingual adaptation: How minds accommodate experience. *Psychological Bulletin* 143: 233–62. [CrossRef] [PubMed]

Bialystok, Ellen, and Fergus Craik. 2010. Cognitive and linguistic processing in the bilingual mind. *Current Directions in Psychological Science* 19: 19–23. [CrossRef]

Bialystok, Ellen, Fergus Craik, Raymound Klein, and Mythili Viswanathan. 2004. Bilingualism, aging, and cognitive control: Evidence from the Simon task. *Psychology and Aging* 19: 290–303. [CrossRef]

Bialystok, Ellen, Fergus Craik, Cheryl Grady, Wilkin Chau, Ryouhei Ishii, Atsuko Gunji, and Christo Pantev. 2005. Effect of bilingualism on cognitive control in the Simon task: Evidence from MEG. *NeuroImage* 24: 40–49. [CrossRef]

Branzi, Francesca, Marco Calabria, Maria Boscarino, and Albert Costa. 2016. On the overlap between bilingual language control and domain-general executive control. *Acta Psychologica* 166: 21–30. [CrossRef]

Braver, Todd, Jeremy Reynolds, and David Donaldson. 2003. Neural mechanisms of transient and sustained cognitive control during task switching. *Neuron* 39: 713–26. [CrossRef]

Bunting, Michael, Nelson Cowan, and J. Scott Saults. 2006. How does running memory span work? *The Quarterly Journal of Experimental Psychology* 59: 1691–700. [CrossRef] [PubMed]

Calabria, Marco, Cristinai Baus, and Albert Costa. 2019. Cross-talk between language and executive control. In *The Handbook of the Neuroscience of Multilingualism*. Edited by John W. Schwieter. Maldon: Wiley, pp. 447–66.

Christoffels, Ingrid, Annette De Groot, and Lourens Waldorp. 2003. Basic skills in a complex task: A graphical model relating memory and lexical retrieval to simultaneous interpreting. *Bilingualism: Language and Cognition* 6: 201–11. [CrossRef]

Colzato, Lorenza, M. Teresa Bajo, Wery van den Wildenberg, Daniela Paolieri, Sander Nieuwenhuis, Wido La Heij, and Bernhard Hommel. 2008. How does bilingualism improve executive control? A comparison of active and reactive inhibition mechanisms. *Journal of Experimental Psychology: Learning, Memory and Cognition* 34: 302–12. [CrossRef]

Costa, Albert, and Mikel Santesteban. 2004. Lexical access in bilingual speech production: Evidence from language switching in highly proficient bilinguals and L2 learners. *Journal of Memory and Language* 50: 491–511. [CrossRef]

Costa, Albert, Michelle Miozzo, and Alfonso Caramazza. 1999. Lexical selection in bilinguals: Do words in the bilinguals' two lexicons compete for selection? *Journal of Memory and Language* 41: 365–97. [CrossRef]

Costa, Albert, Mikel Santesteban, and Iva Ivanova. 2006. How do highly proficient bilinguals control their lexicalization process? Inhibitory and language-specific selection mechanisms are both functional. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 32: 1057–74. [CrossRef]

De Baene, Wouter, Simone Kühn, and Marcel Brass. 2012. Challenging a decade of brain research on task switching: Brain activation in the task-switching paradigm reflects adaptation rather than reconfiguration of task sets. *Human Brain Mapping* 33: 639–51. [CrossRef]

De Bot, Kees. 2008. Review article: The imaging of what in the multilingual mind? *Second Language Research* 24: 111–33. [CrossRef]

De Groot, Annette, and Ingrid Christoffels. 2006. Language control in bilinguals: Monolingual tasks and simultaneous interpreting. *Bilingualism: Language and Cognition* 9: 189–201. [CrossRef]

Declerck, Mathieu, Jonathan Grainger, Iring Koch, and Andrea Philipp. 2017. Is language control just a form of executive control? Evidence for overlapping processes in language switching and task switching. *Journal of Memory and Language* 95: 138–45. [CrossRef]

Dijkstra, Ton, and Walter Van Heuven. 2002. The architecture of the bilingual word recognition system: From identification to decision. *Bilingualism: Language and Cognition* 5: 175–97. [CrossRef]

Engle, Randall. 2002. Working memory capacity as executive attention. *Current Directions in Psychological Science* 11: 19–23. [CrossRef]

Festman, Julia, and Thomas Münte. 2012. Cognitive control in Russian–German bilinguals. *Frontiers in Psychology* 3: 115. [CrossRef]

Festman, Julia, Antoni Rodríguez-Fornells, and Thomas Münte. 2010. Individual differences in control of language interference in late bilinguals are mainly related to general executive abilities. *Behavioral and Brain Functions* 6: 5. [CrossRef]

Friedman, Naomi, and Akira Miyake. 2004. The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology: General* 133: 101–35. [CrossRef]

Garbin, G., Albert Costa, Ana Sanjuan, Cristina Forn, Aina Rodriguez-Pujadas, Noelia Ventura, Vicente Belloch, Mireia Hernandez, and Cesar Ávila. 2011. Neural bases of language switching in high and early proficient bilinguals. *Brain & Language* 119: 129–35.

Gelman, Andrew, and Jennifer Hill. 2007. *Data Analysis Using Regression and Multilevel/Hierarchical Models*. New York: Cambridge University Press.

Green, David. 1998. Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and Cognition* 1: 67–81. [CrossRef]

Grundy, John, and Kalinka Timmer. 2017. Bilingualism and working memory capacity: A comprehensive meta-analysis. *Second Language Research* 33: 325–40. [CrossRef]

Guo, Taomei, Hongyan Liu, Maya Misra, and Judith Kroll. 2011. Local and global inhibition in bilingual word production: fMRI evidence from Chinese-English bilinguals. *NeuroImage* 56: 2300–9. [CrossRef]

Hermans, Daan. 2000. Word Production in a Foreign Language. Doctoral dissertation, University of Nijmegen, Nijmegen, The Netherlands.

Hermans, Daan, Theo Bongaerts, Kees De Bot, and Robert Schreuder. 1998. Producing words in a foreign language: Can speakers prevent interference from their first language? *Bilingualism: Language and Cognition* 1: 213–29. [CrossRef]

Hernandez, Arturo E. 2009. Language switching in the bilingual brain: What's next? *Brain & Language* 109: 133–40.

Hernandez, Arturo, Antigona Martinez, and Kathryn Kohnert. 2000. In search of the language switch: An fMRI study of picture naming in Spanish-English bilinguals. *Brain and Language* 73: 421–31. [CrossRef] [PubMed]

Hernandez, Arturo, Mirella Dapretto, John Mazziotta, and Susan Bookheimer. 2001. Language switching and language representation in Spanish-English Bilinguals: An fMRI study. *Neuroimage* 14: 510–20. [CrossRef] [PubMed]

Hilchey, Matthew, and Raymound Klein. 2011. Are there bilingual advantages on nonlinguistic interference tasks? Implications for the plasticity of executive control processes. *Psychonomic Bulletin and Review* 18: 625–58. [CrossRef] [PubMed]

Jakobson, Roman. 1960. Linguistics and poetics. In *Style in language*. Edited by Thomas Sebeok. Cambridge: MIT Press, pp. 350–77.

Kaushanskaya, Margarita, and Kimberly Crespo. 2019. Does Exposure to Code-Switching Influence Language Performance in Bilingual Children? *Child Development* 90: 708–18. [CrossRef] [PubMed]

Koch, Iring, Miriam Gade, Stefanie Schuch, and Andrea Philipp. 2010. The role of inhibition in task switching: An overview. *Psychonomic Bulletin and Review* 17: 1–14. [CrossRef]

Kornblum, Sylvan, Thierry Hasbroucq, and Allen Osman. 1990. Dimensional overlap: Cognitive basis for stimulus-response compatibility—A model and taxonomy. *Psychological Review* 97: 253–70. [CrossRef]

Kroll, Judith, Erica Michael, Natasha Tokowicz, and Robert Dufour. 2002. The development of lexical fluency in a second language. *Second Language Research* 18: 137–71. [CrossRef]

Kroll, Judith, Susan Bobb, and Zofia Wodniecka. 2006. Language selectivity is the exception, not the rule: Arguments against a fixed locus of language selection in bilingual speech. *Bilingualism: Language and Cognition* 9: 119–35. [CrossRef]

Levelt, Willem. 1989. *Speaking: From Intention to Articulation*. Cambridge: MIT Press.

Levinson, Stephen. 2017. Speech acts. In *The Oxford Handbook of Pragmatics*. Edited by Yan Huang. Oxford: Oxford University Press, pp. 199–216.

Levinson, Stephen. 2018. Spatial cognition, empathy and language evolution. *Studies in Pragmatics* 20: 16–21.

Levy, Benjamin, and Michael Anderson. 2002. Inhibitory processes and the control of memory retrieval. *Trends in Cognitive Sciences* 6: 299–305. [CrossRef]

Levy, Benjamin, Nathan McVeigh, Alejandra Marful, and Michael Anderson. 2007. Inhibiting your native language: The role of retrieval-induced forgetting during second-language acquisition. *Psychological Science* 18: 29–34. [CrossRef] [PubMed]

Linck, Jared, John W. Schwieter, and Gretchen Sunderman. 2012. Inhibitory control predicts language switching performance in trilingual speech production. *Bilingualism: Language and Cognition* 15: 651–62. [CrossRef]

Liu, Cong, Chin-Lung Yang, Lu Jiao, John W. Schwieter, Xun Sun, and Ruiming Wang. 2019. Training in language switching facilitates bilinguals' monitoring and inhibitory control. *Frontiers in Psychology* 10: 1–13. [CrossRef] [PubMed]

Lotman, Yuri. 1990. *Universe of the Mind: A Semiotic Theory of Culture*. London: I.B. Tauris.

Mayr, Ulrich, and Steven Keele. 2000. Changing internal constraints on action: The role of backward inhibition. *Journal of Experimental Psychology: General* 129: 4–26. [CrossRef]

Meuter, Renata, and Alan Allport. 1999. Bilingual language switching in naming: Asymmetrical costs of language selection. *Journal of Memory and Language* 40: 25–40. [CrossRef]

Morales, Luis, Daniela Paolieri, and M. Teresa Bajo. 2011. Grammatical gender inhibition in bilinguals. *Frontiers in Psychology* 2: 284. [CrossRef]

Price, Cathy J., David W. Green, and Roswitha Von Studnitz. 1999. A functional imaging study of translation and language switching. *Brain* 122: 2221–35. [CrossRef]

Prior, Anat, and Tamar Gollan. 2011. Good language-switchers are good task-switchers: Evidence from Spanish–English and Mandarin–English bilinguals. *Journal of the International Neuropsychological Society* 17: 682–91. [CrossRef]

Prior, Anat, and Tamar Gollan. 2013. The elusive link between language control and executive control: A case of limited transfer. *Journal of Cognitive Psychology* 25: 622–45. [CrossRef] [PubMed]

R development core team. 2010. *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing. Available online: http://www.R-project.org (accessed on 20 December 2019).

Raudenbush, Stephen, and Anthony Bryk. 2002. *Hierarchical Linear Models: Applications and Data Analysis Methods*. Thousand Oaks: Sage.

Runnqvist, Elin, and Albert Costa. 2012. Is retrieval-induced forgetting behind the bilingual disadvantage in word production? *Bilingualism: Language and Cognition* 15: 365–77. [CrossRef]

Schwieter, John W. 2019. *The Handbook of the Neuroscience of Multilingualism*. Malden and Oxford: Wiley-Blackwell.

Schwieter, John W., and Gretchen Sunderman. 2008. Language switching in bilingual speech production: In search of the language-specific selection mechanism. *The Mental Lexicon* 3: 214–38. [CrossRef]

Schwieter, John W., and Gretchen Sunderman. 2009. Concept selection and developmental effects in bilingual speech production. *Language Learning* 59: 897–927. [CrossRef]

Schwieter, John W., and Gretchen Sunderman. 2011. Inhibitory control processes and lexical access in trilingual speech production. *Linguistic Approaches to Bilingualism* 1: 391–412. [CrossRef]

Searle, John. 1969. *Speech Acts*. Cambridge: Cambridge University Press.

Segal, Dorit, Alena Stasenko, and Tamar Gollan. 2019. More evidence that a switch is not a switch: Binning bilinguals reveals dissociations between task and language switching. *Journal of Experimental Psychology* 148: 501–19. [CrossRef]

Simon, J. Richard, and Alan Rudell. 1967. Auditory S-R compatibility: The effect of an irrelevant cue on information processing. *Journal of Applied Psychology* 51: 300–4. [CrossRef]

Snodgrass, Joan, and Mary Vanderwart. 1980. A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory* 6: 174–215. [CrossRef]

Timmer, Kalinka, Marco Calabria, and Albert Costa. 2019. Non-linguistic effects of language switching training. *Cognition* 182: 14–24. [CrossRef]

Vygotsky, Lev. 1962. *Thought and Language*. Cambridge: MIT Press.

Wiseheart, Melody, Mythili Viswanathan, and Ellen Bialystok. 2016. Flexibility in task switching by monolinguals and bilinguals. *Bilingualism: Language and Cognition* 19: 141–46. [CrossRef]