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RESEARCH NOTE

Increased processing speed in young adult bilinguals: evidence from source memory judgments*

ANGELA GRANT
Department of Psychology, The Pennsylvania State University
NANCY DENNIS
Department of Psychology, The Pennsylvania State University

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Although many studies have investigated the consequences of bilingualism on cognitive control, few have examined the impact of bilingualism on other cognitive domains, such as memory. Of these studies, most have focused on item memory and none have examined the role of bilingualism in source memory (i.e., the memory for contextual details from a previous encounter with a stimulus). In our study, young adult bilinguals and monolinguals completed a source memory test, whose different conditions were designed to stress working memory and inhibitory control. Bilinguals performed significantly faster than monolinguals across all conditions without compromising accuracy, and also showed an overall speed advantage on the Flanker task. We interpret these processing speed advantages within the context of current models of bilingual production.

Keywords: Bilingualism, processing speed, source memory, inhibitory control

Introduction

With the recent growth of bilingualism research many studies have suggested that bilingualism benefits non-linguistic task performance. Specifically, bilingualism has been associated with differential performance on a variety of executive control tasks, including the Attention Network Test (ANT; Pelham & Abrams, 2014; Tao, Marzecová, Taft, Asanowicz & Wodniecka, 2011), Simon (Bialystok, Craik, Klein & Viswanathan, 2004; Bialystok, Craik & Luk, 2008), and Stroop (Bialystok et al., 2008; Coderre, Van Heuven & Conklin, 2013) wherein bilinguals have shown smaller effects of conflict, as measured by reduced reaction time, across these tasks. These findings have recently come under scrutiny (e.g., Paap, Johnson & Sawi, 2015; Duñabeitia, Hernández, Antón, Macizo, Estévez, Fuentes & Carreiras, 2014), with multiple studies failing to replicate previous results (e.g., Paap & Greenberg, 2013; but see Zhou & Krott, published online November 25, 2015, on the effects of data trimming) and calls for better cognitive models of the relationship between non-linguistic function and bilingualism (Paap, Johnson & Sawi, 2016). However, these calls fail to recognize the potential of bilingualism as a transdisciplinary field, where investigators from different disciplines work together to create new theories that move beyond discipline-specific approaches. It is only by continuing to investigate that we can begin to develop theories that account for the effects of bilingualism.

While the behavioral advantages associated with bilingualism were initially attributed specifically to improved inhibitory control, more recent theories have suggested that the variety of potential bilingual experiences may result in differing effects on brain and behavior (e.g., Bialystok & Barac, 2013; Green & Abutalebi, 2013; see Macnamara & Conway, 2014, for a longitudinal demonstration of the effects of changing bilingual demands on cognitive control and working memory). This interpretation is based partially on data showing bilinguals' improved reaction time on tests of inhibitory control is not limited to conflict trials (e.g., Hilchey & Klein, 2011; but see Hilchey, Saint-Aubin & Klein, 2015, for a review of recent issues replicating these findings) and data showing enhanced accuracy in other domains, such as spatial working memory (verbal working memory tasks typically elicit no effect or a bilingual disadvantage, due to lexical interference; Bialystok, Craik, Green & Gollan, 2009; Luo, Craik, Moreno & Bialystok, 2013).

Executive control processes, however, do not operate in a vacuum. These processes interact with other daily cognitive tasks, such as encoding and retrieval. Consequently, researchers have begun to examine the effect of bilingualism on memory as well. One of the first studies in this area examined the performance of

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Address for Correspondence:
Angela Grant, 454 Moore Building, Department of Psychology, University Park, PA 16802, USA
amc497@psu.edu

younger (M = 20.5 years) and older (M = 70.1 years) monolinguals and bilinguals on a free recall task. The stimuli were presented auditorily, and the investigators found that both older age and bilingualism were associated with lower recall scores (Fernandes, Craik, Bialystok & Kreuger, 2007). Since then, however, studies examining bilingual memory have shown more positive effects of bilingualism (Ljungberg Hansson, Andrés, Josefsson & Nilsson, 2013; Schroeder & Marian, 2012; Wodniecka, Craik, Luo & Bialystok, 2010). For example, Wodniecka and colleagues (2010) found that older (M = 70.8 years, averaged across both experiments) bilinguals were advantaged at non-verbal recollection, although only at the longest lag. Schroeder and Marian (2012) found a similar bilingual advantage in older (M = 80.8 years) adults in a recall test. Additionally, they showed that recall performance was positively correlated with a reaction time advantage on the Simon task, suggesting a relationship between the advantage bilinguals experience in episodic memory and executive control. Ljungberg and colleagues (2013), who examined episodic memory in 178 older (M = 49.9 years at baseline, participants were followed for 20 years) bilinguals and monolinguals, presented further supporting evidence. Their analyses found that bilinguals were significantly advantaged on the episodic recall tasks, while a similar advantage was found for letter, but not category, fluency. Letter fluency is commonly thought to require more executive control skill compared with category fluency (see Martin, Wiggs, Lalonde & Mack, 1994), and consequently the authors interpreted these results as supporting the notion that executive control advantages are related to advantages in episodic memory.

To summarize, the majority of previous work examining the effects of bilingualism on episodic memory found positive effects in older adults that were related to executive functioning. However, many of these studies either did not test or did not find effects in younger adults. One possible reason for this is that the item memory tasks used in the aforementioned studies were not difficult enough to tap into the differences between young bilinguals and monolinguals (Costa, Hernández, Costa-Faidella & Sebastián-Gallés, 2009). To test this notion we sought to examine the effect of bilingualism on memory performance using a relatively difficult source memory task that would recruit executive control. In the typical source memory task, individuals are asked to retrieve not simply whether an item was presented previously, but in what context the item previously appeared (e.g., location or color of a word). Consequently, it has been argued that source memory is more difficult than item memory as it cannot rely on familiarity, but requires recollection and monitoring processes beyond that which is required for item memory (Johnson, Hashtroudi & Lindsay, 1993; Mitchell & Johnson, 2009; Schacter, Harbluk & McLachlan, 1984; Shimamura & Squire, 1991; Spaniol & Grady, 2012).

Given the previous literature on executive functioning in bilinguals, we predicted that bilinguals would be advantaged at a source memory task in comparison with monolinguals. Furthermore, given the difficulty of the task, one might expect that this advantage would present in young bilinguals, as task difficulty has been identified as one of the key factors affecting the ability to observe differences between bilinguals and monolinguals (Costa et al., 2009). Consequently, we hypothesized that bilinguals should show improved performance on a test of source memory and that this advantage would increase as task difficulty and hence the need for executive functioning increased. More specifically, we hypothesized that this bilingual advantage would be related to their inhibitory control and/or working memory abilities. To test this, we developed a source memory task that specifically manipulated these factors (based on a task by Yubero, Gil, Paul & Maestú, 2011; see the Methods section). If the effect of bilingualism was due to one or another of these factors, then we expected to find an interaction between language group and condition of the source memory task. Alternatively, improved bilingual performance across conditions would indicate a general effect of bilingualism, which would be congruent with current findings in the neuroimaging literature that bilinguals show differential function and structure across the brain, and not only in structures associated with executive control (e.g., Grant, Dennis & Li, 2014; Hervais-Adelman, Moser-Mercer & Golestani, 2011; Li, Legault & Litcofsky, 2014). Equal performance, or a monolingual advantage, would not be predicted by current theories of bilingual language production and cognitive control, and would instead add to the literature suggesting that the effect of bilingualism on cognitive control is limited (de Bruin, Treccani & Della Sala, 2015; Paap et al., 2015).

Methods

Participants

English monolingual participants (19 female, 6 male) and bilingual participants (20 female, 6 male) completed the experiment. Participants were recruited from the Penn State Psychology subject pool and compensated with course credit. Participants' ages ranged from 18 to 26. Participants were divided into language groups post hoc based on their self-ratings of their bilingual status and proficiency in their L2. Participants whose average L2 proficiency across reading, writing, listening, and speaking was at least 5 out of 7 were admitted to the bilingual group. Participants who considered themselves monolingual or rated their L2 proficiency as less than 4 out of 7 were admitted to the monolingual group. Participants

Table 1. *Means (SD) of participants' language background measures.*

	Monolingual	Bilingual
English Proficiency[1]	0.73 (.08)	0.69 (.08)
Hours of L2 use per day*	0.25 (.70)	5.55 (4.44)
Self-rated L2 Proficiency*[2]	2.25 (1.51)	5.85 (.66)

[1]Scores represent accuracy on the PPVT. [2]Scale ranged from 1 to 7: 1 = Not at all proficient, 7 = Native-like. *Asterisks represent a significant difference between groups.

whose average L2 proficiency did not fit into one of these groups were excluded from analysis (5 participants, for a final sample of 20 monolingual participants, 16 female, 4 male). Among the bilingual group, 35% of the participants reported English as their first language (L1). Other L1s included Chinese, Korean, Czech, Nepali, Thai, Polish, Malayalam, Spanish, Hebrew, and Russian. L2s included English, Spanish, French, German, Malay and Hungarian. Among the monolingual group, participants reported taking Spanish, German, French and Latin. There was no significant difference between the Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 1997) scores of the bilinguals and monolinguals, indicating high English proficiency in both groups (see Table 1). Bilinguals, however, reported both significantly higher L2 proficiency (t (44) = 9.176 equal variances not assumed, $p < .001$) and significantly more time spent using the L2 than monolinguals (t (44) = 5.521 equal variances not assumed, $p < .001$).

Materials

Background tasks

In addition to our source memory task (described below), participants also completed several tasks measuring their language abilities and general cognitive functioning. English language ability was measured using the Peabody Picture Vocabulary Test, a normalized test of English vocabulary (Dunn & Dunn, 1997). In this task, participants hear a word while viewing four pictures and then identify which picture represents the word. Item memory was assessed with the Logical Memory I task (Glisky, Rubin & Davidson, 2001). In this task, participants hear two stories, one of which is repeated, and then are asked to recite the story as closely as possible. Their recitation was scored for details, and scores from this test were normalized using the WMS-III scoring guide (Wechsler, 1997b).

Working memory was assessed using two tasks. The letter-number sequencing (LNS) task requires participants to listen to a string of numbers and letters, repeating back each by providing the numbers followed by letters, in ascending order (Wechsler, 1997a). The spatial span task requires participants to observe a spatial tapping pattern on a board with raised tiles and then replicate that pattern. Participants first complete the task with sequences of increasing length in the forward direction, and then in the backward direction (Wechsler, 1997a).

Inhibitory control was assessed using the Flanker task (adapted from Emmorey, Luk, Pyers & Bialystok, 2008). In this task participants complete three types of blocked tasks: control blocks, Go-Nogo blocks, and conflict blocks. In control blocks, participants see one arrow and are asked to identify its direction. In Go-Nogo blocks, the arrow is flanked by either diamonds (Go trials) or Xs (Nogo trials). In conflict blocks the center arrow is flanked by five arrows, which may be in the same direction (congruent trials) or a conflicting direction (incongruent trials). In addition, participants completed a mixed block with conflict and Go-Nogo trials. This task allows for the calculation of the classic Flanker effect, by subtracting the reaction time to congruent trials (where all arrows face the same direction) from incongruent trials (where the flanking arrows face the opposite direction) in the conflict block. In addition, we are able to compute mixing costs by subtracting the RTs to Go, congruent, and incongruent trials in single blocks from the RTs to those same trial types in the mixed block.

Experimental task

Our source memory task (SMT) was adapted from Yubero and colleagues (2011) to manipulate category membership and source difficulty in order to emphasize the need for inhibitory control and working memory, respectively. Each stimulus consisted of an image of a concrete object set on a colored background. The category membership of the object and the number of background colors presented to the participant during each encoding block were factorially manipulated, so that we had four conditions: Same Category(SC)/10 Colors (10Diff), SC/2 Colors (2Diff), Different Categories (DC)/10Diff, and DC/2Diff. In the inhibitory control stress (SC) conditions, the objects shown in a block were members of the same category (e.g., cameras), as remembering many exemplars from a single category requires the participant to inhibit the categorical gist in order to encode individual details to be used at retrieval (see Levy & Anderson (2002) for a review of established paradigms, such as retrieval-induced forgetting and the think/no-think paradigm, that use category membership as a manipulation of inhibition). In the DC condition, each object came from a different category (e.g., camera, fork, butterfly, etc). We paired this manipulation with a manipulation of the number of background colors presented during a block, as many current standardized measures of working memory, such as Digit Span and the Letter-Number Sequencing task (Wechsler, 1997a), all increase the number of items

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in order to test working memory. In the high working memory stress conditions (10Diff), participants were exposed to a unique background color for each trial and in the low working memory stress conditions (2Diff), participants were exposed to only two background colors during the block.

Procedure

Participants gave their consent and completed a language history questionnaire (Li, Zhang, Tsai, & Puls, 2014), the PPVT, source memory task, strategy questionnaire, Flanker task, the Letter-Number Sequencing task and two measures from the Wechsler Memory Scale-III: Logical Memory I and Spatial Span, both forwards and backwards. Participants completed the SMT as described below.

In the SMT participants completed 8 encoding blocks (2 from each condition), each followed by a recognition block. Each encoding block consisted of 10 trials and each trial was presented for 3 seconds in the center of the computer screen. Recognition blocks consisted of 12 items: 6 targets or previously seen items, 4 distractor items that consisted of a previously seen object with a different background color, and 2 completely new items (presented on a colored background that was shown in the preceding encoding block). Presentation of block order was pseudorandomly distributed such that blocks of the same condition did not occur consecutively. During encoding, participants were asked to remember the picture and the background color. During retrieval, they made old/new recognition judgments to each item/source pair, and then rated their confidence on a 1–7 Likert scale from *not at all confident* to *highly confident*. After completing the task, participants completed a strategy questionnaire that asked them to indicate if they had used any of the following strategies (or a combination thereof) while completing the SMT: passive viewing/no strategy, repetition, sentence generation, imagery, meaningful grouping, or another strategy.

Results

We used a mixed repeated measures ANOVA as implemented in SPSS 22 (IBM Corp., 2013) to analyze the data from our SMT and assess the influence of both Memory Condition and Language Background on median reaction time (RT), as well as accuracy. The RT model showed a significant main effect of Condition $F(3,44) = 68.06$, $p < .001$, as well as Language Background $F(1,44) = 6.316$, $p = .016$. The main effect of Condition was characterized by slower RTs during the conditions that stressed working memory (DC/10Diff) and inhibitory control (SC/2Diff), as well as the combined (SC/10Diff) condition. The RT results are summarized in Figure 1. Results show that the bilinguals were significantly faster than the monolinguals across all conditions.

In contrast to these dramatic group differences in RT, the accuracy results show that despite the varying difficulty, participants in both groups maintained high accuracy across all conditions of the SMT. In the mixed repeated measures ANOVA assessing accuracy, only Condition exhibited a significant main effect ($F(3, 44) = 26.24$, $p < .001$) although the effect of Language Background exhibited a marginal effect ($F(3,44) = 3.56$, $p = .066$). The accuracy results are summarized in Figure 2.

In addition to the analysis of the source memory data, we also examined the effect of Language Background on flanker task performance. Our a priori hypothesis was that there would be a difference in the flanker effect between the two groups, but we did not observe this (t $(44) = 1.304$, $p = .201$), and we also did not observe an effect of language background on the mixing cost data ($F(2, 44) = 1.828$, $p = .183$) which we analyzed using a 3 (Congruent, Incongruent, Go) x 2 (Monolingual, Bilingual) ANOVA. We further investigated overall task performance using a 2 (Congruent, Incongruent) x 2 (Monolingual, Bilingual) mixed repeated measures ANOVA. That analysis revealed significant main effects of both Trial Type ($F(1,44) = 180.41$, $p < .001$) and Language Background ($F(1,44) = 4.63$, $p = .037$) such that bilinguals were significantly faster than monolinguals during conflict blocks (see Table 2 for details and Figure 3 for an illustration).

In order to assess the extent to which our cognitive measures related to their associated conditions (e.g., the Flanker task with the SC condition) in the SMT, we correlated the scores on the relevant cognitive measure with the accuracy and RT across each of the relevant SMT conditions, using a Bonferroni correction for multiple comparisons. If we first consider our tests of working memory, the LNS and spatial span tasks, we observe that RT performance on the SC/10Diff condition (stressing working memory and inhibitory control) of our source memory task was positively correlated with RT in the LNS task ($R = .411$, $p = .005$). The results for the DC/10Diff condition (stressing only working memory) and the accuracy data were trending but did not survive correction. In addition, we did not observe any significant correlations between participants' spatial span and their source memory performance. We also examined the relationship between our measure of inhibitory control, the Flanker task, and the relevant conditions of our task, but there were no significant relationships. Our test of item memory, the Logical Memory task, also did not correlate with source memory performance, and we observed no between groups differences for this task (t $(44) = 1.573$, $p = .124$).

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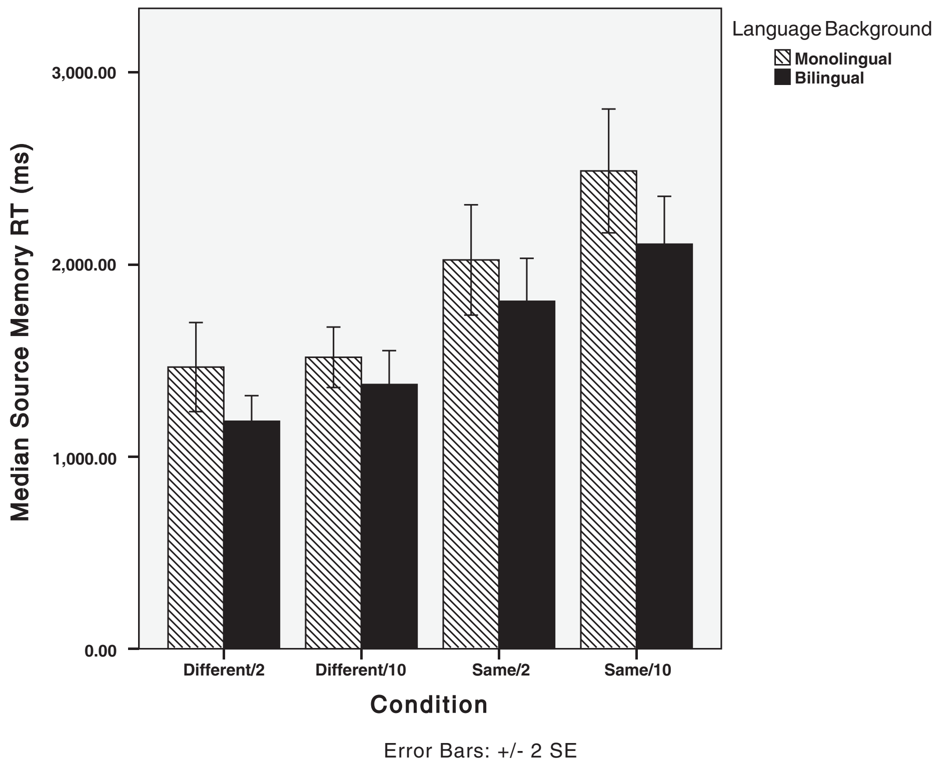

Figure 1. Median Reaction Time on the Source Memory Task for Monolinguals and Bilinguals. Error bars represent standard error.

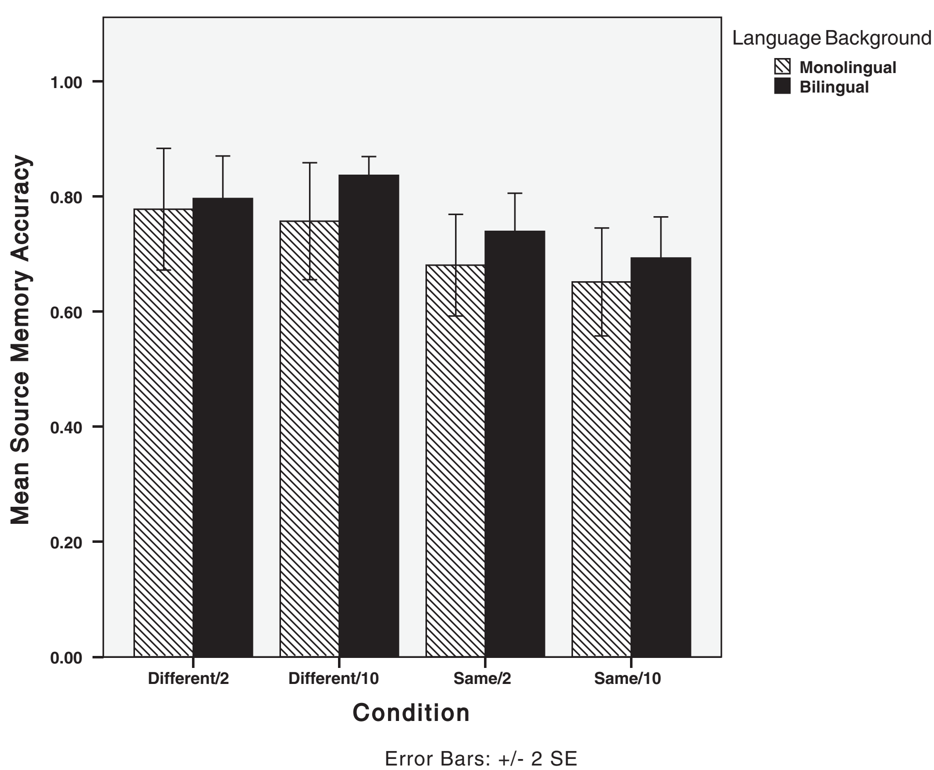

Figure 2. Mean Accuracy on the Source Memory Task for Monolinguals and Bilinguals. Error bars represent standard error.

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Table 2. *Means (SD) of memory and inhibitory control performance.*

	Monolingual		Bilingual	
	ACC	RT in ms	ACC	RT in ms
Strategy Use[1]	2.26 (1.30)		2.36 (1.09)	
Flanker Effect[2]		55.26 (27.35)		66.03 (26.12)
Congruent	97.22 (4.68)	478.31* (71.41)	99.37 (1.90)	426.82* (58.14)
Incongruent	91.81 (8.52)	533.57* (71.78)	91.16 (7.93)	492.84* (53.89)
Letter-Number Sequencing	0.46 (0.16)	11650.26 (4568.10)	0.43 (0.20)	9938.63 (3237.44)
Logical Memory I	37.80 (9.20)	N/A	33.08 (9.84)	N/A
Spatial Span Forward	9.89 (2.24)	N/A	9.32 (1.79)	N/A
Spatial Span Backward	9.67(3.13)	N/A	8.00 (1.70)	N/A

[1]Scores represent an average number of strategies used, rather than accuracy or reaction time. [2]The first row for the Flanker task shows the Flanker effect, whereas the second and third rows show the results on individual trial types. Smaller Flanker effects represent better performance. *Asterisks represent a significant difference between groups.

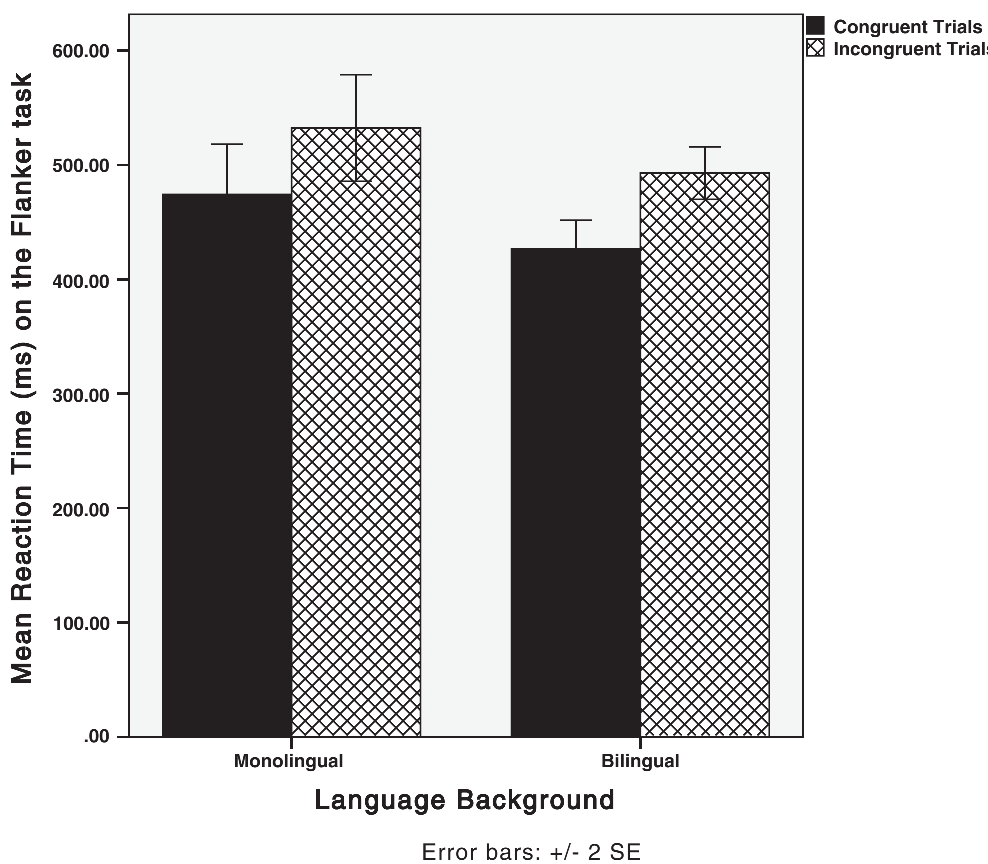

Figure 3. Mean Reaction Time on the Flanker Task for Monolinguals and Bilinguals. Error bars represent standard error.

Discussion

This study is the first to examine the influence of bilingualism on source memory. Specifically, our results show that bilinguals make faster source memory decisions than monolinguals, without compromising accuracy. Furthermore, this speed benefit occurs across each of the conditions of our task, suggesting that the effect of bilingualism is ubiquitous in the SMT and not limited to conditions emphasizing inhibitory control.

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When we consider these results in the context of our original hypotheses, our findings are congruent with a general effect of bilingualism, as opposed to an effect specifically tied to inhibitory control or working memory processes. This general effect of bilingualism is congruent with current findings in the neuroimaging literature that show, compared to monolinguals, bilinguals exhibit both widespread functional and structural differences that are not isolated to structures associated with executive control (e.g., Grant et al., 2014; Hervais-Adelman et al., 2011; Li et al., 2014a). Furthermore, the overarching nature of the observed RT difference, especially in the absence of accuracy differences between groups, is congruent with current approaches that view bilingual experience as a source of general neuroplasticity rather than an 'advantage' over monolinguals (Baum & Titone, 2014).

Our analysis of the Flanker task supports this assertion. We, like others in the field (see Hilchey & Klein, 2011) did not observe a difference in the size of the Flanker effect between monolinguals and bilinguals. However, we did observe significant differences between these groups in overall speed, such that bilinguals were generally faster than monolinguals for both congruent and incongruent trials, a finding that is congruent with the bilingual executive processing advantage (BEPA) hypothesis, if not the bilingual inhibitory control advantage (BICA) hypothesis. However, given the overall lack of replication of the BEPA effect since 2011 (Hilchey et al., 2015), we question the value of this explanation. An alternative possibility is that the advantage we observe is due to improved processing speed, rather than executive control.

Processing speed, like executive control, improves during development and deteriorates during aging, and while its effects may overlap with those associated with inhibition and working memory, it has also been shown to be functionally distinct from those processes (Albinet, Boucard, Bouquet & Audiffren, 2012; Kail & Salthouse, 1994; McAuley & White, 2011). Furthermore, processing speed can also affect non-speeded processes, such as memory (e.g., McCabe, Roediger, McDaniel, Balota & Hambrick, 2010; Perrotin, Isingrini, Souchay, Clarys & Taconnat, 2006). This pattern is largely congruent with the current literature investigating the cognitive effects of bilingualism, in that results are more robust in children and older adults and have extended beyond inhibition into working and episodic memory. Surprisingly, only one published study that we are aware of (Bonifacci, Giombini, Bellochi & Contento, 2011) has specifically investigated processing speed, but even this study did not use a standardized measure of processing speed. Another, more recent, study by Blumenfeld, Schroeder, Bobb, Freeman and Marian (2016) administered a word recognition and Stroop task to younger and older monolinguals and bilinguals, and used the overall response times on these tasks to index processing speed. They found that some effects, such as residual target activation and competitor inhibition, showed between group differences even after controlling for processing speed, but others such as target activation were influenced by differences in processing speed between the groups. Understanding how bilingualism may affect processing speed and how those effects may relate to cognitive control represents an important area for future research. Given that measures of processing speed share some – but not all – variance with traditional inhibitory control measures, it is possible that some of the replication issues in the current bilingualism literature may be due to the focus on inhibition and executive control, rather than processing speed more generally.

Of course, there are reasons to focus on inhibition, the largest being that many models of bilingual language processing suggest that bilinguals use inhibition to control activation of the unintended language. This reasoning neglects, however, the fact that many of these very same models also involve increasing the activation of the intended language (e.g., the BIA+ and the Inhibitory Control model; Dijkstra & Van Heuven, 2002; Green, 1998). A focus on the language activation aspect of language selection is relevant because current models of action selection (e.g., Verbruggen, McClaren & Chambers, 2014) suggest that action selection and control can be modeled as a competitive process wherein one response is selected over another based on the rate at which accumulating information for each option reaches an action threshold. This idea of accumulating information in the action selection literature is analogous to the idea of activation in the language selection literature, and consequently processing speed may be a relevant factor in the success of language selection.

While our results cannot speak to this hypothesis directly, as we did not administer standard measures of processing speed, future research should investigate this possibility. Our results are a first step towards understanding the effects of bilingual experience on source memory and other complex memory tasks. While we did not see an interaction between complexity and language group in our data, we did observe that the effect of bilingualism was limited to the source memory task, and not the item memory task. This pattern of results is congruent with studies finding that processing speed is critical for estimating task complexity effects in both young and older adults (Oberauer & Kliegel, 2001; Rodríguez-Villagra, Göthe, Oberauer & Kliegel, 2013).

Another avenue for future research could investigate the relationship between bilingualism, processing speed, and white matter. Previous research has shown that increased myelination, which speeds neural communication, is related to processing speed throughout the lifespan (Chevalier, Kurth, Doucette, Wiseheart,

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Deoni, Dean, O'Muircheartaigh, Blackwell, Munakata & LeBourgeois, 2015; Ferrer, Whitaker, Steele, Green, Wendelken & Bunge, 2013; Penke, Maniega, Murray, Gow, Valdes Hernandez, Clayden, Starr, Wardlaw, Bastin & Deary, 2010; Peters, Ikuta, Derosse, John, Burdick, Gruner, Prendergast, Szeszko & Malhotra, 2014). In addition, previous research has observed increased white matter integrity in bilingual populations (see García-Pentón, Fernández García, Costello, Duñabeitia & Carreiras, 2015, for a review). Investigating the neural mechanism behind our results has the potential for immense practical importance, as a speed advantage in youth could translate to reduced slowing in old age, and consequently preserved cognitive functions (see Kail & Salthouse, 1994, for the role of cognitive slowing in aging; Alladi, Bak, Duggirala, Surampudi, Shailaja, Shukla, Chaudhuri & Kaul, 2013, for preserved cognitive functions in older bilinguals). An important step to develop this line of research would be to replicate this study in older adults, as one might expect that the RT difference we observed may be enhanced in aging, where source memory shows substantial age-related decline in monolinguals (e.g., Naveh-Benjamin, 2000).

To review, this study is the first to examine the effect of bilingualism in source memory. Our results showed that young adult bilinguals are able to make source memory judgments more quickly than their monolingual peers without compromising accuracy, and this overall speed advantage was also evident in our results from the Flanker task. These results support previous research suggesting that the effects of bilingualism are both widespread and multi-faceted, and may inspire a new research direction into the relationship between bilingualism and processing speed.

References

Albinet, C. T., Boucard, G., Bouquet, C. A., & Audiffren, M. (2012). Processing speed and executive functions in cognitive aging: How to disentangle their mutual relationship? *Brain and Cognition, 79,* 1–11. doi:10.1016/j.bandc.2012.02.001

Alladi, S., Bak, T. H., Duggirala, V., Surampudi, B., Shailaja, M., Shukla, A. K., Chaudhuri, J.R., & Kaul, S. (2013). Bilingualism delays age at onset of dementia, independent of education and immigration status. *Neurology, 82,* 1938–1944. doi:10.1212/WNL.0000000000000400

Baum, S., & Titone, D. (2014). Moving toward a neuroplasticity view of bilingualism, executive control, and aging. *Applied Psycholinguistics, 35,* 857–894. doi:10.1017/S0142716414000174

Bialystok, E., & Barac, R. (2013). Cognitive effects. In P. Li & F. Grosjean (eds.) *The Psycholinguistics of Bilingualism*, pp. 193–213. Malden, MA: Wiley-Blackwell

Bialystok, E., Craik, F., & Luk, G. (2008). Cognitive control and lexical access in younger and older bilinguals. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 34,* 859–73. doi:10.1037/0278-7393.34.4.859

Bialystok, E., Craik, F. I. M., Klein, R., & Viswanathan, M. (2004). Bilingualism, aging, and cognitive control: evidence from the Simon task. *Psychology and Aging, 19,* 290–303. doi:10.1037/0882-7974.19.2.290s

Bialystok, E., Craik, F. I. M., Green, D. W., & Gollan, T. H. (2009). Bilingual Minds. *Psychological Science in the Public Interest, 10,* 89–129. doi:10.1177/1529100610387084

Blumenfeld, K. H., Schroeder, S., Bobb, S.C., Freeman, M., & Marian, V. (2016). Auditory word recognition across the lifespan: Links between linguistic and nonlinguistic inhibitory control in bilinguals and monolinguals. *Linguistic Approaches to Bilingualism, 6,* 119–146. doi:10.1075/lab.14030.blu

Bonifacci, P., Giombini, L., Bellocchi, S., & Contento, S. (2011). Speed of processing, anticipation, inhibition and working memory in bilinguals. *Developmental Science, 14,* 256–269. doi:10.1111/j.1467-7687.2010.00974.x

Chevalier, N., Kurth, S., Doucette, M. R., Wiseheart, M., Deoni, S. C. L., Dean, D. C., O'Muircheartaigh, J., Blackwell, K.A., Munakata, Y., & LeBourgeois, M. K. (2015). Myelination is associated with processing speed in early childhood: Preliminary insights. *PLoS ONE, 10,* 1–14. doi:10.1371/journal.pone.0139897

Coderre, E. L., van Heuven, W. J. B., & Conklin, K. (2013). The timing and magnitude of Stroop interference and facilitation in monolinguals and bilinguals. *Bilingualism: Language and Cognition, 16,* 420–441. doi:10.1017/S1366728912000405

Costa, A., Hernández, M., Costa-Faidella, J., & Sebastián-Gallés, N. (2009). On the bilingual advantage in conflict processing: now you see it, now you don't. *Cognition, 113,* 135–49. doi:10.1016/j.cognition.2009.08.001

de Bruin, A., Treccani, B., & Della Sala, S. (2015). Cognitive advantage in bilingualism: An example of publication bias. *Psychological Science, 26,* 99–107.

Dijkstra, T., & van Heuven, W. J. B. (2002). The architecture of the bilingual word recognition system: From identification to decision. *Bilingualism: Language and Cognition, 5,* 175–197. doi:10.1017/S1366728902003012

Duñabeitia, J. A., Hernández, J. A., Antón, E., Macizo, P., Estévez, A., Fuentes, L. J., & Carreiras, M. (2014). The inhibitory advantage in bilingual children revisited. *Experimental psychology, 61,* 234–51. doi:10.1027/1618-3169/a000243.

Dunn, L. M., & Dunn, L. M. (1997). *Peabody Picture Vocabulary Test*, 3rd ed. Circle Pines: AGS Publishing.

Emmorey, K., Luk, G., Pyers, J. E., & Bialystok, E. (2008). The source of enhanced cognitive control in bilinguals: evidence from bimodal bilinguals. *Psychological Science, 19,* 1201–6. doi:10.1111/j.1467-9280.2008.02224.x

Fernandes, M. A., Craik, F., Bialystok, E., & Kreuger, S. (2007). Effects of bilingualism, aging, and semantic relatedness on memory under divided attention. *Canadian Journal of Experimental Psychology, 61,* 128–41.

Ferrer, E., Whitaker, K. J., Steele, J. S., Green, C. T., Wendelken, C., & Bunge, S. A. (2013). White matter maturation supports the development of reasoning ability through its influence on processing speed. *Developmental Science, 16,* 941–951. doi:10.1111/desc.12088

García-Pentón, L., Fernández García, Y., Costello, B., Duñabeitia, J. A., & Carreiras, M. (2015). The neuroanatomy of bilingualism: how to turn a hazy view into the full picture. *Language, Cognition and Neuroscience, 3798,* 1–25. doi:10.1080/23273798.2015.1068944

Glisky, E. L., Rubin, S. R., & Davidson, P. S. R. (2001). Source Memory in Older Adults: An Encoding or Retrieval Problem?. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27,* 1131–1146. doi:10.1037//0278-7393.27.5.1131

Grant, A., Dennis, N. A., & Li, P. (2014). Cognitive control, cognitive reserve, and memory in the aging bilingual brain. *Frontiers in Psychology, 5,* 1–10. doi:10.3389/fpsyg.2014.01401

Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and cognition, 1,* 67–81.

Green, D. W., & Abutalebi, J. (2013). Language control in bilinguals: The adaptive control hypothesis. *Journal of Cognitive Psychology, 25,* 515–530. doi:10.1080/20445911.2013.796377

Hervais-Adelman, A. G., Moser-Mercer, B., & Golestani, N. (2011). Executive control of language in the bilingual brain: integrating the evidence from neuroimaging to neuropsychology. *Frontiers in Psychology, 2,* 1–8. doi:10.3389/fpsyg.2011.00234

Hilchey, M. D., & Klein, R. M. (2011). Are there bilingual advantages on nonlinguistic interference tasks? Implications for the plasticity of executive control processes. *Psychonomic Bulletin & Review, 18,* 625–58. doi:10.3758/s13423-011-0116-7

Hilchey, M. D., Saint-Aubin, J., & Klein, R. M. (2015) Does bilingual exercise enhance cognitive fitness in traditional non-linguistic executive processing tasks? In J. Schwieter (ed.) *The Cambridge Handbook of Bilingual Processing*. pp. 586–613. Cambridge: Cambridge University Press. doi:10.1007/s00221-015-4439-x

IBM Corp. (Released 2013). IBM SPSS Statistics for Macintosh, Version 22.0. Armonk, NY: IBM Corp.

Johnson, M. K., Hashtroudi, S., & Lindsay, D. S. (1993). Source monitoring. *Psychological Bulletin*. doi:10.1037/0033-2909.114.1.3

Kail, R., & Salthouse, T. A. (1994). Processing speed as a mental capacity. *Acta Psychologica, 86,* 199–225. doi:10.1016/0001-6918(94)90003-5

Levy, B. J., & Anderson, M. C. (2002). Inhibitory processes and the control of memory retrieval. *Trends in cognitive sciences, 6,* 299–305.

Ljungberg, J. K., Hansson, P., Andrés, P., Josefsson, M., & Nilsson, L.-G. (2013). A longitudinal study of memory advantages in bilinguals. *PloS One, 8,* e73029. doi:10.1371/journal.pone.0073029

Li, P., Legault, J., & Litcofsky, K. A. (2014a). Neuroplasticity as a function of second language learning: Anatomical changes in the human brain. *Cortex, 58,* 301–324. doi:10.1016/j.cortex.2014.05.001

Li, P., Zhang, F., Tsai, E., & Puls, B. (2014b). Language history questionnaire: a new dynamic web-based research tool. *Bilingualism: Language and Cognition, 17,* 673–680.

Luo, L., Craik, F. I. M., Moreno, S., & Bialystok, E. (2013). Bilingualism interacts with domain in a working memory task: evidence from aging. *Psychology and Aging, 28,* 28–34. doi:10.1037/a0030875

Macnamara, B. N., & Conway, A. R. A. (2014). Novel evidence in support of the bilingual advantage: influences of task demands and experience on cognitive control and working memory. *Psychonomic Bulletin & Review, 21,* 520–5. doi:10.3758/s13423-013-0524-y

Martin, A., Wiggs, C. L., Lalonde, F., & Mack, C. (1994). Word retrieval to letter and semantic cues: a double dissociation in normal subjects using interference tasks. *Neuropsychologia, 32,* 1487–94.

McAuley, T., & White, D. A. (2011). A latent variables examination of processing speed, response inhibition, and working memory during typical development. *Journal of Experimental Child Psychology, 108,* 453–468. doi:10.1016/j.jecp.2010.08.009

McCabe, D. P., Roediger, H. L., McDaniel, M. A., Balota, D. A., & Hambrick, D. Z. (2010). The Relationship Between Working Memory Capacity and Executive Functioning: Evidence for a Common Executive Attention Construct. *Neuropsychology, 24,* 222–243. doi:/10.1037/a0017619.

Mitchell, K.J., & Johnson, M. K. (2009). Source monitoring 15 years later: What have we learned from fMRI about the neural mechanisms of source memory? *Psychological Bulletin, 135,* 638–677.

Naveh-Benjamin, M. (2000). Adult age differences in memory performance: Tests of an associative deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 1170–1187. doi:10.1037/0278-7393.26.5.1170

Oberauer, K., & Kliegl, R. (2001). Beyond resources: Formal models of complexity effects and age differences in working memory. *European Journal of Cognitive Psychology, 13,* 187–215. doi:10.1080/09541440042000278

Paap, K. R., & Greenberg, Z. I. (2013). There is no coherent evidence for a bilingual advantage in executive processing. *Cognitive Psychology, 66,* 232–58. doi:10.1016/j.cogpsych.2012.12.002

Paap, K. R., Johnson, H. A., & Sawi, O. (2015). Bilingual advantages in executive functioning either do not exist or are restricted to very specific and undetermined circumstances. *Cortex, 69,* 265–278. doi:10.1016/j.cortex.2015.04.014

Paap, K. R., Johnson, H. A., & Sawi, O. (2016). Should the Search for Bilingual Advantages in Executive Functioning Continue? *Cortex, 74,* 305–314. doi:10.1016/j.cortex.2015.09.010

Pelham, S. D., & Abrams, L. (2014). Cognitive advantages and disadvantages in early and late bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40,* 313–25. doi:10.1037/a0035224

Penke, L., Maniega, S. M., Murray, C., Gow, A. J., Valdes Hernandez, M. C., Clayden, J. D., Starr, J. M., Wardlaw, J. M., Bastin, M. E., & Deary, I. J. (2010).

A General Factor of Brain White Matter Integrity Predicts Information Processing Speed in Healthy Older People. *Journal of Neuroscience, 30,* 7569–7574. doi:10.1523/JNEUROSCI.1553-10.2010

Perrotin, A., Isingrini, M., Souchay, C., Clarys, D., & Taconnat, L. (2006). Episodic feeling-of-knowing accuracy and cued recall in the elderly: Evidence for double dissociation involving executive functioning and processing speed. *Acta Psychologica, 122,* 58–73. doi:10.1016/j.actpsy.2005.10.003

Peters, B. D., Ikuta, T., Derosse, P., John, M., Burdick, K. E., Gruner, P., Prendergast, D. M., Szeszko, P. R., & Malhotra, A. K. (2014). Age-related differences in white matter tract microstructure are associated with cognitive performance from childhood to adulthood. *Biological Psychiatry, 75,* 248–256. doi:10.1016/j.biopsych.2013.05.020

Rodríguez-Villagra, O. A., Göthe, K., Oberauer, K., & Kliegl, R. (2013). Working memory capacity in a go/no-go task: age differences in interference, processing speed, and attentional control. *Developmental Psychology, 49,* 1683–96. doi:10.1037/a0030883

Schacter, D. L., Harbluk, J. L., & McLachlan, D. R. (1984). Retrieval without recollection: An experimental analysis of source amnesia. *Journal of Verbal Learning and Verbal Behavior, 23,* 593–611. doi:10.1016/S0022-5371(84)90373-6

Schroeder, S. R., & Marian, V. (2012). A bilingual advantage for episodic memory in older adults. *Journal of Cognitive Psychology, 24,* 591–601.

Shimamura, A. P., & Squire, L. R. (1991). The relationship between fact and source memory: Findings from amnesiac patients and normal subjects. *Psychobiology, 19,* 1–10.

Spaniol, J., & Grady, C. (2012). Aging and the neural correlates of source memory: over-recruitment and functional reorganization. *Neurobiology of Aging, 33,* 425.e3–425.18. doi:10.1016/j.neurobiolaging.2010.10.005

Tao, L., Marzecová, A., Taft, M., Asanowicz, D., & Wodniecka, Z. (2011). The efficiency of attentional networks in early and late bilinguals: the role of age of acquisition. *Frontiers in Psychology, 2*. doi:10.3389/fpsyg.2011.00123

Verbruggen, F., McLaren, I. P. L., & Chambers, C. D. (2014). Banishing the control homunculi in studies of action control and behaviour change. *Perspectives on Psychological Science, 9,* 497–524. doi:10.1177/1745691614526414

Wechsler, D. (1997a). WAIS III: Administration and scoring manual. San Antonio, TX: Harcourt.

Wechsler, D. (1997b). Wechsler Memory Scale—Third Edition. San Antonio, TX: The Psychological Corporation.

Wodniecka, Z., Craik, F. I. M., Luo, L., & Bialystok, E. (2010). Does bilingualism help memory? Competing effects of verbal ability and executive control. *International Journal of Bilingual Education and Bilingualism, 13,* 575–595. doi:10.1080/13670050.2010.488287

Yubero, R., Gil, P., Paul, N., & Maestú, F. (2011). Influence of memory strategies on memory test performance: a study in healthy and pathological aging. *Aging, Neuropsychology and Cognition, 18,* 497–515. doi:10.1080/13825585.2011.597840

Zhou, B., & Krott, A. (2015). Data trimming procedure can eliminate bilingual cognitive advantage. *Psychonomic Bulletin & Review*, doi: 10.3758/s13423-015-0981-6. Published online by Springer, November 25, 2015.