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# Too much of a good thing: Stronger bilingual inhibition leads to larger lag-2 task repetition costs

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ABSTRACT

Inhibitory control and monitoring abilities of Hebrew–English bilingual and English monolingual university students were compared, in a paradigm requiring participants to switch between performing three distinct tasks. Inhibitory control was gauged by lag-2 task repetition costs, namely decreased performance on the final trial of sequences of type ABA relative to CBA, due to persisting inhibition of the recently abandoned task. Bilinguals had larger lag-2 repetition costs, which reflect stronger inhibition of a no-longer relevant task to facilitate a switch into a new task. Monitoring ability was measured by the fadeout effect, which reflects adaptation to simpler task demands when a single task block immediately and unexpectedly follows mixed task blocks. Bilinguals did not differ from monolinguals in the magnitude or trajectory of the fade-out effect. Thus, results support the notion of increased bilingual inhibitory control, even when it is detrimental to performance, and do not demonstrate a specific bilingual advantage in monitoring. These findings are discussed in the context of the recent debate concerning the locus of bilingual advantages.



## 1. Introduction

Life-long bilingualism has recently been identified as an experience that might lead to cognitive advantages, especially in the domain of executive function (Bialystok, Craik, Green, & Gollan, 2009). However, executive function is a complex cognitive construct, and the debate regarding the specific locus of the bilingual advantage continues (Costa, Hernandez, Costa-Faidella, & Sebastian-Galles, 2009; Hilchey & Klein, 2011). One account stresses a bilingual advantage in inhibitory control (Bialystok, Craik, Klein, & Viswanathan, 2004), and especially the ability to inhibit irrelevant information and manage interference in conflict displays. Research examining this possibility has used mostly concurrent interference paradigms, such as the Simon task (Simon & Ruddell, 1967), the control component of the Attentional Networks Task (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002) or Stroop paradigms. If bilinguals enjoy enhanced inhibitory control then they should display smaller interference effects in such paradigms. This pattern has been reported by some but by no means all of the studies employing such paradigms (Costa et al., 2009; Hilchey & Klein, 2011; Tao, Marzecova, Taft, Asanowicz & Wodniecka, 2011).

However, bilinguals have also demonstrated shorter RTs for both conflict and non-conflict displays in such studies (e.g. Hernández, Costa, Fuentes, Vivas, & Sebastián-Gallés, 2010; Tao et al., 2011). This pattern has lead to the suggestion that bilingual advantages in cognitive control might extend beyond inhibitory control, or could even be attributed to other components of the executive control system, such as monitoring (Bialystok, 2010; Costa et al., 2009; Hilchey & Klein, 2011; Prior & MacWhinney, 2010). The goal of the current study was to examine these two theoretical accounts put forth for bilingual advantages, namely the inhibitory control account and the monitoring account, using a task that more easily allows dissociation of the two underlying cognitive processes.

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Examining the demands that bilingual language use poses on the cognitive system, both theoretical accounts are plausible. Thus, the inhibitory control model of bilingual language control proposed by Green (1998) describes how competition between the languages is resolved by the application of inhibition to the non-target language, and empirical support for this view comes from several behavioral and imaging paradigms (see Kroll, Bobb, Misra, & Guo, 2008, for a review). However, bilinguals also need to monitor which language is appropriate for different interlocutors or situations and have the ability to flexibly move back and forth between languages when code-switching with other bilinguals (Muysken, 2000). These abilities might rely on aspects of the executive control system other than inhibition, such as monitoring (Costa et al., 2009) or efficient set shifting (Prior & MacWhinney, 2010).

Models of executive function tend to identify various components of this complex construct. For example, Miyake et al. (2000) identify inhibition, set shifting and working memory as three independent, albeit correlated, components of executive function. Many experimental paradigms investigating executive function actually rely on more than a single component of executive function. To illustrate, performance in paradigms such as the Simon task recruits inhibitory processes to allow participants not to be mislead by irrelevant information in conflict displays, but also recruits shifting and monitoring processes to allow participants to react appropriately to the differences between congruent and incongruent trials. Similarly, switch costs apparent in task-switching paradigms have been attributed to various attentional and executive processes, including task-set inertia, set-shifting and overcoming inhibition applied on a previous trial to allow for a shift, or even working memory updating necessary when activating and maintaining current task-response mappings (Kiesel et al., 2010; Meiran, 2010; Monsell, 2003).

Finally, research further partitions even the construct of inhibitory control. Thus, Friedman and Miyake (2004) investigated three types of inhibition (Nigg, 2000) using multiple measures of performance and confirmatory factor analysis. They identified inhibition of prepotent responses and the ability to overcome distractor interference as being correlated with each other, but statistically separable from the ability to overcome proactive interference. Most research to date investigating bilingual advantages used tasks that Friedman and Miyake (2004) report as being associated more strongly with response-distractor inhibition, such as flanker paradigms (Costa, Hernandez, & Sebastian-Galles, 2008; Tao et al., 2011) or Stroop tasks (Bialystok, Craik, & Luk, 2008). Interestingly, Colzato et al. (2008) recently investigated bilingual performance while distinguishing different types of inhibitory control. These authors contrast active inhibition (which is comparable to inhibition of a prepotent response) with reactive inhibition, or the ability to maintain relevant task goals. Their results showed a bilingual advantage only in the latter ability, supporting the notion that bilingualism might not influence all inhibitory processes uniformly.

Recently, several additional studies have examined bilingual performance in tasks that rely on inhibition and shifting abilities, but do not involve conflictual stimulus displays. Thus, bilingual advantages have been reported in task switching paradigms (Garbin et al., 2010; Prior & Gollan, 2011; Prior & MacWhinney, 2010) and in the Trail Making Task (Bialystok, 2010). Additionally, two studies have identified stronger bilingual inhibitory control as leading to decrements in performance – Colzato and colleagues (2008) report a stronger Attentional Blink for bilinguals, and Treccani, Argyri, Sorace, & Della Sala (2009) report larger negative priming accuracy effects in bilinguals when compared with monolinguals. These latter designs are especially powerful in demonstrating the effect of language experience, because they show how cognitive resources that usually would lead to improved performance might actually result in the opposite patterns. Importantly, studies of this nature also contribute to our understanding of the degree to which application of such inhibitory control processes is voluntary and can be modulated by task demands. Results showing that by virtue of increased control bilinguals suffer negative consequences to performance suggest that such inhibitory processes might be ballistic in nature, and once launched are not easily modulated by specific task demands.

The account assigning bilingual cognitive advantages to enhanced monitoring abilities relies mainly on findings of improved performance in both congruent and incongruent displays in concurrent interference tasks. Indeed, recent reviews of the literature point out that a bilingual advantage in overall RTs is the more robust finding (Costa et al., 2009; Hilchey & Klein, 2011; Tao et al., 2011). The monitoring system is recruited in order to evaluate the need for applying conflict resolution or inhibition mechanisms in each trial of such paradigms. Costa and colleagues (2009) have demonstrated that experimental conditions requiring high monitoring lead to a bilingual advantage in overall RTs whereas in a low monitoring condition bilinguals and monolinguals were comparably fast. The authors suggest that this monitoring advantage stems from bilinguals' need to constantly monitor the appropriate language for different interlocutors, and to recruit inhibitory processes appropriately. Hilchey and Klein (2011) similarly locate the bilingual advantage not in inhibitory control per se, but in a central executive system that regulates processing across a wide range of tasks and domains. They trace this bilingual advantage to the need to manage language selection, and refer to bilinguals' enhanced ability to monitor the existence of conflict and then differentially deal with conflict and non-conflict situations.

The present study explores the inhibition and monitoring accounts of the bilingual control advantage using a task-switching paradigm, in an effort to isolate these cognitive components from each other. Participants performed one of three different judgments on visually presented stimuli – color, shape and size. In single task blocks, only one task was performed. In mixed task blocks, the task was cued on each trial and there were no task repetitions. The final block of the experiment included again only a single task. From this setup, two measures of executive control were extracted, the first linked more tightly to inhibition, and the second arguably tapping into processes of monitoring and the ability to adjust behavior and control settings to changes in task demands.

Lag-2 task repetition effects can be measured when participants switch between performing at least 3 different tasks in mixed blocks. This method compares between trials in which a participant is required to switch back to a task that has been recently inhibited after only one intermediate trial (sequences of the type ABA) and trials in which the participant switches back to a task after at least two intermediate trials (sequences of the type CBA). The critical finding is that responses on the third trial of ABA sequences tend to be slower and more error prone than responses on the third trial of CBA sequences (e.g. Gade & Koch, 2007; Mayr & Keele, 2000; Mayr & Kliegl, 2003; Philipp & Koch, 2006; Schuch & Koch, 2003).

The accepted theoretical basis given to lag-2 task repetition costs is that inhibition applied to the task performed in trial n-2 to allow for the task transition required in trial n-1 persists into trial n, and results in a decrement in performance when the same task set needs to be accessed. In fact, lag-2 task repetition effects have been identified in two recent reviews as the empirical signature and most convincing demonstration for the role of inhibitory processes in task switching (Kiesel et al., 2010; Koch, Gade, Schuch, & Philipp, 2010). Interestingly, lag-2 language repetition costs have also been recently reported in a study by Philipp and Koch (2009). Participants alternated in naming digits or colors in one of three languages – German, English or French, and returning on trial n to a language that had been previously used on trial n-2 caused a decrease in performance. This finding supports the previously described role of inhibitory processes in bi- and multi-lingual language control.

Stronger bilingual inhibitory control would in fact lead to more pronounced lag-2 task repetition effects (as in Colzato et al., 2008 and Treccani et al., 2009). This would be the case especially if, as suggested by Koch et al. (2010), task inhibition is a ballistic process, that once launched decays over time. If bilinguals by virtue of their increased use of inhibitory mechanisms for purpose of language control have acquired the ability to launch this process more effectively, then the prediction would be longer sustained inhibition for the recently abandoned task.

Two additional timing factors were manipulated in the current study. The interval between the task cue and the following stimulus could either be short (100 ms) or long (500 ms). This interval is the time that the participant has to instate the task set necessary on the upcoming trial and prepare for its execution. Longer cue-stimulus intervals (CSI) generally lead to smaller task switching costs (Monsell, 2003). We also manipulated the interval between the response given on the previous trial and the appearance of the cue for the next trial. During this interval, the currently performed task set can dissipate passively, and again, longer response-cue intervals are linked with smaller switch costs. With regards to the magnitude of the lag-2 repetition cost, demonstrating that the effects remain robust even with the introduction of longer CSIs supports the inhibitory account and helps in ruling out alternative accounts based on serial expectations (Mayr & Keele, 2000). The different RCI conditions allow identification of the relative contribution of simple task set decay to the effect. Importantly, if these timing factors are found to interact significantly with the magnitude of the lag-2 repetition cost and with language experience, it might be possible to further pinpoint the locus of the bilingual advantage to active vs. passive processes in overcoming inhibition.

In the current paradigm, monitoring could arguably be measured in two ways. First, as in previous research utilizing conflict resolution tasks, bilingual advantages in overall RTs have been linked to improved monitoring processes (Costa et al., 2009). However, the existing studies investigating task switching in young adults have not found evidence for such general reaction time advantages for bilinguals over monolinguals (Garbin et al., 2010; Prior & Gollan, 2011; Prior & MacWhinney, 2010). Therefore, the present study included a final block of single task trials following the mixed task blocks, called a fadeout block. Performance in the fadeout block indicates how quickly monolingual and bilingual participants are able to adjust their performance to the marked decrease in task demands and the reduced load on the monitoring system. Importantly, participants were not told about the different nature of this final block and had to rely on their ongoing interpretation based on the trials they encountered. Further, given that in the mixed blocks there were no task repetitions at all, theoretically the nature of the final block could have been detected within the first several trials.

Previous research has demonstrated that even when participants are explicitly informed of the changing nature of a single task block following mixed task blocks there is a period of adjustment, until vigilance is reduced and RTs grow faster to reach the level of previous performance on single task blocks (Mayr & Liebscher, 2001; Meiran, Diamond, Todder, & Nemets, 2010; Spieler, Mayr, & Lagrone, 2006). If participants are not informed of the change, this adjustment process would arguably be more drawn out. A bilingual advantage in monitoring would manifest in this case as faster adaptability of RTs, and a return to previously established single block response speed earlier within the final block. Viswanathan and Bialystok (2007) used a fadeout manipulation to investigate bilingual advantages, and report that bilinguals noticed the shift to single task trials earlier than monolinguals, and consequently had faster RTs. However, in that study bilinguals were overall faster than monolinguals in the mixed task block as well, and it is unclear whether the advantage seen in the fadeout trials is significantly larger.

The bilingual participants in the current study were Israeli college students who had learned Hebrew and English before the age of 8 and the onset of school instruction, and have continued to use both languages on a daily basis. Most participants came from bilingual homes, or had spent several years as children in an English speaking country. Their performance was compared to that of monolingual English speaking college students in the US. The question of whether the specific language combinations that bilinguals speak might influence the existence or degree of cognitive benefits they enjoy has only recently started to receive attention in the literature (Prior & Gollan, 2011). The current study examines a group of bilinguals that have not previously been tested in the literature on executive function benefits. Hebrew and English are distant typologically and use different orthographies that are both alphabetic scripts.

To reiterate the hypotheses, the claim for a bilingual advantage in inhibitory control leads to a prediction of more pronounced lag-2 task repetition costs for bilinguals over monolinguals. The assumption that bilinguals have enhanced monitoring abilities would be supported if bilinguals have faster response times overall within the mixed task blocks, and if they show a faster trajectory of improving performance within the final fadeout block. Importantly, these two mechanisms are not mutually exclusive, and both may receive support from the current results.

## 2. Method

### 2.1. Participants

Initially 36 highly proficient Hebrew-English bilinguals (17 males) students at the University of Haifa, and 39 monolingual English speakers (15 males), students at Pennsylvania State University, were recruited and were paid or received course credit for participation. Three monolingual and two bilingual participants were eliminated for failure to reach a 70% accuracy criterion in the task-switching paradigm. Examination of the remaining participants showed that the groups differed significantly on non-verbal IQ, as measured by Raven's progressive matrices, with bilinguals outperforming monolinguals. Six additional monolinguals and four bilinguals were eliminated from the analysis, to create groups of 30 participants each that were matched on their non-verbal IQ. It is important to note, however, that all findings reported below held for the entire sample as well.

Bilingual participants had learned Hebrew and English before the age of eight, and had used both languages continuously ever since. Several participants reported knowledge of a third language besides Hebrew and English (Arabic, Spanish, Russian, Yiddish, Italian, French and Chinese) though none were fluent in these languages, and rated their proficiency as lower than in Hebrew and English. Bilinguals were rather balanced in their knowledge of the two languages, and all had a disparity of less than 3 between their self rated proficiency in the two languages, on a 10 point scale ($M = 0.55$, SD = 1.25). Monolingual participants were native English speakers and had not studied any other language extensively before the age of 12, though some had limited exposure to another language at an earlier age. At the time of testing, some participants reported limited proficiency in a second language, but the discrepancy in self-rated proficiency of the two languages was greater than 3 in all cases at the time of testing ($M = 6.8$, SD = 2.4). Participant characteristics are described in Table 1.

**Table 1**
Participant Characteristics, Mean (SD).

| | Monolinguals ($N = 30$) | Bilinguals ($N = 30$) |
|---|---|---|
| Age[a] | 21.3 (3.7) | 25.4 (3.2) |
| Yrs. education | 14.9 (1.9) | 14.5 (1.7) |
| Parental education | 15.4 (1.9) | 15.8 (2.6) |
| Shipley Vocabulary[b] | English: 29.8 (3.8) | English: 25.9 (5.2)<br>Hebrew: 31.2 (7.3) |
| Non-verbal IQ (Ravens) | 49.7 (4.4) | 51.3 (4.8) |
| Computer Games | 1.1 (3.4) | 2.7 (6.2) |
| L1 proficiency | 9.3 (0.9) | 9.1 (1.0) |
| L1 percent use[a] | 90.2 (25.1) | 63.5 (20.7) |
| L2 Proficiency[a] | 4.2 (1.9) | 8.5 (0.90) |
| L2 Age of Exposure[a] | 10.9 (6.0) | 3.6 (2.7) |

[a] Groups significantly different, $p < .001$.
[b] Groups differ significantly in English vocabulary performance, $t(58) = 3.37$, $p < .01$, but do not differ in vocabulary performance in the dominant language, e.g. English for monolinguals and Hebrew for bilinguals, $p = .36$.

### 2.2. Design and procedure

All participants completed the following tasks in two experimental sessions that lasted approximately 45 min each and were conducted on separate days. The study was approved by the ethics committee at the University of Haifa and by the IRB at Pennsylvania State University. All participants gave written informed consent prior to participation.

#### 2.2.1. The language experience and proficiency questionnaire, LEAP-Q (Marian, Blumenfeld, & Kaushanskaya, 2007)

Monolinguals completed the questionnaire in English, and bilinguals completed a parallel version of the questionnaire in Hebrew (Prior & Beznos, unpublished). Two questions about parental education were added to the original questionnaire. Participants completed questions regarding their history and context of acquiring the languages they know, present language use, language preference and proficiency. Participants completed the questionnaire independently in approximately 10 min.

#### 2.2.2. The Shipley Institute of living (part A, Hebrew and English version)

A 40-items multiple choice synonym test. All participants completed the English version (Shipley, 1940; Zachary, 1986) and bilinguals completed a parallel version that was adapted to Hebrew (Gilboa, unpublished). Participants completed the questionnaires independently with a time limit of 10 min for each language.

#### 2.2.3. Raven's progressive matrices (Raven, 1958; Raven, Raven, & Court, 1998)

The test consists of 60 diagrammatic puzzles, which participants need to complete, and measures non-verbal intelligence. Participants completed the test independently in approximately 20 min.

#### 2.2.4. Task switching paradigm

The procedure was adapted from Mayr and Keele (2000) and Mayr and Kliegl (2003). The experiment consisted of 16 blocks. Stimuli in all blocks were red and green circles and triangles. Large stimuli measured 7.5 cm across, and small stimuli measured 5 cm across. Stimuli were always presented at the center of the computer screen. Participants performed one of three judgments on these stimuli – color, shape or size. Each task had a unique task cue – a color gradient signaled the color task, a row of small black shapes signaled the shape task (not including either a circle or a triangle), and a display of two large and two small hexagons signaled the size task (see Fig. 1).

Throughout the experiment each trial started with the presentation of the task cue. The stimuli then appeared below the cue, in the center of the screen. Both the cue and the target remained on the screen until a response was given or for a maximum of 5 s. The responses for all three tasks were mapped to two response buttons, manipulated by the index fingers of the two hands. The responses circle, red and large were mapped to the right hand, and the responses triangle, green and small were mapped to the left hand.

Two timing factors of task and cue presentation were manipulated as follows. The interval between the response to the previous stimuli and the cue of the next trial (RCI) could be set to a short duration of 100 ms, or to a longer duration of 500 ms. This manipulation influenced how long the previous task had to decay before receiving the cue for the following trial. The interval between the cue and the stimulus (CSI) was also manipulated and could either be short, set to 100 ms or long, set to 500 ms. This manipulation influenced how long the participants had to prepare for the upcoming task. In the single task blocks the timing combination was always 500–500. In the mixed task blocks, three combinations of RCI and CSI were implemented: Long – Short (RCI = 500, CSI = 100), Short – Long (RCI = 100 ms, CSI = 500), and Short – Short (RCI = 100, CSI = 100).

The first three blocks of the experiment were single task blocks, in which participants only performed one of the tasks per block – shape, color or size. Each block had 64 trials, and task order was counterbalanced across participants. Blocks 4–15 were mixed task blocks, in which participants alternated between performing the three tasks. The task changed on each trial, and was signaled by the task cue appearing before the stimuli. The eight possible stimuli were presented equally often, and were equally cued with each of the tasks. Two dummy trials were added at the beginning of each of the single task and mixed task blocks, and were not included in any of the analyses.

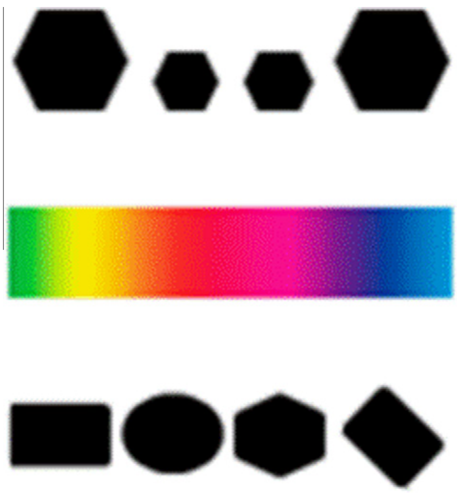

**Fig. 1.** Task Cues: size, color and shape.

In the mixed task blocks, there were 4 blocks for each RCI-CSI combination (long-short, short-long, short-short). The order of the timing combinations was counterbalanced across participants. The first block for each timing combination was a practice block with 64 trials. The remaining three blocks were experimental blocks with 104 trials each. Participants were only told that these were mixed task blocks, but were not informed explicitly of the timing parameters.

To explore the role of persisting inhibition in language-free response sets, two types of critical trials were created and analyzed in the mixed blocks. Lag-2 repetition trials were trials in which the task in trial n was the *same* task that had recently been performed in trial n-2. The task on trial n-1 was always different than that performed on trial n, because there were no immediate task repetitions. For example, a lag-2 repetition trial could consist of performing the shape task on trial n-2, the color task on trial n-1, and then again shape task on trial n. In this case, trial n is labeled as a lag-2 repetition trial. In the lag-2 non-repetition trials the task performed on trial n was *different* from the task that had been performed in trial n-2. For example, a lag-2 non-repetition trial could consist of performing the size task on trial n-2, the color task on trial n-1 and then the shape task on trial n. In this case, trial n is labeled as a lag-2 non-repetition. Thus, lag-2 repetition trials are of the format ABA, whereas lag-2 non-repetition trials are of the format CBA, where each letter represents one of the three tasks. Each of the mixed blocks had approximately equivalent numbers of lag-2 repetition and non-repetition trials (50–54 trials of each type per block), distributed evenly across all three tasks.

The last block (block 16) of the experiment was a fadeout block, in which only one of the three tasks was presented, counterbalanced across participants. The RCI-CSI combination used in the last mixed block was maintained in the fadeout block. Participants were not informed that the block would consist of one task only, as we wished to explore how quickly they would be able to adapt to the single task conditions, as manifested in RT and accuracy. As in the previous single task blocks, each stimulus was preceded by the relevant task cue. There were 104 trials in the fadeout block.

Participants received feedback on their accuracy at the end of each block, and were encouraged to improve their performance if accuracy fell beneath 90 percent. The entire task switching experiment lasted for approximately 45 min, and participants were given multiple opportunities to rest between experimental blocks. The task switching paradigm was presented on a PC computer, with a 19-inch color monitor. Experimental scripts and data collection were managed by E-Prime using a serial response box (Psychological Software Tools Inc., Pittsburgh, PA) to ensure accurate reaction time measurement. Participants were seated approximately 50 cm from the monitor.

Bilingual participants completed the LEAP-Q, Raven's Progressive Matrices and Shipley vocabulary test (Hebrew version) in one session and the task switching paradigm and Shipley vocabulary test (English version) in the other session. Monolingual participants completed the same tasks, with the exception of the Hebrew version of the Shipley. The order of sessions was counterbalanced across participants.

## 3. Results

Response times (RT) and accuracy rates were analyzed. Response times for error trials or correct trials following an error trial were not included in the analysis, eliminating 7.8% of the data. Mean response times were calculated for each participant for each trial type, and were submitted to ANOVAs.

### 3.1. Single task blocks

Performance on the single task blocks was analyzed using a repeated measures ANOVA with language group (monolingual, bilingual) as a between subject variable and task (color, shape, size) as a within subject variable. The effect of task was significant $F(2,110) = 12.32$, $MSE = 47459$, $p < .001$, $\eta^2 = .18$. Examining reaction times showed that the color task was the easiest ($M = 444$ ms), followed by the shape task ($M = 463$ ms) and the size task ($M = 501$ ms). This pattern held across both language groups – the main effect of group and the two-way interaction between group and task were not significant (both $F < 1$). The analysis of accuracy showed an identical pattern – a significant main effect of task, $F(2,110) = 3.36$, $MSE = 0.19$, $p < .05$, $\eta^2 = .06$, with no effect of language group and no interaction (both $F < 1$). The same order of task difficulty was also evident in the accuracy rates – color, shape and size (mean accuracy rates were 98.2%, 97.2% and 94.7%, respectively).

### 3.2. Mixed task blocks

Performance in the mixed task blocks was analyzed by a 4-way repeated measures ANOVA with language group (monolingual, bilingual) as a between subject variable and RCI-CSI timing combination (short-long, long-short, short-short), block order (first, second, third block of each timing combination) and lag-2 trial type (lag-2 repetition, lag-2 non-repetition) as within subject variables.

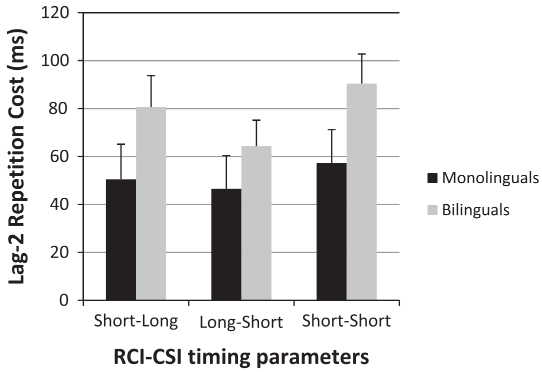


**Fig. 2.** Lag-2 task repetition costs (ms, SEM) for each RCI-CSI timing combination by language group.

The main effect of language group was not statistically significant, $F(1,58) = 2.38$, $p = .13$, although numerically bilinguals had longer response times in all conditions. On the other hand, the main effect of lag-2 trial type was highly robust $F(1,58) = 123.71$, $MSE = 1{,}139{,}424$, $p < .001$, $\eta 2 = .68$, showing a strong effect of lag-2 repetition cost across both groups of participants. Participants were slower to respond on lag-2 repetition trials than on lag-2 non-repetition trials, due to the influence of the persisting inhibition of the task set that had to be reactivated on trial n. Critically, the two-way interaction between lag-2 repetition and language group was also significant, $F(1,58) = 5.36$, $MSE = 49{,}333$, $p < .05$, $\eta 2 = .09$. Examination of the RTs presented in Table 2 and in Fig. 2 shows that the lag-2 repetition effect was larger for bilinguals than for monolinguals.

The two remaining main effects were highly robust, replicating patterns previously reported in the literature, and validating that the task design indeed tapped into the intended cognitive mechanisms. Thus, participants became progressively faster when moving from the first to the second to the third block in each timing combination, a main effect of block order, $F(2,116) = 47.18$, $MSE = 959{,}839$, $p < .001$, $\eta^2 = .45$. The main effect of timing was highly robust as well, $F(2,116) = 15.56$, $MSE = 4{,}051{,}689$, $p < .001$, $\eta^2 = .21$. The results show a joint influence of the length of time allowed for the previous task set to dissipate, manipulated by the RCI, and of the length of time given for preparation for the upcoming task after presentation of the cue, manipulated by CSI. The slowest condition was the 100–100 combination

**Table 2**
Mean reaction times (ms), standard errors and accuracy rates in the task switching paradigm, by language group.

| Timing | Lag-2 | Monolinguals | | Bilinguals | |
|---|---|---|---|---|---|
| | | RT | ACC | RT | ACC |
| Short-long | Non-repetition | 919 (39.8) | 95.7 | 971 (53.1) | 96.2 |
| | Repetition | 969 (41.1) | 96.2 | 1052 (60.0) | 96.0 |
| Long-short | Non-repetition | 1038 (48.0) | 95.7 | 1125 (44.0) | 96.2 |
| | Repetition | 1084 (52.0) | 95.5 | 1189 (44.7) | 95.5 |
| Short-short | Non-repetition | 1106 (57.3) | 95.9 | 1195 (59.9) | 96.8 |
| | Repetition | 1163 (56.4) | 95.5 | 1285 (60.6) | 96.6 |

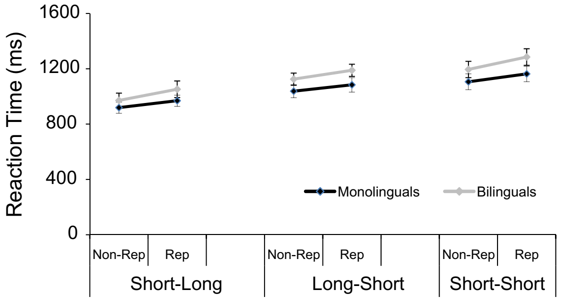


**Fig. 3.** Reaction times (ms, SEM) for lag-2 repetition and non-repetition trials for each RCI-CSI timings combination, by language group.

($M$ = 1188 ms), in which the overall ITI was shorter than in the other conditions (a total of 200 vs. 600 ms). The fastest condition was the 100–500 combination ($M$ = 978 ms), in which participants had the most opportunity to prepare for the upcoming task. Finally, the 500–100 combination fell between these two ($M$ = 1109 ms), demonstrating the stronger relative importance of cue processing and task set preparation than of passive decay of the previous task set, and dissipation of remaining inhibition.

Interestingly, the timing variable did not interact with lag-2 trial type ($F < 1$), showing similar magnitudes of the lag-2 repetition cost across the different conditions even though they differed in the basic response speed (see Figs. 2 and 3). There was also no significant interaction between the timing variable and language group ($F < 1$), demonstrating that the effects of task set dissipation and preparation for the upcoming task following the cue seemed to operate similarly for monolinguals and bilinguals. All remaining interactions were not significant ($ps > .13$).

In the corresponding analyses of accuracy rates only the main effect of lag-2 repetition was significant, $F(1,58) = 11.30$, MSE = .007, $p < .01$, $\eta^2 = .16$, showing more errors on lag-2 repetition than on non-repetition trials, across both participant groups.

A concern at this point might be that the larger lag-2 repetition effect for bilinguals might be a consequence of their slower response times, even though the main effect of group on RTs was not significant. Two arguments can be put forth to counter this possibility. First, bilinguals did not demonstrate larger effects of all manipulations across the board. Thus, the timing manipulation did not interact with language group, despite the somewhat slower performance of bilinguals over all (see Fig. 3). Second, and more importantly, the magnitude of the lag-2 repetition cost was not correlated with reaction times in the non-repetition trials for either group of participants (all $ps > .3$). Thus, it is not the case that participants who were generally slower also had larger lag-2 repetition costs, and therefore this cannot account for the group differences in the magnitude of the lag-2 repetition cost.

To further explore this issue we also conducted an analysis of covariance, despite some inherent limitations of this procedure (Adams, Brown, & Grant, 1992). For each participant we calculated the average lag-2 repetition cost and the average RT for lag-2 non-repetition trials across all three timing combinations, in order to create two orthogonal variables. We then conducted a one-way ANCOVA on the average cost with language group as a between participants factor, and mean RTs on lag-2 non-repetition trials as a covariate. The effect of language group was significant, $F(1,57) = 4.4$, MSE = 9009, $p < .05$, $\eta^2 = .07$, because even after controlling for basic reaction speed bilinguals exhibited larger lag-2 repetition costs than monolinguals (estimated means were 77.4 and 52.5, respectively). In fact, basic reaction speed was not found to be a significant predictor in this model ($p = .29$), further attesting to the independence of the magnitude of the lag-2 repetition cost from the basic reaction times of the two participant groups.

Finally, we examined whether the pattern of responses differed across the three experimental tasks – color, size and shape. Mean reaction times were calculated separately for each of the tasks for lag-2 repetition and lag-2 non-repetition trials, collapsing across the three CSI-RCI combinations, and were submitted to a three way ANOVA with one between-subjects factor of language group (monolingual, bilingual), and two within-subject factors of task (color, size, shape) and lag-2 trial type (lag-2 repetition, lag-2 non-repetition). As in the single task blocks, there was a main effect of task in the mixed blocks $F(1,58) = 49.28$, MSE = 5075333, $p < .001$, $\eta^2 = .46$. Participants responded fastest to the color task, more slowly to the size task and slowest of all to the shape task. It is interesting to note that in the single task blocks the size task was slower than the shape task, but this order was reversed in the mixed block tasks. Additionally, the effect of task difficulty interacted significantly with participant group $F(1,58) = 8.39$, MSE = 864401, $p < .01$, $\eta^2 = .13$. Post hoc comparisons indicated that bilinguals were significantly slower than monolinguals in the color task in the mixed blocks, $t(59) = 3.1$, $p < .01$, but that the two groups did not differ in their reaction times to the shape and size tasks. Importantly, the ranking of task difficulty in the mixed blocks was the same for both participant groups. The lag-2 repetition cost did not differ significantly across the three tasks ($p > .1$) and the three way interaction between task, lag-2 repetition and participant group was not significant either ($F < 1$).

### 3.3. Fadeout block

The performance in the final single-task block of the experiment, the fadeout block, was analyzed by dividing the trials in this block into 6 periods of 17 or 18 trials each (see Fig. 4).

Accuracy rates and RTs were submitted to a two-way repeated measures ANOVA with language group (monolingual, bilingual) as a between subjects variable, and period (1–6) as a within subject variable. The accuracy analysis yielded no significant effects (all $F < 1$). In the RT analysis there was a significant main effect of period, $F(1,58) = 83.54$, MSE = 2,097,093, $p < .001$, $\eta^2 = .59$, because participants became increasingly faster as they progressed through the fadeout block, and it became apparent that there were no more task switches. Planned comparisons demonstrated that in fact the final 3 periods in the fadeout block no longer significantly differed from each other, as the residual effects of the mixed block strategies had

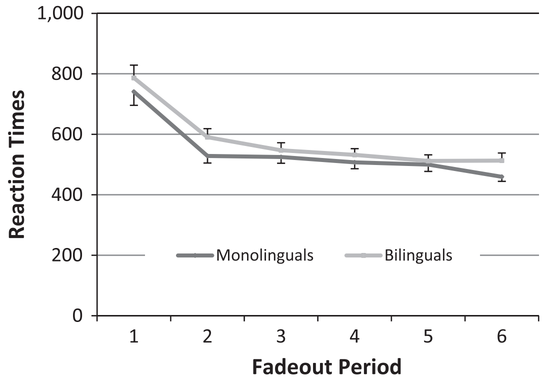


**Fig. 4.** Reaction times (ms, SEM) in the fadeout block by period, by language group.

dissipated by that point in the fadeout block. These effects were similar across monolinguals and bilinguals, the main effect of language groups was not significant ($p > .22$). Finally, there was no interaction between the two factors, $F < 1$.

To summarize, although the bilinguals were more strongly affected by the lag-2 repetition manipulation within the mixed task blocks, the participant groups did not differ in their ability to monitor changes in task demands and to shift their strategy and abandon task set inhibition when it was no longer necessary for optimal task performance.

## 4. Discussion

The current study set out to investigate two leading theoretical propositions regarding the nature and origin of bilingual cognitive advantages, namely the inhibition and the monitoring frameworks. The task switching paradigm introduced in this study allows an examination of the effects of inhibition and monitoring with relatively little overlap. Lag-2 task repetition costs were analyzed as a signature of inhibitory processing, and the fadeout effect was used to indicate monitoring of task demands, and flexibility in adapting to changing requirements. The results demonstrate that bilinguals apply stronger inhibition of task sets, resulting in more pronounced lag-2 repetition costs. However, no group differences were found in the fadeout effect. Additionally, bilinguals were not overall faster in performing the task, a pattern of results found in several previous studies and also taken to support more efficient monitoring in this population (Costa et al., 2009; Tao et al., 2011).

One of the challenges in the research on the cognitive consequences of bilingualism, as in any between groups design that does not include random assignment of participants to conditions, is the concern that variables other than language experience might be contributing to the effects found (Bialystok, 2009; Carlson & Meltzoff, 2008; Hilchey & Klein, 2011; Morton & Harper, 2007; Soveri, Rodriguez-Fornells, & Laine, 2011). Previous studies have controlled for between group differences in SES and non-verbal intelligence when these were not matched in the experimental samples (e.g. Carlson & Meltzoff, 2008; Prior & Gollan, 2011; Tao et al., 2011). As can be seen in Table 1, the groups in the current were well matched on background variables, with the exception of age. Because students in Israel begin their college education only after three years of military service, the groups could either be matched on age or on years of education but not on both. And indeed, the groups were similar with regard to their education experience, but the Hebrew-English bilinguals were significantly older than the English speaking monolinguals. However, because the groups performed similarly in most conditions and there were no significant main effects of group, we believe that the difference found in the lag-2 repetition cost cannot be attributed to the age difference. Further, age was not significantly correlated with the average lag-2 repetition cost in either participant group (both $p>.56$).

Lag-2 repetition costs are taken as a signature of inhibitory processes within the task switching paradigm (Kiesel et al., 2010; Koch et al., 2010). In the current research, the magnitude of the lag-2 repetition effect was the only measure that showed a reliable difference between the two participant groups. This highly specific finding is important in demonstrating stronger application of inhibition by bilinguals, even under conditions where this in fact leads to slower reaction times. Two additional studies using paradigms that more easily enable distinguishing inhibition from other types of executive control found comparable results. Colzato and colleagues (2008) report a stronger attentional blink for bilinguals when compared with monolinguals, though the authors say that this pattern of results can be explained not only by stronger reactive inhibition but by more efficient maintenance of task goals as well. Along the same lines, Treccani and colleagues (2009) report stronger negative priming for bilinguals than for monolinguals, demonstrating continuing inhibition of information that had recently been non-relevant for task performance. Both these studies, as well as the current results, use paradigms in which inhibition was applied and released in a sequential manner, as opposed to the case in tasks requiring inhibiting concurrently presented non-relevant information (such as Simon or ANT), in which conflict resolution advantages for bilinguals seem less stable across various studies (Costa et al., 2009; Hilchey & Klein, 2011).

The specific implementation of the task switching paradigm used in the current study differs from that used previously. In two previous studies, Prior and colleagues (Prior & Gollan, 2011; Prior & MacWhinney, 2010) compared the performance of bilinguals and monolinguals in a task-switching paradigm including only two tasks, and most importantly, including task repetition trials. The inclusion of task repetition trials allows for calculating switching costs, namely, the increased difficulty in responding on trials where the task set changes when compared to trials where the task set remains unchanged. In this paradigm bilinguals demonstrated a smaller switch cost than monolinguals, though in Prior and Gollan (2011) this finding was limited to only one of the two bilingual groups examined. An important question in this regard is how the current findings of a larger lag-2 repetition effect for bilinguals align with the previous results of reduced switching costs.

Previous task switching studies that have used paradigms allowing the calculation of both lag-2 repetition effects and switch costs are highly informative to this discussion.

Experiment 4 in the original Mayr and Keele (2000) study included three different tasks which allows for calculating lag-2 task repetition costs, but also included task repetition trials, that allow for calculating simple switch costs. Both types of costs were evident in this experimental paradigm, and the authors argue that some percentage of switch costs in two-task paradigms (like those used by Prior & MacWhinney, 2010 and by Prior & Gollan, 2011) might be due to persisting inhibition of the switched-to task on switch trials. Under this explanation, one would expect bilinguals to demonstrate larger switch costs in two-task paradigms, similar to the current finding of larger lag-2 repetition costs. One important caveat to keep in mind at this point, however, is that in Mayr and Keele (2000) participants were presented with four stimuli on each trial, and were required to identify the target that differed from distractors on the task dimension relevant for that trial (color, orientation or movement direction). This setup is rather different than the setup used in studies examining task switching performance in bilinguals.

Continuing research into the effects of lag-2 repetition costs and simple switch costs revealed a rather complex picture (Arbuthnott, 2008; Arbuthnott & Frank, 2000; Arbuthnott & Woodward, 2002; Dreher & Berman, 2002; Mayr, 2001; Mayr, 2002), in which some studies report robust lag-2 repetition effects even in the presence of task repetitions, whereas other studies do not. In a well controlled comparison, Philipp and Koch (2006) demonstrate a clear reduction or even reversal of lag-2 repetitions costs in the presence of task repetitions. The intriguing explanation that they offer is that the inclusion of task repetition trials fundamentally changes the strategic performance of the task, by altering the balance between inhibition and activation processes. Specifically, Philipp and Koch (2006) argue that interference resolution within the task switching paradigm, which is necessary to allow switching from one task to another, relies both on activation of the relevant switched-to task set and on inhibition of the no-longer relevant switched-from task set. In an experimental design that includes task repetitions strong task set activation is a more beneficial strategy (because inhibiting a task set would lead to a delay in performance in the case of task repetitions) and therefore the relative use of task set inhibition is reduced. On the contrary, experimental conditions where no task repetitions occur call for the strong implementation of task set inhibition, leading to increased lag-2 repetition costs.

This theoretical framework offers a basis for integrating the current findings with those reported previously by Prior and colleagues (2010); 2011). Thus, bilinguals in the present study were found to apply stronger inhibition to no-longer relevant task sets than monolinguals, leading to more residual inhibition when the task set is reinstated in a later trial, and therefore larger lag-2 repetition costs. Importantly, in this paradigm inhibition is the more dominant strategy for managing task set interference. The previously reported reduced switch costs in bilinguals relative to monolinguals most likely arise from more efficient activation of the relevant task set in switch trials to overcome proactive interference, as a mechanism for transient control processes for selecting between competing task sets (Prior & MacWhinney, 2010). Indeed, according to the theory presented by Philipp and Koch (2006) activation of the relevant task set would be the dominant strategy in paradigms where task repetitions occur. Thus, combining the present findings with those of (Prior & Gollan, 2011; Prior & MacWhinney, 2010) raises the possibility that bilinguals are more efficient at implementing the dominant strategy for overcoming task set interference, dictated by experimental conditions, regardless of whether it is inhibition or activation.

This suggestion of a more generalized control advantage for bilinguals over monolinguals is reminiscent of the conclusions set forth recently in the review by Hilchey and Klein (2011). They claim that the literature on bilingual advantages is commensurate with an advantage in "a central executive system that has some capacity to regulate processing across a wide variety of task demands" (p. 654). The current pattern of results does not align with Hilchey & Klein, 2011 additional claim that there is no bilingual advantage in inhibition per se, but as discussed below, the two are clearly not mutually exclusive.

As far as monitoring abilities, and similarly to previously reported findings using task switching paradigms, bilingual participants in the current study did not exhibit an advantage in this domain. Fadeout effects and overall response speed, two measures that reflect monitoring abilities, were equivalent for the two participant groups. This is similar to previous task switching studies in which bilinguals had smaller switch costs but equivalent overall response times (Garbin et al., 2010; Prior & Gollan, 2011; Prior & MacWhinney, 2010), but contrasts with finding from conflict resolution tasks, where overall speed advantages are robust (Costa et al., 2009; Hilchey & Klein, 2011).

However, the fadeout effect by definition relies on a relatively small number of trials, within a single experimental block. In the current study we did find a significant main effect of the fadeout manipulation, demonstrating some sensitivity of this measure for detecting differences in performance and alleviating concerns of a strong ceiling effect. Despite these findings, it is still possible that the lack of a main effect of group or of an interaction might be due to the lower power of this comparison. It is also possible that an advantage in maintaining high levels of monitoring under circumstances of changing demands (as in the concurrent conflict paradigms) does not translate directly to the ability to quickly adjust to a precipitous drop in demands as in the transition from the mixed block to the single task block measured in the fadeout block. Thus, we acknowledge that while the lack of overall speed advantages for the bilinguals is a robust finding, the fact that we found no differences in the fadeout effect between the groups should probably be taken as more suggestive.

Indeed, the possibility outlined above, that bilinguals might be more efficient in using activation and inhibition mechanisms specifically as determined by experimental conditions (e.g. the presence or absence of task repetitions) might suggest that bilinguals could be more adept at tailoring control mechanisms to experimental conditions.

This facility might be construed as an advantage in monitoring, or in the central executive system as suggested by Hilchey and Klein (2011). In this light, the lack of evidence for monitoring advantages for bilinguals in the current paradigm should be investigated at greater depth. For example, future work can examine this issue by directly comparing lag-2 repetition effects in the presence or absence of task repetitions in monolinguals and bilinguals. Further, more sensitive and specific measures of monitoring abilities within the task switching paradigm should also be investigated.

Thus, the main significance of the current results is in demonstrating stronger bilingual inhibition and the apparent absence of monitoring advantages in a paradigm that allows an easy distinction between these two processes that tend to be confounded in other paradigms. Taken in isolation, it is tempting to take these findings as strong evidence supporting the inhibition, or conflict resultion, explanation of bilingual advantages over the monitoring theory. However, an attempt to interpret these findings in conjunction with previous findings in the recent literature leads to a more complicated explanation. Recent reviews of the literature comparing bilinguals and monolinguals in conflict resolution tasks (Costa et al., 2009; Hilchey & Klein, 2011) claim that evidence supporting a bilingual advantage in inhibitory control are less robust than evidence supporting an advantage in monitoring. But as described above, several studies have used other paradigms to examine bilingual and monolingual inhibitory control in young adults and have found stronger inhibition for bilinguals (Colzato et al., 2008; Treccani et al., 2009). The current results are in accord with these latter findings, in that they not only demonstrate the application of stronger inhibition by bilinguals, but they do so when such inhibition comes at a cost to performance. And finally, still other studies demonstrate bilingual advantages in further aspects of executive function, such as shifting and cognitive flexibility (Bialystok, 2010; Prior & Gollan, 2011; Prior & MacWhinney, 2010). Thus, it might be that the specific control demands posed by concurrent interference as opposed to proactive interference paradigms are differentially sensitive to bilingual advantages in the specific executive components of overall control and inhibitory control, respectively (also suggested by Hilchey & Klein, 2011).

Complicating this already diverse literature is the fact that bilingual populations are highly heterogeneous with regards to the language combination they speak, the age of acquisition of each language, and the relative proficiency in each language, to name only several factors. Currently, the literature is at a stage where such factors are most likely confounded with the specific methodology adopted in any single study, which makes the variability in results rather difficult to interpret with any degree of certainty. Two recent studies have made first attempts to investigate these issues. Prior and Gollan (2011) compared Spanish–English and Mandarin-English bilinguals with English speaking monolinguals in a non-linguistic task switching paradigm. After controlling for SES and basic response speed, only the Spanish–English bilinguals were found to have smaller task switching costs relative to the monolinguals. The Spanish–English bilinguals reported switching languages more often in daily use, and also switched languages more efficiently than the Mandarin-English bilinguals in a language switching paradigm, which lead the authors to suggest that it might be the experience with switching languages frequently that lead to the advantage in non-linguistic task switching (see Soveri et al., 2011, for converging results, but Calabria, Hernandez, Branzi, & Costa, 2012, for a different perspective). Tao and colleagues (2011) investigated the roles of age of acquisition and proficiency in influencing bilingual executive control using the ANT. The study compared early and late Chinese-English bilinguals with English speaking monolinguals, and again found differences between the groups. The early bilinguals, who were relatively less balanced in their Chinese and English proficiency, showed advantages in monitoring, whereas the late bilinguals, who were more balanced, showed advantages mainly in conflict resolution. These results again support the notion that different aspects of language experience may differentially shape the mechanisms and manifestations of cognitive control in bilinguals.

A similar proposal has also recently been put forth by Green (2011), citing the behavioral ecology of bilingual speakers. Green suggests that different bilingual life experiences might lead to the development of different mechanisms of language control, and consequently to different advantages in cognitive control generally. The current study does not address this issue directly, because it included a single relatively homogeneous bilingual population. However, we do believe that it is important to keep these issues in mind in any attempt to offer an integrated understanding of the extant literature.

## 5. Conclusion

We suggest that the significance of the present results is not in settling the discussion between competing theories on bilingual language and cognitive control, as indeed no single study can do. But rather, these findings should be taken as one of a growing number of data points that will ultimately lead to a better understanding of the nature and variability of bilingual language and cognitive profiles. Specifically, we have demonstrated the application of stronger inhibition by bilinguals in a task switching paradigm, where such inhibition leads to a decrease in performance. Further, although it is clearly important to continue examining previously used experimental tasks in new and diverse populations, we believe it is also important to benefit from the great variety of complex and sensitive tasks that have been developed in the general cognitive control literature in the ongoing investigation of the cognitive consequences of bilingualism.

At this point in time both the inhibition account and the monitoring account of bilingual advantages receive empirical support, albeit mostly from different paradigms. There is also accruing data demonstrating bilingual advantages in other components of executive function, such as set shifting (Bialystok, 2010; Prior & MacWhinney, 2010). However, it is still premature to conclude whether the variability between studies is related to the specific task demands of the different paradigms used, or to differences between the bilingual populations recruited in different studies and the specific characteristics of their bilingual experience, a possibility that is far more interesting theoretically and practically.

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