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Examining the Bilingual Advantage on Conflict Resolution Tasks: A Meta-Analysis

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Abstract

A great deal of research has compared monolingual and bilinguals on conflict resolution tasks, with inconsistent findings: Some studies reveal a bilingual advantage on global RTs, some reveal a bilingual advantage on interference cost, and some show no advantage. We report a meta-analysis of 73 comparisons (N = 5538), with estimates of global RTs and interference cost for each study. Results revealed a moderately significant effect size that was not moderated by type of cost (global RT or interference cost) or task. Age interacted with type of cost, showing a pattern difficult to reconcile with theories of bilingualism and executive control. Additionally there was a significant main effect of lab, which might be due to sociolinguistic differences in samples, data treatment and methodology, or Hawthorne effects.

Keywords: bilingual advantage; inhibitory control; monitoring; conflict resolution tasks; meta-analysis

Introduction

There is widespread agreement that during language use, lexical representations from both of a bilingual's languages are active (Kroll, Dussais, Bogulski & Kroff, 2012). For example, bilinguals name cognates more quickly than matched non-cognates (van Hell & Djikstra, 2002). Some researchers have speculated that these representations compete for selection (Kroll et al., 2012). Green (1998) proposed that competition between these two sets of representations is resolved by a domain-general inhibitory control mechanism. One prediction from this proposal is that bilinguals' regular engagement of this mechanism strengthens it, leading to smaller interference costs on conflict resolution tasks.

Examples of conflict resolution tasks include the Simon, Flanker and Stroop tasks. All three tasks contain trials with and without distracting information (incongruent and congruent trials, respectively). For example, in the Simon task, participants see colored squares, which appear on either the right or left hand side of the screen. One color is assigned a left-key response and the other is assigned a right-key response. It is assumed that both the color of the square and its location elicit separate responses and that when these responses differ (i.e. on incongruent trials) they compete. The difference in reaction time (RT) between congruent and incongruent trials, called the interference cost, is assumed to reflect the extra time needed to engage a domain-general inhibitory mechanism to suppress the non-target response. Smaller interference costs are assumed to reflect superior inhibitory control.

Many studies have tested the prediction that bilinguals exhibit smaller interference costs than monolinguals. In a literature review, Hilchey and Klein (2011) noted that the bilingual advantage on interference costs was mixed. However, they also noted that many studies observed a bilingual advantage on global RTs, that is, the average RT across both congruent and incongruent trials. Global RTs in conflict resolution tasks are often thought to reflect the cost of monitoring, searching for and identifying cues that that signal the need for changes in inhibitory control. Some authors have speculated (e.g., Costa et al., 2009) that this system detects conflict created when lexical items from both languages are activated. Others have argued that living in a multilingual environment might tax the monitoring system because socio-linguistic cues for which language to speak may compete (Hernandez et al., 2013). If either of these claims is true, bilinguals may engage the monitoring system to a greater extent than monolinguals during regular language use.

However, several recent studies have failed to replicate the bilingual advantage on global RTs: Some researchers have observed a bilingual advantage on interference cost, but not global RTs (e.g., Luk, De Sa & Bialystok; Yang, Yang & Lust, 2011), whereas others have observed no bilingual advantage on either global RTs or interference cost (e.g., Paap & Greenberg, 2013; Antón et al., 2014).

Two recent reviews on the aforementioned studies reach different conclusions about the bilingual advantage on conflicting resolution tasks. First, after noting the many non-replications of the bilingual advantage on global RTs, Hilchey, Saint-Aubin, & Klein (2015) suggest that the bilingual advantage may be due to correlated background variables. Second, Valian (2015) argues that the bilingual advantage may be real, but that, given the number of other variables and experiences that engage mechanisms of executive control, its individual impact may often be obscured.

Both of these interpretations suggest that an important next step is to compare monolinguals and bilinguals from diverse social and linguistic backgrounds, so that the effects of correlated background variables may wash out. A single empirical study of this sort would prove very difficult to conduct. However, given the large number of studies from many different labs that have been conducted on this topic, meta-analysis would be especially elucidating. An additional benefit of meta-analysis is the ability to systematically model the effects of potential moderator variables, including the measure of cost (i.e. the dependent variable (DV): global RT vs interference cost).

Three additional moderator variables are especially relevant to this meta-analysis. First, although the Simon, Stroop and Flanker tasks are often interpreted as reflecting the same construct, they are often uncorrelated (see Paap & Sawi, 2014, for an overview). If these three tasks reflect different constructs, then the bilingual advantage (on global RTs or interference cost) might materialize on some but not other tasks.

A second important moderator variable is age of participants. Studies of the bilingual advantage have included participants as young as two and a half (Bialystok et al., 2010) and as old as seventy (Bialystok et al., 2004). Given the developmental trajectory of executive control, Bialystok et al (2004) argued that the bilingual advantage might be more pronounced among children and older adults than younger adults, for whom executive control is at peak levels. While there is some evidence for this claim (e.g. Engel de Abreu et al., 2011), other authors have failed to observe a bilingual advantage amongst children (e.g. Antón et al., 2014) and older adults (Kirk et al., 2014).

A third important moderator, research group, is important for two reasons. First, different research groups likely have access to different populations of bilinguals. Second, different research groups may differ in their administration of tasks and analysis of data. For example, different labs define and handle outliers differently. This is especially important since empirical and theoretical work on RT distributions suggests that changes in task demands often affect the tail as well as mean of the distribution (Tse & Altarriba, 2012).

The present meta-analysis aimed to answer two questions: (1) whether there is a reliable bilingual advantage on the global RTs or the interference cost of interference control tasks; and (2) whether this advantage is moderated by task, age, or research group.

Method

Literature Search and Inclusion Criteria

PsycINFO and other databases were searched periodically until January 2015. Search terms included some combination of Bilingualism and Executive Control, Executive Function or Inhibition. Additionally, the references sections of recent review papers and a recent meta-analysis on this topic (de Bruin, Treccani & Della Salla, 2015) were consulted. A total of 39 studies, with 73 comparisons and 5538 participants met the following criteria:

A) Study includes at least one bilingual group. Because different studies have used different measures as indicators of bilingualism (e.g., age of onset, frequency of use, and overall proficiency), it is impossible to identify a single definition of bilingualism. Therefore, a group of participants will be designated as bilingual if any of the following are true: the age at which they began learning their second language is equal to or less than one half their age at the time of testing; the participants report near equal proficiency in their languages; the participants report native or near-native attainment in their second language; the participants report using each of their two languages in at least forty percent of their daily activities; the participants report using both languages at home; the participants report using one language at home and one language at school (with the exception of children who are recently enrolled in immersion programs).

B) Study includes at least one monolingual group. A group will be defined as monolingual if they have had only minimal exposure to a second language, e.g., through a foreign language class at school.

C) Participants are at least five years old and without psychological impairment. This analysis therefore excludes many of the studies on the potentially beneficial effect of bilingualism on dementia.

D) It contains RT data from at least one conflict resolution task, such as the Flanker, Simon, or Stroop tasks. A conflict resolution task was defined as follows: Participants are asked to make a judgment about a visually presented stimulus; a second, non-target cue was systematically varied across trials; on some trials the non-target cue elicited a different response than the target cue; on other trials the non-target cue elicited the same response as the target cue. Tasks were not included if they contained an unconventionally small number of trials of either type.

Data Reduction

This study used a three-level meta-analysis to model dependence between global RTs and interference cost. To do so, other forms of dependence between the effect sizes within studies needed to be eliminated. The following strategies and assumptions were employed to eliminate dependence. It was assumed that there was no dependence between separate studies within the same paper. It was assumed that there was no dependence between comparisons of different groups in the same study; for example, studies that report on bilingual-monolingual comparisons for two age groups contributed independent effect sizes to the meta-analysis. If a study reported on multiple blocks for one task, the first block was selected for the effect size. If a study reported on multiple bilingual groups and a single monolingual group, or multiple monolingual groups and a single bilingual group, the multiple groups were averaged into a single group. Finally, if a study reported multiple conflict resolution tasks, each task contributed independent effect sizes. This can be justified as multiple studies have failed to find consistent correlations between conflict resolution tasks (Paap & Greenberg, 2013; Paap & Sawi, 2014).

Moderator Coding

This study included four moderator variables. DV (i.e., type of cost) was coded as a factor with two levels, global RT and interference cost. Age was coded as factor variable with three levels: children were participants less than 18 years old; younger adults were participants between 18 and 60 years old; and older adults were participants above 60 years old. Task was coded as a factor variable with the following levels: Simon included the classic Simon task and the Simon Arrows task; Flanker included the Flanker task and the Attentional Networks Test; Stroop included color-letter Stroop tasks; and Other included all other tasks. The lab variable was coded according to the corresponding author on each study. All authors who were the corresponding author on at least four comparisons were treated as separate levels on the lab variable. All authors who were corresponding author on fewer than four comparisons were grouped into the Other level. There were six levels of the lab variable (5 labs and Other).

Effect Size Calculation

Many studies report the means and standard deviations of congruent and incongruent trials separately. In order to calculate effect sizes for global RTs and interference cost, the correlation between congruent and incongruent trials was needed for estimating standard deviations. As these correlations are typically not reported, they were imputed. A random-effects meta-analysis of the correlations between congruent and incongruent trials from several interference control tasks was conducted. Correlation coefficients were then simulated from this model.

Two studies (Namazi & Thordardottir, 2010; Gathercole et al., 2014) reported means but no standard deviations. Standard deviations were simulated from linear models with the mean RT as a predictor variable. This approach is defensible because both theoretical and empirical work indicates that the standard deviation of an RT distribution is a linear function of its mean (Wagenmakers & Brown, 2007).

Model

As global RTs and interference cost are dependent, a three-level meta-analysis was conducted using the *metasem* package in *R* (Cheung, 2013). Unlike traditional random effects meta-analysis, which decomposes effect size variance into two types, three-level meta-analysis decomposes variance into three sources: sampling error, within-cluster variance, and between-cluster variance. Clusters were defined as comparisons between one group of monolinguals and one group of bilinguals on a specific task. So if a study reported on monolinguals and bilinguals of two different age groups, two clusters were included for that study. Each cluster contained two effect sizes, one for the interference cost and one for the global RTs. All other moderator variables varied between comparisons.

Results

Prior to running the three-level meta-analysis, traditional random-effects meta-analyses with no moderators were conducted and forest plots were produced in order to visualize variation in effect sizes across studies. Effect sizes for global RTs are shown in Figure 1, and for interference cost in Figure 2. Before accounting for the dependence between effect sizes, or including any moderators, the average effect size for global RTs was d = .43 (*CI*: .19 – .67) and the average effect size for interference cost was d = .29 (CI: .13 – .49).

Several three-level meta-analyses of increasing complexity were then fit. First, the Null Model, with no moderator variables estimated the pooled effect size for global RTs and interference cost. The model yielded an effect size of d = .39 (*CI*: .19 – .59), and, consistent with Figures 1 and 2, suggested significant heterogeneity of effect sizes, $Q(145) = 885.918$, $p < .001$. Both within- and between-cluster standard deviations significantly differed from zero, $\tau^2_{within} = .11$, $p < .001$, $\tau^2_{between} = .38$, $p < .001$. Second, to test whether effect sizes varied according to DV (global RTs vs interference cost), Model 1 included DV as a moderator. Surprisingly, including DV as a moderator did not improve fit according to the likelihood ratio test (p = .52). However, because DV was a theoretically important variable, it was included in subsequent models testing the effects of other moderators.

Third, a series of models including task, age, and research group as moderators was fit to the data. For each moderator two models were fit: An additive model, testing just the effect of the moderator on the pooled effect size, and an interaction model, testing whether the moderator affected global RTs and interference cost differently. Each model was compared to both the Null Model and Model 1 according to the likelihood ratio statistic. Key results are presented in Table 1. For task, neither the additive model nor the interaction model improved fit relative to the Null Model or Model 1. For age, the additive model did not improve fit; however, the interaction model fit significantly better than both the Null Model and Model 1.

To determine the source of the interaction, the two interaction coefficients were examined. The interaction between DV and the Older Adult group was positive and statistically significant (B = .47, Z = 2.29, p = .02. The interaction between DV and the Child group was non-significant (B = -.27, Z = -1.77, p = .08). To facilitate interpretation of these interactions, three separate meta-analyses of the children, younger adults and older adults were conducted. Amongst younger adults, DV did not significantly moderate effect size (B = -.03, Z = -.31, p = .76). Amongst children, the effect of DV was negative and marginally significant (B = -.42, Z = -1.86, p = .06), suggesting that the effect on global RTs tended to be larger than that on interference cost. Amongst older adults, the positive effect of DV was statistically significant (B = .47, Z

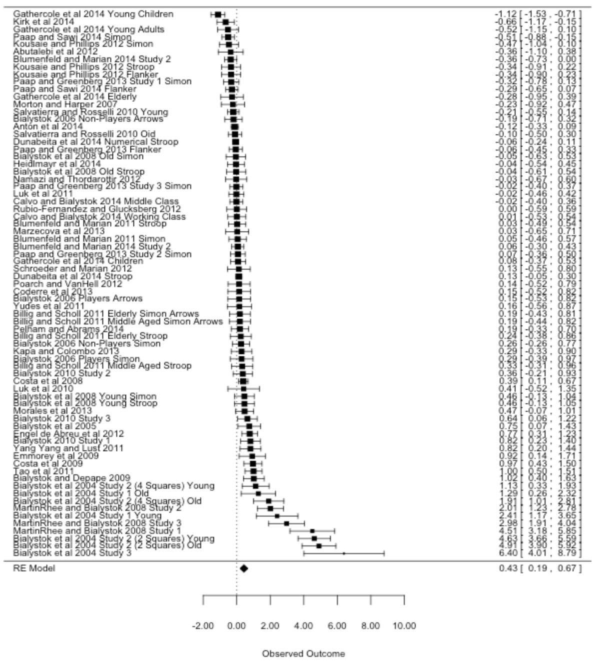

Figure 1: Forest Plot for Global RTs

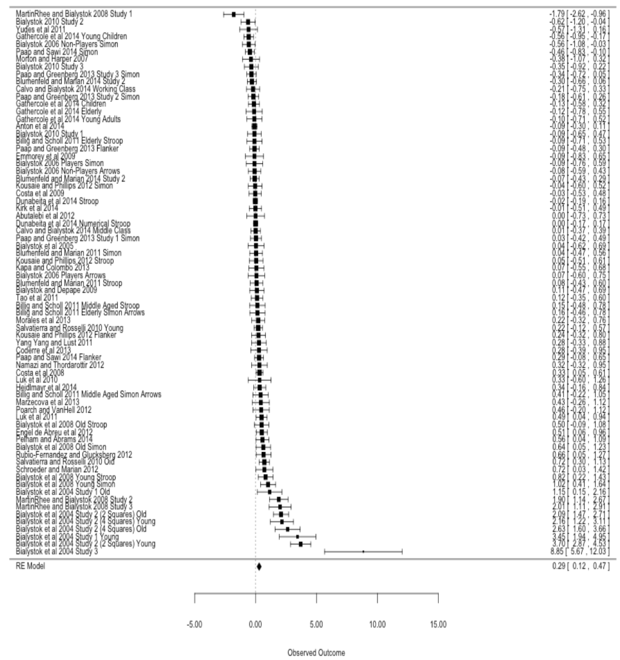

Figure 2: Forest Plot for Interference Costs

= 3.31, p < .001), and indicated larger effect sizes for interference costs than global RTs. Both the additive model and interaction model for research group improved fit relative to both the Null Model and Model 1. According to a likelihood ratio test, the additive and interaction models did not differ significantly from one another (p = .09), suggesting that the effect of lab is consistent across both global RTs and interference costs. Examination of the forests plots revealed several outlier effect sizes that might have contributed to lab effects. To test this possibility a sensitivity analysis was conducted: 72 three-level meta-analyses with additive effects of DV and Research Group were fit to data. Each model dropped one of the comparisons. Every model fit significantly better than the Null Model (max p-value = .002; min R^2 = .34), indicating that the results cannot be attributed to a single outlier.

Discussion

The present study had two aims: 1) to test the reliability of the bilingual advantage on global RTs and interference costs from conflict resolution tasks; 2) to test whether effect sizes to test whether effect sizes are moderated by age, task and lab. The overall effect size from the Null Model was moderate and statistically significant, suggesting a reliable bilingual advantage.

However, while another meta-analysis of bilingual advantages in cognition found evidence of publication bias (de Bruin et al., 2014), it should be noted that we did not assess publication bias and included only published studies.

This was unexpected because global RTs and interference costs are generally thought to reflect different cognitive constructs, namely monitoring and inhibitory control.

However, DV had different effects for the three age groups. Amongst older adults, effect sizes were significantly larger for interference cost than global RTs; amongst younger adults, there was no significant difference between the two costs; and amongst children, there was a trend in the opposite direction, with larger effect sizes for global RTs than for interference cost. The reason for this pattern of results is unclear, as there is no model of language control in bilinguals that predicts different advantages at different developmental periods. It is possible that this pattern could be an artifact of calculating interference costs as additive rather than multiplicative effects.

The effect of lab was large, robust, and did not interact with DV. We offer three possible explanations for the lab effect. First, it might stem from sociolinguistic differences of subject pools across the different universities (e.g., immigrant status) that might affect the degree to which executive control is recruited and subsequently strengthened. Second, there may be differences in methods across labs, e.g., in the treatment of outliers of RT distributions. At least one study has found evidence of a bilingual advantage in the tail of RT distributions (Tse & Altarriba, 2012, but see Duñabeitia et al., 2014). If this phenomenon is common, variation in outlier removal strategies would lead to different findings across labs. There was not sufficient information about outlier handling to include this as a moderator. Third is the possibility of Hawthorne effects. Whether lifelong bilingualism strengthens executive control is a hotly debated question that has received a great deal of public attention. It is plausible that participants might be aware of the researcher's hypothesis prior to entering their lab, which could bias results.

Model	Within Cluster Variance	Between Cluster Variance	R^2 Within	R^2 Between	AIC	P -value (Null)	P- Value (Cost)
Null	.11	.65	.00	.00	95.39		
Cost	.11	.65	.00	.00	96.79	.44	
Cost + Task	.11	.62	.00	.05	100.60	.60	.53
Cost * Task	.10	.63	.07	.04	102.72	.46	.43
Cost + Age	.11	.65	.00	.00	100.19	.75	.74
Cost * Age	.08	.00	.26	.00	93.56	.04	.02
Cost + Lab	.11	.42	.00	.36	83.07	<.001	<.001
Cost * Lab	.08	.43	.26	.36	83.41	<.001	<.001

Table 1: Summaries of Moderator Variables

The observed pattern of results is inconsistent with existing models of bilingual language control and does not provide conclusive evidence for or against the bilingual advantage on conflict resolution tasks. This is, in part, due to limitation with the present study and the existing literature. First, the present study did not include socio-linguistic variables, such as age of onset of bilingualism and frequency of use as moderators. Future work will include these variables. Second, most of the existing literature has treated bilingualism as a one-dimensional, categorical variable: participants are either bilingual or monolingual. A more fruitful approach might be to identify specific dimensions of bilingual experience that recruit executive control and look for individual differences therein (Kroll & Bialystok, 2013). Future modeling work on bilingual lexical development and lexical access should to clarify the role of executive control in bilingual language management and suggest more specific hypotheses about where and when to expect a bilingual advantage.

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