

ABSTRACT

Title of thesis: THE ROLE OF DOMAIN GENERAL
COGNITIVE MECHANISMS IN BILINGUAL
LANGUAGE PRODUCTION

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Bilingual language production is widely believed to be a competitive process. Bilinguals may manage this competition by relying on inhibiting one language while speaking in the other. However, it remains unclear if this process relies on domain general inhibitory mechanisms, and, if so, when and where during language production control is applied. The current study investigates these issues by experimentally manipulating demand on domain-general inhibitory control during a language switching paradigm. If inhibitory control is required to switch between languages, inhibitory demand during the switch trials is predicted to make switching more difficult. Across three experiments, switching costs were not exacerbated when inhibitory control was taxed, language switching was *less* costly during inhibition-demanding trials. These findings question the role of inhibitory control in language switching and suggest revising the current models of language control in bilingual production.

THE ROLE OF DOMAIN GENERAL COGNITIVE MECHANISMS IN
BILINGUAL LANGUAGE PRODUCTION

by

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Introduction

To begin to understand the complexity of language production consider that for a speaker to simply say a single word, she must first select an appropriate lexical item, which represents her intended concept, and eventually map this onto an articulation of sounds that represent this chosen lexical item. The process however, is more complex than a single mapping from concept to sound, and it is generally agreed that it involves a hierarchy of stages from start to end (e.g., Caramazza, 1997; Dell & O'Seaghdha, 1992; Levelt, Roelofs, & Meyer, 1999). Though the procedure of speaking involves processes at multiple stages, the focus of this paper specifically concerns processing involved in the selection of an appropriate lexical representation and thus discussion will concentrate on this aspect of the process.

A consensus model of word production, which focuses on these stages, is depicted below in Figure 1a. As shown, a lexical concept activates an array of lexical items. These items, (often called *lemmas*; Kempen & Huijbers, 1983), are abstract word representations which carry semantic and syntactic information without word-form information (thus, for instance, distinguish between homonyms; Kempen & Huijbers, 1983; Levelt et al., 1999). Early speech error data served as important evidence in developing and supporting a model which included spreading activation to both the target lemma and those lemmas sharing properties with the target, finding that whole-word substitution errors tend to occur between items that share both semantic and syntactic properties (e.g., substituting 'dog' with 'cat', but not 'table' or 'bark'; Garrett, 1976). Since activation to the lemmas spreads both to the target and to meaning-similar lemmas, selection is influenced by the ratio of the activation of the

target relative to all activated lexical items, as well as the absolute difference between activation of a target and its competitor; suggesting that both the number of competitors, and the strength of each competitor play a role in the competition for selection (Levelt et al., 1999).

Indeed, lemma selection is generally agreed to be a competitive process, (e.g., Harley & MacAndrew, 2001; Levelt et al., 1999; Miozzo & Caramzza, 2003). One type of evidence for competitive lexical selection is that distractor items can compete during selection and therefore interfere with production. For instance, picture naming becomes more difficult (i.e., is slower) with increased activation of semantically similar lexical items from recent production (e.g., Belke, 2013; Damian, Vigliocco & Levelt, 2001). A well-studied paradigm used to investigate competition in production is the picture word interference (PWI) task, which manipulates the level of competition in picture naming by adjusting the target-distractor relationship. Classically, this task has found slowed picture naming when distractor words (presented either aurally or superimposed in print), are semantically related to the pictured item (Damian & Bowers, 2003; Glaser, & Döngelhoff, 1984; Schriefers, Meyer & Levelt, 1990). As the production model suggests, a lexical concept will activate not only its lemma but also semantically similar lemmas. Thus, a semantically similar distractor can additionally activate a competing lemma, making competition greater. Importantly, these effects are only seen when the distractor is timed to appear at or just before the picture onset, suggesting that semantic interference occurs at the early stages of production, presumably reflecting competition at lexical selection. More recently, however, it has been argued that the

story is not so straightforward, as manipulating time or the type of semantic target-distractor relation may, in fact, sometimes result in facilitation (Caramazza & Costa, 2001; Costa, Alario & Caramazza, 2005). Other findings question the role of activation levels in the selection process wherein low frequency distractors, believed to have lower levels of activation in the mental lexicon (e.g., McClelland & Rumelhart, 1981), may cause more interference than high frequency distractors (Miozzo & Caramazza, 2003). Yet, while the details of lexical interference in word production are clearly complicated and still under debate, it is nevertheless clear that competition in selection does exist and plays a role in the process of language production.

Bilingual Production

As reviewed, selecting a word requires overcoming competition from related lexical items. Imagine then, a case of lexical competition among not only semantically *similar* items, but also among semantically *identical* items in another language: that is, bilingual language production. In bilingual production, if lexical items in both languages are available for selection, competition should become even greater. It is generally agreed, and is well substantiated with evidence of cross language facilitation and interference, that multiple languages are in fact active at the point of selection (e.g., Costa, Miozzo, & Caramazza, 1999, Kroll, Bobb & Wodniecka, 2006), and thus that there is additional competition in bilingual production (e.g., Bialystok & Craik, 2010 Gollan & Silverberg, 2001). Figure 1b depicts a schematic of bilingual production, demonstrating increased competition from the additional active lemmas.

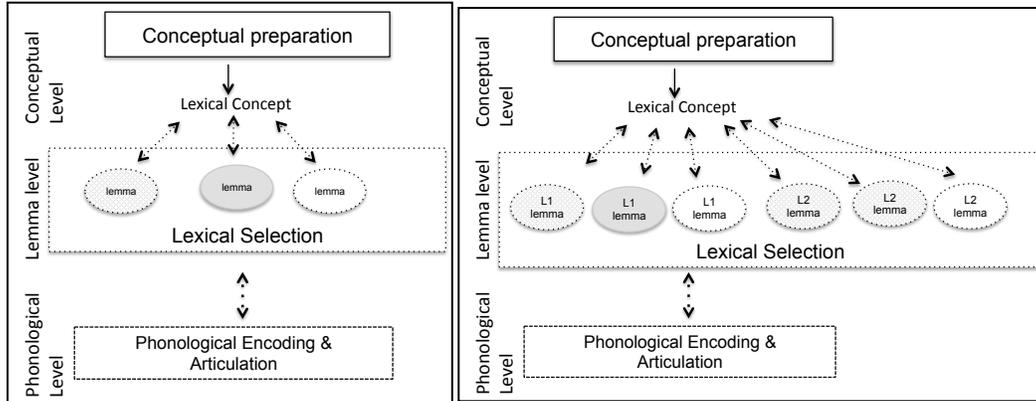


Figure 1.

- a) (Left): Model of monolingual speech production process (adapted from Levelt et al., 1999; Kroll, Bobb & Wodniecka, 2006). Arrows represent activation between levels while shading in nodes represents amount of activation. The model is zoomed in on the lemma level and does not specify the details at the phonological level.
- b) (Right): Model of bilingual speech production process Note that the location of the lemma nodes is representative and do not specify that dominant language (L1) and second language (L2) lemmas must be in distinct regions.

It then follows that this additional competition from the non-target language needs to be resolved in order to successfully produce the lexical item in the target language. How speakers are able to deal with this conflict is still unsettled, however, an influential model of bilingual production, the inhibitory model, proposes that bilinguals use inhibitory control to suppress the non-target language (Green, 1998). Specifically, the claim is tied to the role of domain-general control, suggesting that, rather than a mechanism devoted specifically to language control, these mechanisms are likely to also be involved in non-linguistic inhibitory tasks. Evidence for the domain generality of inhibitory control in language will be discussed, with the aim to better understand its specific role in bilingual language control and how this might impact domain general cognitive performance. Furthermore, its role will be investigated experimentally in the studies to follow.

Much of the evidence for the role of domain-general inhibitory control in lexical competition is found in correlational studies using separate measures of inhibitory control and of language performance. Mercier, Pivneva, and Titone (2013) investigated the role of domain-general inhibitory control in language *comprehension* using an eye-tracking paradigm to monitor the influence of competing lexical items on a target word. Using a battery of inhibition tasks, they created a separate measure for two types of inhibitory control: cognitive (Simon and Stroop) and oculomotor (pure and mixed anti-saccade tasks). They found that cognitive inhibitory control was negatively correlated with within-language competition for all participants and that both cognitive and oculomotor inhibition modulated between-language competition for bilinguals with lower levels of proficiency in their second language (L2). This suggests that domain-general inhibitory control can modulate both within and between-language competition and additionally, that greater recruitment of this control might be needed for low proficiency bilinguals who may experience more competition from a more active first language (L1). Another type of, albeit controversial, support for the role of domain-general inhibitory control in bilingual language production comes from literature suggesting that a bilingual's lifetime of practicing inhibitory control in guiding her language use may *transfer* to improved performance in domain-general attention and inhibitory control tasks, i.e., the bilingual advantage (e.g., Abutalebi et al., 2012, Bialystok, 1999; Bialystok and Martin, 2004; Bialystok, Craik, Grandy, et al., 2005; but see de Bruin, Treccani, & Della Sala, 2014; Papp & Greenberg, 2013).

Experimental support for the general role of inhibitory control in bilingual production is frequently shown in the context of language-switching tasks. Similar to classic task-switching paradigms, a language-switching task requires a speaker to name items in a particular language, indicated by a language cue. The paradigm involves both staying within a single language (stay trials), and switching from one language to the other (switch trials). There is considerable evidence that there is a cost associated with a switch between tasks (measured in increased reaction time in a switch trial vs. stay trial; cf. switching costs outside of the linguistic domain; see Monsell, 2003, for a review). There are often findings that switching costs are, counter-intuitively, typically smaller when switching from a stronger to a weaker task (Wylie & Allport, 2000; cf. Monsell, Yeung & Azuma, 2000). This is often taken as evidence of interference from the non-target task, which needs to be inhibited in order to perform the target task. (Specifically, because the dominant task is more active, it competes more for selection, and therefore requires a higher level of inhibition that must then be overcome on the next dominant-task trial.) Similarly, in switching between languages, a speaker incurs a language-switching cost, and, in unbalanced bilinguals, an analogous switch cost asymmetry. That is, there is a larger cost when switching into a dominant language (L1) than into a less dominant L2 (e.g., Guo, Liu, Misra & Kroll, 2011; Meuter & Allport, 1999, but see Finkbeiner et al, 2006, Verhoeft et al., 2009).

These findings generally suggest that the L1 is a stronger competitor for selection than the L2, and thus needs to be suppressed to a greater extent in order to produce the L2. This L1 inhibition *persists* into the following trial, making a future

switch back *into* the L1 more difficult. Interestingly, these switch costs have been shown to vary as a function of individual differences in performance on a domain general inhibitory task (Linck, Schwieter, & Sunderman, 2012). Linck and colleagues (2012) reported a correlation between inhibitory control, as measured by a modified Simon task (Simon & Ruddle, 1967), and language switching in trilingual speakers. Those speakers who were better able to overcome interference on the Simon task incurred smaller switch costs when switching into to their L1 (which, again, is assumed to incur the most inhibition due to its dominance). This suggests that similar processes are likely used in these two tasks and therefore supports a role of inhibitory control in language switching.

Note that while these switch costs have been argued to reflect, in part, reconfiguration of the requirements of the upcoming task, rather than simply an effect of prior-task inhibition, reconfiguration does not appear to account for the cost in its entirety (e.g., Koch, Gade, Schuch & Philipp, 2010; Philipp & Koch, 2009; Wylie & Allport, 2000). Specifically, evidence that language switching costs reflect inhibition of the non-target language and not just task set reconfiguration comes from Philipp and Koch (2009), who demonstrated the lingering effects of inhibition using a design that helped to dissociate reconfiguration *into* a new task set and switching *out* of a particular language. Their paradigm involved a language-switch task with three languages, where speakers showed reduced performance (increased latency) on a particular language trial after recently switching out of that language (i.e., French, English, *French*) compared to performance when it had not been switched out of recently (i.e., German, English, *French*). These costs, reflecting an effect of trial n-2

repetition (repetition of the language used two trials back), are taken as evidence for lingering inhibition from the first language switch. That is, in order to successfully switch out of French to produce English, French becomes inhibited. This residual inhibition thus makes the switch back *into* French more difficult, thereby further supporting the inhibitory control model in language switching. Note, however, that while these findings may support inhibition in this paradigm, other findings suggest that the processes used in task switching (i.e. n-1 repetition) and this n-2 repetition paradigm, are not one in the same. For example, as reviewed by Kiesel, Wendt, Jost, et al. (2010), manipulations of preparation time and the strength of the cue to task association can influence task n-1 repetition costs, but not the n-2 repetition cost, supporting dissociation between these task types. Thus, while inhibitory processes do play a role in task control, task-switching paradigms do not necessarily provide complete support for the role of inhibitory control in task switching.

In contrast, a *lack* of an asymmetric switch cost has been used as evidence that inhibition is *not* required for language control for all bilinguals. For instance, Costa and Santesteban (2004) demonstrate that while bilinguals with a dominant L1 show typical asymmetrical switch costs, balanced bilinguals (who are equally proficient in L1 and L2) fail to show an asymmetry in cost between L1 and L2. Importantly they also fail to show the asymmetry between L1 and a third language (L3) in which they are relatively unskilled. This is taken as evidence against the use of inhibitory control in language switching tasks in balanced bilinguals, regardless of the demands of the language task.

One account that is a viable alternative for the inhibitory control model, and can explain some of the findings in language selection is the response exclusion hypothesis, rooted in the concept of relative activation of lexical items. Instead of relying on inhibition of non-target items, this account assumes that an item can be rejected more or less easily based on its level of relevance, that is, how similar it is to the target item in terms of how many features they share (e.g., Costa, Mizzo, & Carmazza, 1999). Similarly, a differential activation account (Finkbeiner, Almeida, Jansenn & Carmazza, 2006) proposes that higher activation of a word (due to factors such as frequency, length, language dominance, etc.), can speed response exclusion on task-switch trials, where it is likely the active response is irrelevant to the non-target task. This differential activation account is able to explain classic task switching asymmetries in that a less dominant language is less accessible, and accordingly, incurs a smaller switch cost. These accounts, which support activation levels, rather than inhibition, in language control will be considered further in the discussion.

Other accounts that offer alternatives to the inhibitory control hypothesis are also based on activation, rather than inhibition. First, “persistent activation” (e.g., Philipp et al., 2007; Gade & Koch, 2005) suggests that strong activation of the weaker task persists, making the upcoming switch into a dominant task more difficult. Thus, rather than dealing with overcoming previous inhibition, persistent activation is more concerned with the current level of activation and is rooted in classic task switch literature’s task set inertia hypothesis (e.g., Wylie and Allport, 2000). Additional support for an important role of activation, rather than inhibition, has been

demonstrated by the “stay benefit” (e.g., De Baene et al, 2012), showing both reduced reaction times and neural adaptation over consecutive stay trials.

Alternatively, some accounts of language selection claim that it is *not* a competitive process. For example, Costa, Miozzo, and Caramazza (1999) found that in a PWI task, interference effects of a semantic competitor occurred both when the word was presented in the target naming language and when it was written in the non-target language. These findings are taken as evidence that while both languages are in fact activated, they do not compete for selection. Bloem and La Heij (2003) take this even further, suggesting a language specific account of lexical access without competition at the lexical level. Based on findings that while related words hindered naming in a translation task, related *pictures facilitated* translation, they propose that competition is resolved at the earliest stage of production, the conceptual level, that only the target concept is lexicalized, and therefore lexical competition, as has been discussed, does not occur. (Note that, their theory does account for the effect of semantic interference in PWI tasks, proposing that interference occurs due to spreading activation from target to related items, as a by-product of the lexicalization process.) As discussed, while there is certainly some evidence against competition, as well as the role of inhibitory processes in language selection, there is also substantial evidence supporting competition between active languages in bilingual production.

So far, this paper has pointed to evidence proposing a role of competition in lexical selection, which may be exacerbated in bilinguals, and a role of domain-general inhibition in resolving the competition. However, as reviewed, support for

this competition is mixed (e.g., Bloem & LaHeij, 2003; Costa et al., 1999). In addition, inferences based on the asymmetrical switch costs are beginning to be questioned (e.g., Bobb & Wodnieka, 2013). Furthermore the research supporting a correlation between individual differences in domain-general inhibitory control and successful lexical production has been mainly correlational. So it remains possible that other factors (e.g., social economic status, education, etc.) may be responsible for the link between the inhibitory measures and language performance. Accordingly the role of domain-general inhibitory control in these competitive language processes, specifically in the process of bilingual production, is still uncertain. As such, it is also unclear if maintenance of multiple languages has any extra-linguistic cognitive consequences. An aim of this paper is thus to clarify the role of domain-general inhibitory control in bilingual language production by experimentally manipulating the availability of inhibitory control during bilingual production tasks. If domain-general processes do play a role in production, there are at least two ways they may interact with demands of bilingual lexical access: as a competition for limited resources, or as an adaptation from induced conflict; these will be discussed in turn in the following sections.

The Limited Resource Model

Lexical selection can be considered a resource-limited process, in that when demands are too high or resources are depleted, task performance may be diminished. In production, dual-task paradigms have substantiated this resource-limited model either by manipulating the demands imposed by lexical selection and monitoring its impact on a concurrent task, or conversely by manipulating the demands on the

concurrent task and monitoring its impact on production. As the demands become greater, a detrimental impact from a concurrent task would support shared resources. For example, in Ferreira and Pashler's (2002) sentence completion task with a concurrent tone discrimination task, when demands of the sentence completion task were high, there was not only an increase in reaction time on the completion task, but also on the concurrent tone discrimination task. The authors discuss the interaction from increased demands on one task affecting another in terms of an impasse at a 'central bottleneck', which requires the first task be completed before the second. It is argued that when a task is subject to this bottleneck, it indicates use of domain-general resources (Pashler, 1994). Note, that not all tasks are subject to this bottleneck; for example automatized processes such as word reading may bypass the bottleneck, and it is important to consider how this may effect the relative timing of tasks (Kleinman, 2013). Another way to interfere with lexical selection is by manipulating demands on working memory. Belke (2013) demonstrated this using a blocked cyclic naming task, comparing item naming in homogenous blocks (high competition), where items all fell within one semantic category, to heterogeneous blocks (low competition), where items spanned multiple categories. She found that a concurrent working memory load, in the form of a digit-retention task, impaired naming performance (increased naming latencies) selectively in the homogenous block, where competition among items was higher. These studies demonstrate the impact of a concurrent task, or load, on production, and suggest an over additive interaction between a cognitive load and demands in production due to limited resources. As such, if bilingual production does in fact require domain-general

resources, it is predicted that it will be subject to the limited capacity of these resources. That is, a concurrent task that shares resources with language selection should interact with a bilingual production task by reducing the ability to deal with the language conflict, and therefore increase difficulty in selecting appropriate lexical items. Though this effect should occur on all production trials, it is predicted to be particularly pronounced on a language switch (i.e. it should lead to an over-additive interaction between inhibitory demands and language switching), if additional control is in fact needed in order to switch into the new language.

The Adaptation Model

While the limited resource model predicts over-additive interactions when resources are shared, the theory of conflict monitoring and adaptation suggests that conflict on one task can in turn *reduce* conflict on an upcoming task, positing an *under additive* interaction between the two tasks. Gratton, Coles and Donchin (1992) demonstrated this with a continuous flanker task (Eriksen, 1995)¹ used to investigate adjustments in response after conflict, vs. non-conflict trials. Interestingly, there seemed to be more susceptibility to interference on trials that followed congruent, compared with incongruent stimuli. They propose that in the context of congruent and incongruent choices, a congruent trial encourages greater bottom-up (parallel) processing compared to top-down (focused) processing of the upcoming stimulus (Gratton, et al., 1992). This finding, termed *conflict adaptation* (or sometimes the *Gratton effect*) is more typically discussed as a *reduced* interference effect (that is, the

¹ The flanker task is an inhibitory control task, which involves response to the direction of the middle arrow within a series of arrows in a line (e.g., <<><< vs. <<<<<<). The middle arrow either points in

reaction time for incongruent (I) minus congruent (C) trials) following incongruent (I-I), compared to congruent trials (C-I) (e.g., Botvinick, Braver, Barch, Carter & Cohen, 2001; Kan, Tuebner-Rhodes, Drummey, Nutile, Krupa & Novick, 2013; Kerns, 2004). This reduced interference suggests that adaptation from conflict on a previous incongruent trial allows more efficient responding to a subsequent incongruent stimulus. As it has been shown that conflict adaptation can occur between tasks that share similar levels of conflict processing (Kan et al., 2013), it is possible that adaptation could potentially occur between the two tasks in a dual task paradigm. If so, an under-additive effect might indicate a shared level of conflict processing between the tasks.

The current study aims to examine the role of domain-general inhibitory control in bilingual language switching by combining a domain-general task requiring inhibitory control and a language-switching task. Experiments 1a and 1b were designed to investigate this with a limited resource model approach. By this account, switching between a bilingual's two languages and managing interference in the Simon arrow task rely on shared resources, so there should be an interaction between the two tasks. According to classic language switch accounts, if both the language switch and the incongruent arrow task draw on a shared pool of inhibitory control resources, taxing inhibitory control by introducing an incongruent arrow during a language switch should make the switch more difficult, and increase the switch cost. If, however the tasks do not rely on shared resources, there should be no interaction between these tasks. The set of experiments discussed in the remainder of this paper use a set of similar methods as a means to better grasp the connection between

language switching, lexical competition, and domain general control with the aim of better defining bilingual language control. Note that for all experiments, recruitment of participants was aimed at 40 participants per experiment. However, due to participant availability and qualification, this number was not always obtained, thus the total number will be reported for each experiment.

Experiment 1a

Methods

Participants. For Experiment 1, a total number of 37 native English-speaking adults with intermediate proficiency in a second language (currently or recently having taken intermediate to upper level college language courses) were recruited from the University of Maryland and paid \$10 for their participation. The enrolled participants' second languages included French (10), Spanish (26), and Japanese (1).

Materials and Procedure. Forty black and white drawn images from the International Picture Naming Project (IPNP) database (Szekely et al., 2004) were chosen to have high name agreement in Spanish and English (mean agreement rates were 93%, for both Spanish and English). Name agreement statistics are presented in Appendix B. Each picture appeared in the center of the screen, and appeared equally often within one of two language cues: a square, to indicate naming in the L1, or a circle, to indicate naming in the L2. For the arrow task, left and right pointing black arrow symbols, 2.5 cm in length each of which appeared equally often on the left or right side of the screen, (1 cm to the left or right of the picture stimulus) created congruent (stimulus-location match) an incongruent (stimulus-location mismatch) arrow conditions. Items were pseudo-randomized into two lists of 320 total trials, using the Mix program (van Casteren & Davis, 2006) according to the following constraints:

1. A fixed order for L1 and L2 language cues with a pattern of L1, L1, L2, L2, based on alternating runs design (Rogers & Monsell, 1995).

2. A minimum distance of 10 items between two of the same picture items.
3. A maximum of 5 sequential trials with the same arrow congruency condition.
4. A maximum of 4 sequential trials with the same arrow direction.
5. A maximum of 4 sequential trials with the same arrow locations.

The two lists were alternately assigned to the participants to counter any order effect of the items. As no differences were found between participants in either group, the data were analyzed and are discussed across lists.

All reported experiments were administered using PsyScope X (Build 57; Bonatti, n.d.; Cohen, MacWhinney, Flatt & Provost, 1993), and vocal responses and voice onset times were digitally recorded with a head-mounted microphone connected to an IOlab response box. The microphone sensitivity was calibrated for each participant at the start of the session.

Naming practice. During Experiment 1 there were 40 practice item-naming trials in L1 (English), and 40 in the speaker's L2 (Spanish, French, or Japanese). Each item in this set was displayed within a square, which indicated that the picture should be named in the L1, or a circle, which indicated that the picture should be named in the L2. During the practice, if the participant could not name the item, the experimenter provided the name and ensured that the participant was comfortable with the missed items at the end of the practice block. One participant who needed assistance with more than five items was excluded from the analysis.

Switching practice. Following each single-language naming session was an 80-trial practice language-switch session. Each picture was presented once with each language cue, in a pre-randomized order, again indicated with a square (for L1) or circle (for L2) following the alternating runs pattern. Participants were informed that languages would alternate predictably, i.e., two naming trials in the L1 would be followed by two trials in the L2.

Arrow practice. The arrow task, a variant of the Simon task (Simon & Rudel, 1967) involved directional arrows in congruent and incongruent locations. Participants were told that left and right pointing arrows (direction) would appear on either side of the screen (location) and were instructed to press a button corresponding to the direction of the arrow (M for right and Z for left), while ignoring its location on the screen. Each trial began with a fixation cross in the center of the screen for 200ms followed by the arrow onset, which appeared after one of four randomized delays: 180, 210, 240, or 270ms. These delays were chosen to match the stimulus onset asynchronies (SOAs) in the combined task (as described below). There were 100 trials, with auditory feedback following incorrect responses (a low sound—the stock “basso” sound clip from the Mac OS).

Combined task. The combined task totaled 320 trials, with a break every 80 trials. The instructions indicated that participants would be performing the switching task and the arrow task at the same time. The items were presented in the predetermined order for each list as described above. Each trial began with a picture within either a square (the cue for L1 naming) or a circle (the cue for L2 naming), as described in the switching task. After a randomly selected SOA (from four options:

180, 210, 240, or 270ms), an arrow appeared. This onset range was chosen so that the arrow would likely appear during lemma selection, the point of predicted competition in the production process, based on estimates of the timing of word production (Indefrey & Levelt, 2004). Thus, the conflict from the arrow was timed to tax inhibitory resources at the predicted time point of lexical conflict in the language switching task. The picture remained on the screen until the voice key was triggered at the onset of the participant's speech (voice key RT) while the arrow remained on the screen until a keyboard response was recorded (key press and arrow RT). There was a 2 second ITI between the picture stimuli. An experimenter remained in the room during this session to monitor for, and record, errors in production or voice key errors (accidental voice key triggers due to extraneous sounds, or failure to detect speech onset). Figure 2 gives a schematic of a single trial.

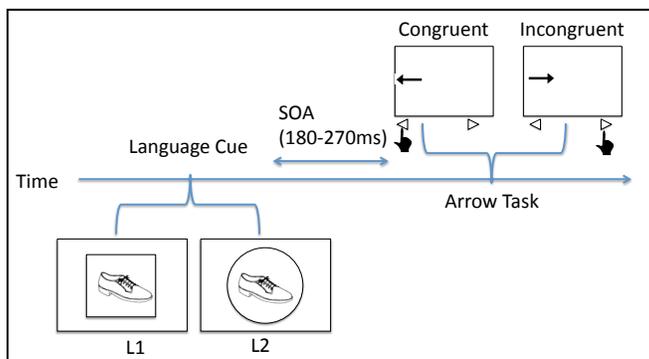


Figure 2. Schematic of Experiment 1a combined task.

Questionnaire. Participants completed the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian, Blumenfeld, & Kaushanskaya, 2007), which assesses language proficiency and exposure for all languages spoken, following completion of the combined task. This was used to verify English dominance and

proficiency in the second language (see Appendix A for language history data for all experiments).

Design and Analysis

Reaction Time. All trials with errors in the verbal response (499, 4.2%) or the arrow response (200, 1.7%) and all voice key detection errors (i.e. when a trial was skipped or not appropriately detected due to the microphone calibration or extraneous noises, 108, 0.9%) were removed from the reaction time data analysis. The following trimming protocol was implemented for all experiments reported in this paper: the most extreme 3% of values (trials with RT's above the 98.5 percentile and below the 1.5 percentile) from the entire dataset were excluded. Following this, RT's greater than 2 standard deviations from each subject's mean (528, 4.93%) were removed from analysis. In total these criteria led to the removal of 11,662 trials (14.03% of all trials).

For all experiments, voice key response times were log transformed and analyzed using generalized linear mixed effects models in the statistical software R version 3.1.1 (R Core Team, 2014).² Switch condition (switch or stay language trial) and arrow congruency (incongruent or congruent) were entered as fixed effects using orthogonal contrast coding. The fully specified random effects structure was included for both participants and items (pictures), however only the fixed effects will be reported here, as these were the only effects of theoretical interest. Because the lmer function (Bates, Maechler, Bolker & Walker, 2014) does not calculate *p*-value for

² Note that for ease of interpretation, data in plots and tables are reported as untransformed means of mean participant RT's.

models with random-effect slopes, in part due to difficulty calculating degrees of freedom, t -values with an absolute value greater than 2 were considered to indicate a significant effect (Gelman & Hill, 2007).

Accuracy. For all experiments, accuracy data from the main tasks are reported both for descriptive statistics and statistical analyses along with the RT data for experiment. Due to the nature of the accuracy data, with very few errors, the fully specified random effects models (including random slopes) were unable to converge. Therefore for the accuracy analyses the random intercept models are reported.

Results and Discussion

As can be seen in Figure 3 and by the statistical tests presented in Table 1a, participants showed a typical language switch cost, where picture naming in the switch condition (when switching into a new language) took longer than in the stay condition (naming an item in the same language as the preceding trial). There was also a main effect of arrow congruency on naming times and accuracy (see Table 1b for accuracy). That is, pictures were named more slowly, and less accurately on trials with incongruent arrows compared to trials with congruent arrows. There was a main effect of language, with longer naming times in L2 than in L1 (note that there was also higher accuracy in the L2 than the L1, reflecting a tendency to remain in the L2). Finally, there was an interaction between switch condition and arrow congruency, where the effect of switching (switch cost) was smaller on incongruent arrow trials than on congruent arrow trials, however this was not reflected in naming accuracy. No other effects reached statistical significance.

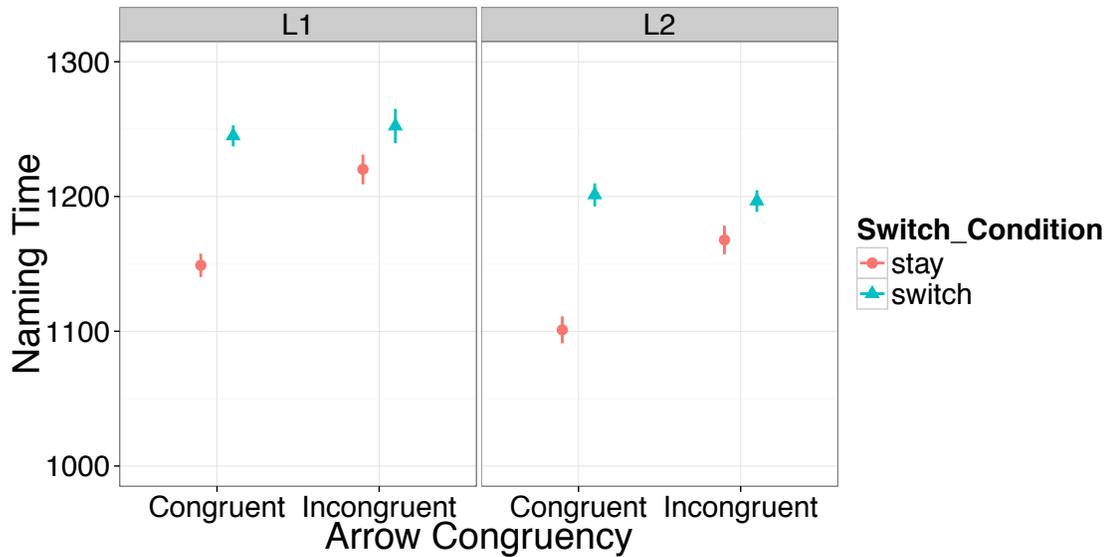


Figure 3. Experiment 1a: Naming reaction time (ms) by arrow congruency condition and switch condition and language. Plotted data are means of subject means (though note that analyses were conducted over non-averaged log-transformed data). Error bars indicate standard error of the mean.

Table 1a

Experiment 1a: Fixed Effects for Fully Specified Model of Naming Reaction Time

Naming RT Fixed effects	Estimate	Std Error	t-value
(Intercept)	7.01	0.03	266.01
Switch Condition	0.09	0.01	5.75
Arrow Congruency	0.06	0.02	3.46
Lang	-0.04	0.02	-2.39
Switch Condition*Arrow Congruency	-0.05	0.02	-2.24
Switch Conditions*Lang	0.00	0.02	-0.01
Arrow Congruency*Lang	0.00	0.02	0.07
Switch Condition*Arrow Congruency*Lang	-0.01	0.04	-0.24

Table 1b

Experiment 1a: Fixed Effects for the Random Intercepts Model of Naming Accuracy

Name Accuracy Fixed effects	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	3.63	0.13	27.01	<.001
Switch Condition	-0.30	0.17	-1.75	0.08
Arrow Congruency	-0.78	0.18	-4.36	<.001
Lang	1.01	0.23	4.34	<.001
Switch Condition*Arrow Congruency	0.46	0.40	1.17	0.24
Switch Conditions*Lang	-0.18	0.35	-0.50	0.62
Arrow Congruency*Lang	-0.39	0.36	-1.08	0.28
Switch Condition*Arrow Congruency*Lang	0.61	0.76	0.81	0.42

The significant interaction between arrow congruency and switch costs supports the hypothesis that a demand on domain general inhibitory control interacts with language switching costs. Note, however that the direction of the interaction is not as predicted (see Table 2a for mean RT values). That is, while the limited resource account of inhibitory control predicted an over-additive interaction, the results reflect an *under-additive* interaction wherein during incongruent arrow trials (where inhibitory control is presumably taxed) the switch cost was *reduced* compared with the congruent condition. Although unexpected, this interaction between the two conditions suggests that there is nevertheless a role for domain general inhibitory control in bilingual language switching.

Table 2a
Experiment 1a: Voice Onset Times, and Switch Cost (Switch-Stay RT) as a Function of Language, Arrow Congruency and Language Switch Condition

Arrow Condition	L1					L2					
	Stay		Switch		Cost	Stay		Switch		Cost	
	M	SD	M	SD	M	M	SD	M	SD	M	
Reaction time (ms)											
Congruent	1148.91	52.71	1245.01	47.43	96.10	1101.03	61.06	1201.19	51.83	100.17	
Incongruent	1220.14	67.35	1252.26	77.40	32.12	1167.77	64.80	1196.64	48.98	28.88	

Table 2b.
Experiment 1a: Mean Name Accuracy, by Subjects, as a Function of Language, Arrow Difficulty and Language Switch Condition

Arrow Condition	L1				L2			
	Stay		Switch		Stay		Switch	
	M	SD	M	SD	M	SD	M	SD
Mean Name Accuracy								
Congruent	1.00	1.00	0.99	0.99	1.00	1.00	1.00	1.00
Incongruent	0.98	0.98	0.95	0.95	0.98	0.98	0.97	0.97

It could, however, be argued that both the incongruent arrow task and the language switching task were simply more difficult and that it may be something about the shared *difficulty*, rather than inhibitory control, encountered on both of these

tasks that is responsible for their interaction. Perceptual load, such increased visual complexity, has been shown to produce very different effects on attentional processes than a working memory load (see Lavie, 2010 for a review). Specifically, evidence from perceptual load studies show that increasing task difficulty by, for example increasing visual complexity in a scene, may actually reduce interference and improve performance on certain tasks. That is, a greater perceptual load might in fact predict an *under-additive* interaction with a secondary task. These findings however are based on perceptual difficulty, whereas the inhibitory control account is concerned with the control of internal representations, which is what was targeted in Experiment 1a. As such, one way to distinguish between these two accounts is to specifically manipulate perceptual, but not cognitive, difficulty by replacing the incongruent Simon arrows from Experiment 1a with a task requiring the same response, and with an equivalent level of difficulty (see below for details on how this was determined), but with no need for inhibitory control. In this case the manipulation in the arrow task was in the ease of visual discrimination, of the arrows, without any representational conflict.

Experiment 1b

Experiment 1b was designed as a control study for Experiment 1a. That is, it served as a means to narrow in on the root cause of the interaction between the Simon arrow task and the language switch in Experiment 1a, and as a check to ensure that the influence of the arrow task on language switching was in fact due to its demand on inhibitory control rather than to a more general type of task difficulty. Therefore, the procedure itself remained the same while the difficulty manipulation was changed

from the congruency of the arrow to the visual discriminability of the arrow. This served to remove need for inhibitory control while maintaining an equivalent level of difficulty. If the findings from Experiment 1b are the same as 1a, that is, an under-additive interaction is found between switching and arrow difficulty, then level of difficulty, rather than inhibitory control might be said to interact with language switching, in line with the perceptual load account. If on the other hand, the same pattern is not found between studies, it will rule out the possibility that difficulty, rather than the representational conflict was driving the effect.

Perceptual Difficulty Control Norming

To create a comparable task to Experiment 1a, Experiment 1b also employed an arrow direction detection task, however, instead of manipulating the congruency of arrow direction and arrow location, materials for this perceptual difficulty task were arrows displayed in the center of the screen with varying degrees of pixelated noise. A norming task to determine the appropriate level of noise was a between-subjects task with both a block of the Simon arrow (congruency) task, as in Experiment 1a, and a perceptual difficulty block, with arrows of varying levels of noise, to compare arrow congruency cost with visual noise cost. The goal of this norming task was to ultimately choose the level of noise in the perceptual block that induced a comparable cost as that of the incongruent arrow in the Simon block.

Materials. All arrows were the same dimensions as in Experiment 1a. In the perceptual difficulty block, there were 4 levels of difficulty in the arrows, created by increasing the visual noise of the arrow image and its background, using the ‘salt &

pepper' component of the 'imnoise' function in MATLAB 7.6 (MathWorks, 2008). The levels of noise (1-4) ranged between density of 0.5 (easy) and 0.95 (difficult). The basic arrow, with no added noise, served as a baseline. (See Figure 4 for examples of the stimuli). The stimuli in the congruency block were the same as those used in Experiment 1a.

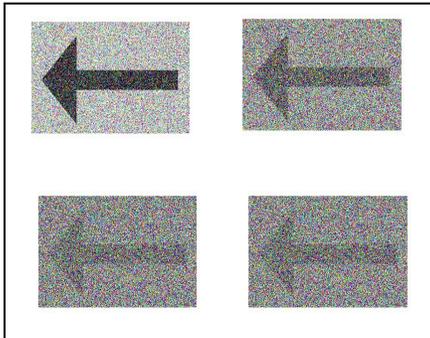


Figure 4. Sample arrows used for the perceptual difficulty norming task. Clockwise from the top left are left arrows with noise levels 1-4.

Participants and procedure. Ten adults from the University of Maryland participated in this norming experiment in exchange for course credit. The task was similar to the arrow task from Experiment 1, but modified to include the perceptually difficult arrow stimuli and a centered location where they appeared. There were two blocks with 40 trials each. In the congruency block the instructions emphasized disregarding the location while in the perceptual difficulty block the instructions warned that some images might be hard to see. For each block, the participant was instructed to press the key that corresponded to the direction of the arrow ("Z" for left and "M" for right). Between trials a fixation point appeared on the screen for 500ms. Incorrect responses were followed by auditory feedback. Each participant completed both blocks; the order was counterbalanced across participants.

Norming results. All incorrect arrow responses (231, 22.6% of trials) were excluded from RT analysis. After removing the extreme 3% of RT values, reaction times greater than 2 standard deviations from each subject's mean RT were excluded (32 trials, 4.06 %). In total, 263, (26% of trials) were excluded from the analysis. The congruency effect (incongruent minus congruent response time) and the perceptual difficulty effect (noise conditions 1 through 4 minus basic) were calculated for each participant. The congruency cost was compared to the difficulty cost for each noise condition (1-4) using matched-pairs t-tests. The noise level 3 (with a visual noise level of .9) led to a RT cost of 30.63 ms (SD = 24.82), which was the most similar to, while still being larger than, the cost of incongruent Simon arrows ($M = 45.09, SD = 34.28$). This level of perceptual difficulty was not significantly different from that of the Simon arrow task ($t(9) = -.34, n.s.$) thus was chosen to ensure the control task was of equivalent difficulty to the Simon task. See Table 3 for mean difficulty costs and their respective t-test values, as compared to the congruency condition.

Table 3
Perceptual Difficulty Arrow Norming Task: Difference Scores (Level of Perceptual Difficulty – Baseline Condition) and t-test Values (Perceptual Cost-Congruency Ccost).

	Congruency Cost	Level 1 Cost	Level 2 Cost	Level 3 Cost	Level 4 Cost
Arrow RT M(SD)	30.63 (24.82)	2.71 (25.58)	8.78 (34.4)	40.09 (24.29)	228.26 (154.78)
t-value		-2.29	-2.17	0.34	3.72
p-value		0.024	0.029	0.371	0.002

Experiment 1b Method

Participants. Thirty-seven participants who did not participate in Experiment 1a were recruited following the same procedure as in Experiment 1a. The enrolled participants' L2s included French (13), Spanish (23), and Japanese (1), and each was paid \$10 for participating.

Materials and procedure. Experiment 1b was a modified version of Experiment 1a, with changes to the arrow stimuli themselves and the arrow locations. In this experiment, all arrows (2.5 cm in length) were displayed in the horizontal center of the screen (neutral location) to remove the stimulus-location conflict (congruency), however they were presented either at the top or the bottom of the screen, (1 cm above or below the picture and language cue) mirroring the unpredictable stimulus location in Experiment 1a, to ensure similar demands on spatial attention (See Figure 5 for a schematic of the arrow task). The difficulty in this task was in visual detection of the stimulus itself: the “hard” arrow had pixelated noise added to both the arrow and its background, making visual discrimination difficult, as shown below in Figure 5. All other components of the materials, including the ordering of the stimuli (substituting congruent trials with “easy” trials and incongruent trials with “difficult” trials) and the procedure, remained the same as Experiment 1a.

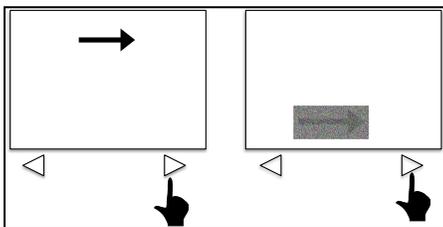


Figure 5. Schematic of the arrow task for Experiment 1b.

Design and Analysis

Response times were analyzed just as in Experiment 1a, replacing the factor of arrow congruency with arrow difficulty. All trials with verbal response errors (384, 3.5%) or arrow response errors (114, 1.0%) and all voice key detection errors (46, 0.42%) were removed from the reaction time data analysis. Following the 3% (extremes) data trim as described in Experiment 1a, all RT's greater than 2 standard deviations from each subject's mean (468, 4.67%) were removed from analysis. In total these criteria led to the removal of 783 trials (7.58 % of all trials).

Experiment 1b Results and Discussion

As can be seen in Table 4a and 4b and Figure 6, naming times were longer in switch than in stay trials (switch cost) and naming responses during difficult arrow trials took longer than responses in the easy arrow condition (difficulty cost). These main effects of switching and arrow difficulty, a main effect of language (indicating faster responses overall in L2 than L1), and an interaction between switch condition and arrow difficulty (indicating a larger switch cost in the easy, rather than the hard condition), were qualified by a three-way interaction with language (L1/L2; see Table 5a), such that switch costs were greater when accompanied by difficult than easy arrows in L1, but greater when accompanied by easy than difficult arrows in L2. While in naming accuracy there was a main effect of switch condition, with stay trials being more accurate than switch, there was no interaction with arrow congruency (see Table 4b for accuracy means, and 5b for the fixed effects).

Table 4a

Experiment 1b: Voice Key Reaction Time by Subjects, as a Function of Language, Arrow Difficulty and Language Switch Condition

Arrow Condition	L1					L2					
	Stay		Switch		Cost	Stay		Switch		Cost	
	M	SD	M	SD	M	M	SD	M	SD	M	
Reaction time (ms)											
Easy	1277.47	75.95	1315.44	60.41	37.96	1214.22	93.53	1274.61	66.83	60.39	
Difficult	1373.44	90.36	1421.48	67.12	48.04	1327.94	48.79	1368.94	83.51	40.99	

Table 4b

Experiment 1b: Naming Accuracy by Subjects, as a Function of Language, Arrow Difficulty and Language Switch Condition

Arrow Condition	L1				L2			
	Stay		Switch		Stay		Switch	
	M	SD	M	SD	M	SD	M	SD
Mean Name Accuracy								
Easy	1.00	0.01	0.99	0.01	1.00	0.01	0.99	0.02
Difficult	0.99	0.02	0.99	0.03	0.98	0.02	0.98	0.03

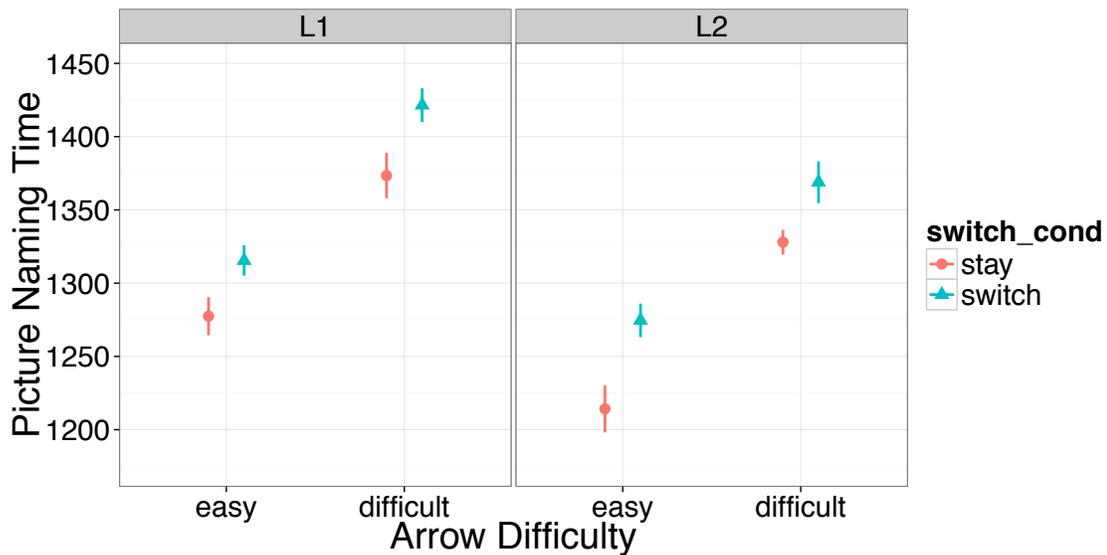


Figure 6. Experiment 1b: Naming reaction time by arrow difficulty condition and switch condition between languages. Plotted data are means of subject means. Error bars indicate standard error of the mean.

Table 5a

Experiment 1b: Naming Time Fixed Effects as a Function of Arrow Condition

Naming Time Fixed Effects	Estimate	Std Error	t value
(Intercept)	7.14	0.04	199.73
Arrow Cond	0.03	0.01	2.50
Switch Cond	0.04	0.01	3.38
Lang	-0.04	0.01	-4.45
Arrow Cond*Switch Cond	-0.03	0.02	-2.02
Arrow Cond*Lang	0.02	0.01	1.44
Switch Cond*Lang	0.00	0.01	0.31
Arrow Cond*Switch Cond*Lang	-0.07	0.03	-2.00

Table 5b

Experiment 1b: Fixed Effects for the Random Intercepts model of Naming Accuracy as a Function of Arrow Condition

Naming Accuracy Fixed Effects	Estimate	Std. Error	z	p-value
(Intercept)	3.96	0.23	17.53	<.001
Arrow Cond	-0.32	0.24	-1.32	0.19
Switch Cond	-0.69	0.23	-3.06	<.001
Lang	-0.28	0.23	-1.21	0.23
Arrow Cond*Switch Cond	0.22	0.32	0.69	0.49
Arrow Cond*Lang	1.15	0.35	3.25	<.001
Switch Cond*Lang	0.44	0.30	1.49	0.14
Arrow Cond*Switch Cond*Lang	-1.00	0.44	-2.28	0.02

Experiment 1 General Discussion

The pattern of results found in Experiment 1b, by modifying the type of cognitive load in the secondary task from inhibitory to perceptual, is clearly distinct from that in Experiment 1a. While there was a small underadditive interaction between language switching and arrow difficulty, the additional interaction with language makes this interaction hard to interpret. Thus, while these results may suggest that the interaction from Experiment 1a is due in *part* to task difficulty, this is not conclusive. Additionally, as the perceptually difficult arrow task was designed to have a greater level of difficulty than the Simon task, the small and qualified interaction with switching suggests that difficulty alone was not the driving force of the interaction in Experiment 1a.

Interestingly, as reported, the results of Experiment 1a showed a larger cost during a language switch on congruent trials, compared with incongruent trials. The underadditive interaction between two tasks involving conflict found here is similar to the findings described in Gratton et al.'s (1992) conflict adaptation study looking at the underadditive interaction that exists between conflict trials. As such, conflict adaptation could be a possible explanation for the current results. While conflict adaptation typically is discussed as trial-to-trial effect, Scherbaum, Fischer, Dshemuchadse, and Goschke (2011) demonstrate that this adaptation actually occurs, at least in part, within a single trial. Thus, it is possible that conflict adaptation within the current study's dual task paradigm could have occurred, and may explain the unpredicted pattern of results. Note that while the timing of Experiment 1a was designed so that the language cue occurred *before* the arrow, the arrow onset was timed to occur *during* the critical point in lexical selection, where conflict was predicted to occur. Therefore, it may be that the arrow task conflict and the naming task conflict were actually encountered simultaneously, as the design of the paradigm intended, and so within-trial conflict adaptation account may still account for these findings.

If it is the case that the arrow and naming conflict were encountered at the same time during Experiment 1a, and that conflict adaptation occurred at this point, it would be predicted that not only might the arrow task influence the naming due to shared resources, but that the switch task might in turn influence the arrow response. To assess this, the arrow RT data in Experiment 1a were analyzed in the same manner as the naming RT- excluding any inaccurate trials: verbal response errors (384, 3.5%)

arrow response errors (114, 1.0%) and voice key errors (46, 0.42%), the 3% extreme arrow RTs, and finally all RTs above 2 standard deviations from each participant's mean arrow RT (525 trials, 4.9%). In total, these criteria led to the removal of 1661 trials (14.0% of all trials). As shown in Figure 7, the effect of switch condition on arrow RT was similar to that of the arrow condition on naming times reported above: the effect of congruency was smaller in the switch condition compared with the stay condition reflected by a significant interaction between switch condition and arrow congruency on the Arrow RT data, (see Table 6).³ Thus, the language switch task appears to influence the responses in the arrow task just as the arrow task influences language switching performance.

Though original conflict adaptation findings were between two trials of the same type, more recently, conflict adaptation has been shown to occur between different types of tasks, both between and across linguistic and non-linguistic domains, as long as they share domain general mechanisms (e.g., Kan, Tuebner-Rhodes, Drummey et al., 2013). That is, finding conflict adaptation between two different tasks suggests that these tasks require the same mechanisms for conflict resolution. Thus, if the results from Experiment 1a reflect effects of adaptation in language switching this may support a role of domain general control in bilingual language production.

Table 6.

Experiment 1, Mean arrow RT Data, by Subjects, as a Function of Language, Arrow Difficulty and Language Switch Condition

³ The full model with correlated random slopes did not converge, therefore a reduced model, with uncorrelated random slopes, is reported in the analysis.

Arrow Condition	L1					L2					
	Stay		Switch		Cost	Stay		Switch		Cost	
	M	SD	M	SD	M	M	SD	M	SD	M	
Arrow Response time (ms)											
Congruent	898.11	66.92	993.08	53.49	94.97	867.64	68.23	982.44	57.30	114.81	
Incongruent	978.23	80.69	1019.26	88.82	41.03	949.92	64.71	982.12	55.22	32.20	

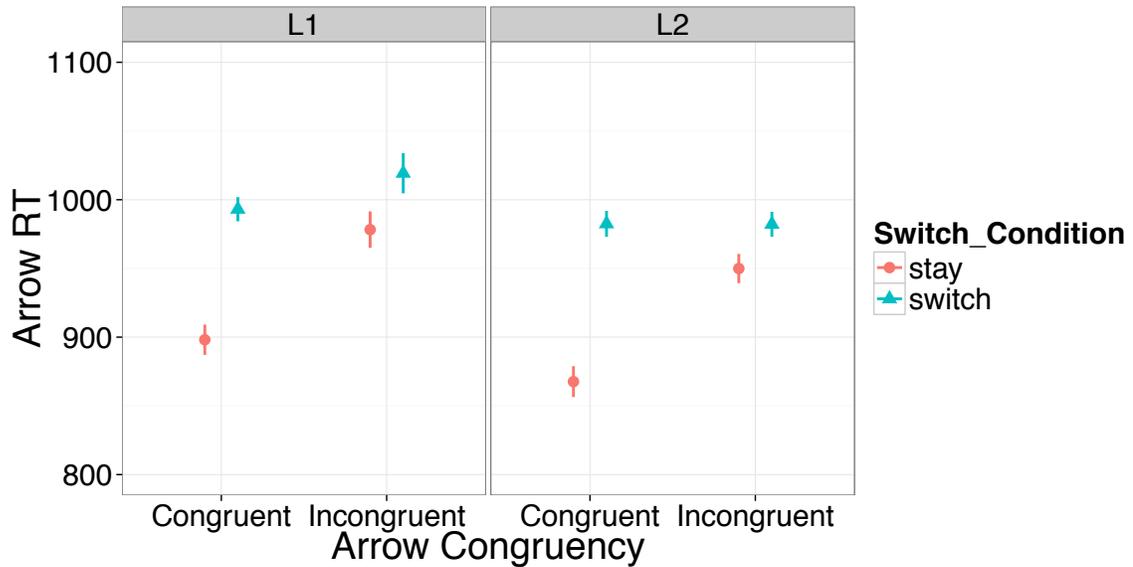


Figure 7. Experiment 1a: Arrow reaction time by arrow congruency condition and switch condition and language. Plotted data are means of subject means. Error bars indicate standard error of the mean.

Table 7

Experiment 1a. Fixed Effects for Arrow RT as a Function of Arrow and Switch Condition

Arrow RT Fixed effects	Estimate	Std Error	t-value
(Intercept)	6.78	0.04	188.75
Switch Condition	0.08	0.01	6.53
Arrow Congruency	0.04	0.01	3.63
Lang	0.04	0.01	3.22
Switch Condition*Arrow Congruency	-0.07	0.03	-2.45
Switch Condition*Lang	-0.01	0.02	-0.31
Arrow Congruency*Lang	0.00	0.02	0.24
Switch Condition*Arrow Congruency*Lang	0.01	0.04	0.28

While these results are consistent with within-trial adaptation both from arrow conflict to switch task and vice versa, note that the patterns of arrow RT and picture naming RT look quite similar and as such it may be that these two tasks were actually responded to simultaneously. (In fact, while the arrow RT's appear to be consistently shorter than naming RT's, recall that the arrows were timed to appear approximately 200ms into the naming trial and that the arrow RT's reflect timing from arrow onset. Thus the arrow RT with the addition of its SOA reflects when within the naming trial the arrow response occurred.) Figure 8 below, depicts the correlation between Arrow RT and Naming RT by subject and condition. As shown, these times are highly correlated, ($r = .95, p < .001$), suggesting that the response times for the two tasks were yoked. Therefore, while still interesting to note that there was certainly not a trade off between arrow task and naming task, it is likely not possible from this data to tease out the timing of the individual tasks or to assess their individual influence on one another.

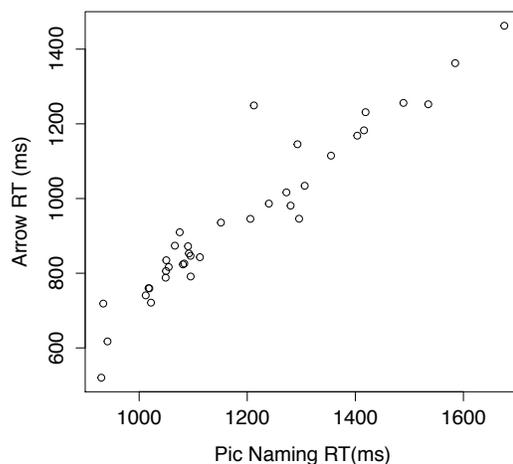


Figure 8. Experiment 1a: Picture naming RT by Arrow RT, plotted as means of subject means.

Experiment 2, thus, separated the arrow and naming tasks, both to investigate the possibility of conflict adaptation in a typical trial-to-trial paradigm and to better isolate the influence of the arrow task on the naming response time alone. The current data also cannot establish if the under-additivity in Experiment 1a is due to adaptation from conflict-inducing trials (both switch tasks and incongruent arrow trials are here considered conflict-inducing) speeding responses, or to slowed responses during low conflict trials when conflict is encountered. This question was addressed in Experiment 2, however note that directionality is not usually discussed in conflict adaptation literature. That is, though typically conflict adaptation is thought of as *adapting* to conflict, in that conflict reduces subsequent costs (e.g., Botvinick et al., 2001), this might not be the case. In fact, the “Gratton effect” (Gratton et al., 1992), upon which conflict adaptation is based, is framed as finding increased interference following *congruent* trials; an interpretation that has been supported by more recent research (Compton, Huber, Levinson et al., 2012). This is discussed as congruency within a task increasing parallel, or bottom-up, processing, which is generally more susceptible to interference. To examine the directionality of the effect, Experiment 2, as described below, included a baseline arrow condition to help determine the driving force of the interaction and narrow in on how conflict, or lack thereof, can influence language switching.

Experiment 2

To test the possibility that conflict adaptation was the source of the under-additive interaction seen in Experiment 1a, Experiment 2 used a similar procedure as Experiment 1, but importantly, the arrow task and naming task were separated in time to create a more typical conflict adaptation context and reduce any simultaneous-task effects. Additionally, as discussed above, Experiment 2 included a neutral arrow (centered on the screen) to act as a baseline and help determine which, if either, congruent or incongruent trials are driving the effect on language switching. Additionally, to simplify the design, the naming stimuli were pared down to the set of Arabic digits, 1-9, rather than the larger set of images used in Experiment 1. This change allowed for an increase in the size and diversity of the participant pool to include speakers with a greater range of proficiencies in their second language, assuming that counting numbers in a second language are more commonly known than vocabulary sets. The design of this paradigm thus involved switching between the arrow-task and the digit-naming task, and switching or maintaining a language across arrow trials. The results of this experiment can therefore speak to both the maintenance of a language task across non-linguistic trials, as well as the maintenance of adaptation across unrelated language trials. While it is unclear if an intervening arrow trial might cause an unwanted task switch cost (between naming task and arrow task) the task switching literature suggests that switch costs only occur between tasks that have shared response conflict (Monsell, 2003). As such, while the naming and arrow task may share conflict processes at a representational level, they involve different response mechanisms. Accordingly, while the language switch cost

should be maintained, it is not certain that in the current paradigm, the language “switch” will remain a true switch with an intervening arrow task. Along these lines, while conflict adaptation is known to only occur between tasks that share conflict type (e.g., Kan et al., 2014), it is uncertain if the conflict adaptation effect will be maintained across a naming trial. Accordingly, if conflict adaptation is able to persist across naming trials, this may suggest that that language switching does not engage conflict-processing mechanisms shared with dealing with arrow conflict.

Method

Participants. Forty-one native English-speaking adults with self-reported intermediate proficiency (mean proficiency score was 6.7/10 averaged across speaking, reading, and comprehension) in a second language (22 Spanish, 13 Hebrew, 1 Hindi, 5 French) were recruited from the University of Maryland’s Psychology participant pool and given course credit for their participation.

Materials and Procedure. The materials and procedure of Experiment 2 were based generally on those from Experiment 1a, but included several important changes. First, the timing of the arrow and picture onset was modified so that each was presented, and responded to, separately. Second, in addition to left and right-pointing arrows, appearing on the left or right side of the screen, this experiment included a neutral spatial location (centered). Finally, the picture stimuli were replaced with Arabic digits, presented in the same size and position as the pictures in Experiment 1.

Digit-naming practice. At the beginning of the experiment participants practiced naming the digits in their second language (L2). Each digit appeared within

a circle as a language cue indicating L2. During the first block of practice naming, items appeared in counting order, 1-9, to ensure comfort with the number words in the L2. Following this block, the participants named the digits in a randomized order. The randomized practice block included 36 total trials with each digit appearing exactly four times. The response-stimulus-interval (RSI) between digits was 750ms, which remained consistent throughout the blocks in the experiment.

Language-switching practice. The language-switching practice block followed the same procedure as in Experiment 1a, modifying only the stimuli (digits 1-9) and the timing (RSI of 750ms). There were 72 trials, randomized so that each item appeared equally in each of the four conditions (L1 stay, L1 switch, L2 stay, and L2 switch). An experimenter remained in the room during this session to monitor for, and record, voice key and naming errors.

Arrow task. Following switching practice the participants practiced performing the arrow task in a block of arrow-only trials. The procedure was based on Experiment 1a but with a constant RSI of 750 ms between trials and with the addition of a neutral arrow location. As described, on each arrow trial a left or right-pointing arrow could appear in one of three positions on the screen: left, right, or center. The center position served as a neutral condition, and a baseline with which to compare the congruent and incongruent conditions. The task remained the same as the previous experiments: respond by keypress to the direction of the arrow (M for right pointing and Z for left pointing arrows), regardless of its position on the screen. Errors elicited auditory feedback (Mac OS audio file “basso”) to encourage accuracy.

There were 60 arrow trials in total, presented randomly without replacement, with each arrow condition appearing equally often.

Combined task. Finally, the participants completed the combined task, where each trial consisted of an arrow to be responded to by button press (M for right pointing and Z for left pointing arrows), followed by a digit to be named in the L1 or L2, according to the cue. Unlike Experiment 1, the arrows and digits were presented and responded to sequentially. The procedure remained otherwise the same (See Figure 9 for a schematic of the task). The digit and its language-cue shape appeared after a 750ms RSI and disappeared after the participant's naming response was detected. Another 750ms RSI occurred before the presentation of the next arrow-digit trial. The arrows and digits were presented randomly without replacement, in an alternating runs L1-L1-L2-L2 order for the language task. All items including digit, language cue, arrow direction, and arrow location, appeared equally often. Additionally, each of the six arrow-language paired conditions (Neutral-Stay, Neutral-Switch, Incongruent-Stay, Incongruent-Switch, Congruent-Stay, Congruent-Switch) appeared equally. There were 3 blocks of 72 trials, with a scheduled self-timed break between each block.

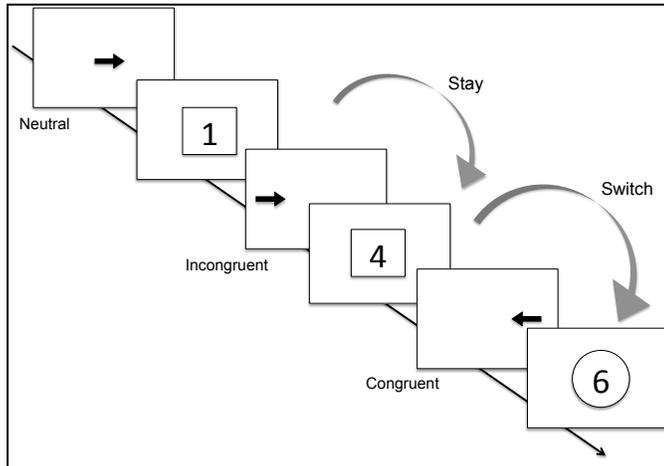


Figure 9. Schematic of Experiment 2. Square and circles surrounding the digit are cues to name the digit in the L1, and L2, respectively.

Questionnaire. The participants completed a shortened version of the LEAP-Q (Marian et al, 2007), after completing the switching task. These questions included number of languages spoken, order of acquisition and dominance, and self-rated comfort in speaking, reading, and writing the two languages used during the study. This was used to verify proficiency in the second language.

Design and Analysis

Response times were analyzed just as in Experiment 1, except that the factor of current arrow congruency was replaced with previous arrow congruency. All trials with naming errors (382, 2.2% of trials), voice key errors (47, 0.3 % of trials), or errors on the preceding arrow (556, 3.1% of trials) were removed from the reaction time data analysis. After removing the extreme 3% of RT trials, RT's greater than 2 standard deviations from each subject's mean (792, 4.8% of accurate trials) were removed from analysis. In total, these criteria led to the exclusion of 1850 trials, 10.4% of all trials).

The arrow RT data were treated the same way: after removing all inaccurate responses (10 trials) and the the extreme 3% of RT trials, RT's greater than 2 standard deviations from each subject's mean (754, 4.5% of accurate trials) were removed from analysis. In total, these criteria led to the exclusion of 1283 trials, 7.4% of all trials). Both previous arrow condition (incongruent, congruent, neutral) and current arrow condition (incongruent, congruent, neutral) were dummy coded with neutral as the reference level.

Results and Discussion

Digit Naming. As shown in Figure 10 and (and see the statistical test results in Table 12a) there was a main effect of switching, where naming during switch trials took longer than during stay trials. In this paradigm, with an intervening Simon arrow trial, the maintained switch cost demonstrates that, regardless of the congruency of the arrow, both the language task and the costs associated with switching were maintained. There was also a main effect of language, wherein naming in the L1 was faster than the L2. The typical switch cost asymmetry was reflected in the interaction between switch condition and language. That is, the effect of switching into the L1 was larger than in the L2. As the participants in this task were unbalanced bilinguals, these results are relatively unsurprising. However, considering the demands of the task, the fact that these costs were found is certainly notable.

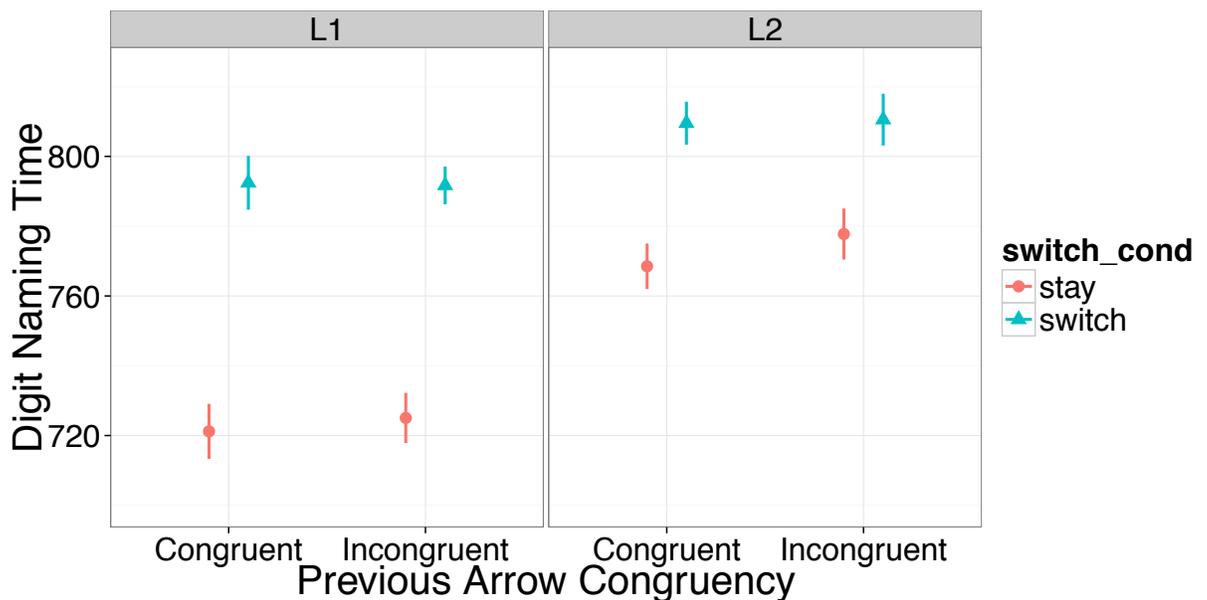


Figure 10. Experiment 2: Naming reaction time by previous arrow congruency condition and switch condition, across languages. Plotted data are means of subject means. Error bars indicate standard error of the mean.

Arrow Task. Interestingly, there was an effect of trial-to-trial conflict adaptation when looking at the arrow trials alone, as shown in Figure 11, despite an intervening naming trial. That is, on incongruent arrow trials that were preceded by an incongruent arrow (I-I), responses were faster when than when preceded by a congruent arrow (C-I). On current congruent trials, however, the effect was reversed (see Table 10 for response times and standard deviations, and Table 11 for fixed effect analyses). Importantly, note that this conflict adaptation was able to persist across the naming task. This suggests that the control necessary for both maintenance of a language and switching between languages cannot alone produce conflict adaptation on the upcoming arrow task.

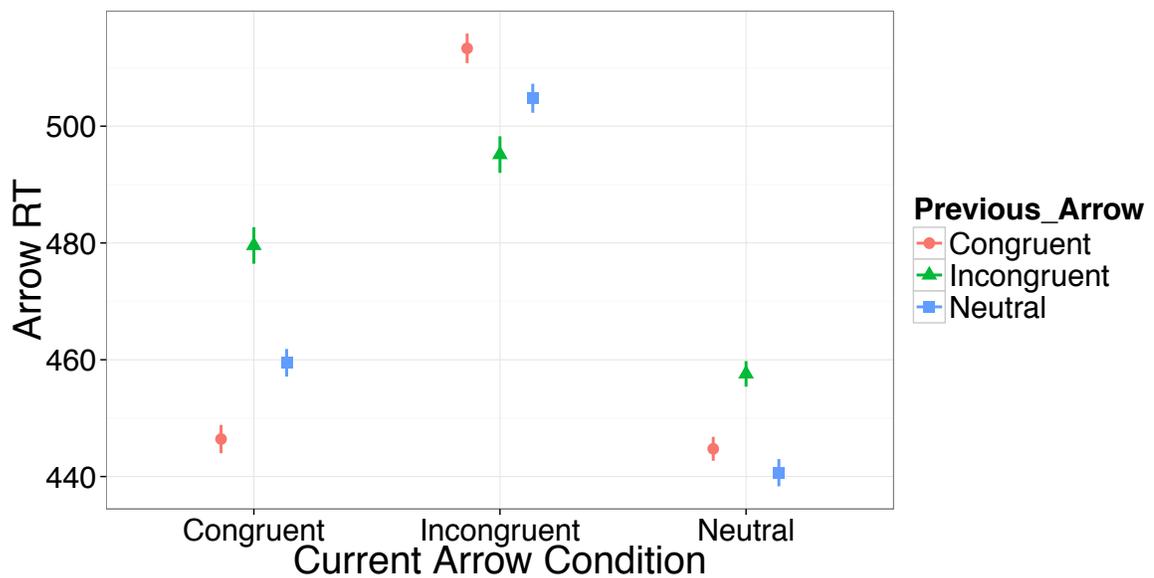


Figure 11. Experiment 2 Response times to the arrow task as a function of arrow congruency on the current trial and the congruency of the preceding arrow trial. Values are means of subject means. Error bars represent standard error of the mean.

Table 10
Mean Subject Arrow RT's as a Function of Current Arrow and Previous Arrow Congruency Condition

Current Arrow Condition	Previous Arrow Condition					
	Neutral		Congruent		Incongruent	
	M	SD	M	SD	M	SD
Arrow Response time (ms)						
Neutral	440.66	14.97	444.75	13.15	457.58	14.00
Congruent	459.48	15.16	446.42	15.54	479.56	20.00
Incongruent	504.77	15.88	513.32	16.18	457.58	14.00

Table 11
Experiment 2: Arrow RT in Arrow-to-Arrow Conflict Adaptation (see Table 10 and Figure 11). Estimates of the fixed effects model

Arrow RT Fixed effects	Estimate	Std. Error	t value
(Intercept)	6.07	0.02	401.9
prev arrow	0.04	0.01	5.9
prev arrow	0.14	0.01	20.5
current arrow(con v neutral)	0.01	0.01	1.9
current arrow(inc)	0.04	0.01	6.8
prev arrow(con v neutral)*current arrow(con v neutral)	-0.04	0.01	-4.7
prev arrow (inc v neutral) * current arrow(con v neutral)	0.01	0.01	1.2
prev arrow(con v neutral)* current arrow(inc v neutral)	0.01	0.01	0.8
prevarrow(inc v neutral)* current arrow (inc v neutral)	-0.06	0.01	-7.5

While there was an arrow to arrow effect of conflict adaptation, note, however, that there was not an effect of the preceding arrow on the current trial *naming time*, as was predicted by the conflict adaptation account proposed to support findings from Experiment 1. Thus conflict adaptation, as is typically discussed as a trial-to-trial adaptation, cannot straightforwardly account for the findings of Experiment 1a. Response times and standard deviations to number naming trials as a function of previous arrow congruency are reported in Table 12, and fixed effects are reported in Tables 13a and 13b.

Table 12a

Experiment 2: Mean Reaction Time as a Function of Language, Previous Arrow Congruency, and Language Switch Condition

Prev Arrow Condition	L1					L2					
	Stay		Switch		Cost	Stay		Switch		Cost	
	M	SD	M	SD	M	M	SD	M	SD	M	
Reaction time (ms)											
Congruent	740.55	55.97	816.97	58.10	76.42	803.03	51.14	842.10	51.76	39.06	
Incongruent	755.93	55.81	824.17	47.27	68.24	824.04	60.01	849.40	52.31	25.36	

Table 12b

Experiment 2: Mean Accuracy as a Function of Language, Previous Arrow Congruency, and Language Switch Condition

Prev Arrow	L1				L2			
	Stay		Switch		Stay		Switch	
	M	SD	M	SD	M	SD	M	SD
Mean Name Accuracy								
Congruent	0.98	0.02	0.97	0.03	0.97	0.03	0.97	0.02
Incongruent	0.99	0.02	0.97	0.03	0.98	0.03	0.97	0.03

Table 13a

Experiment 2: Fixed Effects Estimates For Naming RT's

Naming RT Fixed effects	Estimate	Std. Error	t value
(Intercept)	6.63	0.02	265.99
Switch Cond	-0.07	0.01	-8.74
Prev Arrow Cond	0.01	0.00	1.72
Lang	0.05	0.01	4.14
Switch Cond *Prev Arrow Cond	0.01	0.01	1.4
Switch Cond* Lang	0.04	0.01	5.3
Prev Arrow Cond*Lang	0.01	0.01	0.84
Switch Cond*PrevArrowCond*Lang	0.01	0.02	0.73

Table 13b

Experiment 2: Fixed Effects Estimates for Naming Accuracy

Name Accuracy Fixed effects	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	4.53	0.30	15.18	<.001
Switch Cond	-0.47	0.30	-1.58	0.11
Prev Arrow Cond	0.65	0.32	2.07	0.04
Lang	-0.37	0.25	-1.52	0.13
Switch Cond *Prev Arrow Cond	-0.80	0.38	-2.09	0.04
Switch Cond* Lang	-0.48	0.39	-1.24	0.22
Prev Arrow Cond*Lang	0.40	0.34	1.19	0.24
Switch Cond*PrevArrowCond*Lang	0.54	0.50	1.07	0.29

In sum, Experiment 2 found switching costs in the naming task as well as conflict adaptation effects across arrow trials, but failed to find an interaction between previous arrow congruency and current trial switch condition. The lack of an interaction between the previous arrow and the switch condition challenges the hypothesized conflict adaptation explanation for the effects observed in Experiment 1a. Additionally, as both the language switch-cost was maintained across arrow trials, and conflict adaptation of the arrow task was maintained across naming trials, the lack of interaction between the two tasks cannot be attributed to the intervening task paradigm design. Thus the results suggest that these two processes do not interact when they are separated in time, as predicted by an account of conflict adaptation between tasks with shared conflict processing (Kan et al., 2014).

Experiment 3

The lack of interaction between the naming trials and the arrow trials in Experiment 2 might be due to the fact that the type of conflict, even at a representational level, is too different. That is, the type of conflict being investigated in bilingual production, presumably at the lexical level, may not share processes with the conflict encountered in the arrow trials. Thus, to more directly target conflict at the lexical level, Experiment 3 implemented the picture word interference (PWI) task. Experiment 3 combined the PWI task with a language switch task to investigate whether the resolution of lexical competition induced by PWI influences the ease of language control induced by a language switch task. As described in the introduction, PWI tasks require naming pictures while ignoring a distractor word, which adds conflict in lexical selection when the distractor is semantically similar to the target (e.g., Schriefers et al., 1990; Meyer & Schriefers, 1991). As such, this paradigm allowed for manipulation of level of conflict on a naming trial by manipulating the distractor word's relation to the picture. This paradigm also eliminated any direct change in task beyond the language switch (and level of conflict) and thus, eliminates any effect of task switching or task prioritization. Finally, modifying the secondary task to a linguistic task would address any question that the arrow task used to manipulate inhibitory control demands in Experiments 1 and 2 was tapping a fundamentally different type of control than that used in language switching. In the paradigm, both the PWI and the language switch task do rely on lexical selection, however it is unclear if the type of control required for lexical selection in the PWI task and that required to overcome competition in the switching task involve the same processes.

Importantly, the PWI task has been shown to require inhibitory mechanisms that overlap with those used during the Stroop task, (see de Zubricaray, Wilson, McMahon & Muthiah, 2001), a classic cognitive control measure (Stroop, 1935) and so interactions of language switching with the PWI task may yet reflect shared reliance on more domain general cognitive control mechanisms, beyond the lexical level.

In addition, this paradigm is able to investigate whether the ease of lexical access -as suggested by a differential activation account (e.g. Finkbeiner et al., 2006)- affects language switching. In PWI, semantically related competitors create additional competition in naming and thus, if the relative ease of access is the driving force behind the switch-cost asymmetry, one might expect that making lexical access harder (via PWI interference) would reduce the switch cost. On the other hand, if inhibitory control is responsible for the switch asymmetry, an additional task that draws on inhibitory control resources should make it harder to switch languages; that is, with fewer resources to allocate to the task of inhibiting the non-target language, it might take longer to overcome competition from the non-target language.

The design of Experiment 3 allowed the language-switching task to be the singular task, while conflict and need for inhibition was manipulated by the relationship between the distractor word and the target picture. Rather than the typical alternating runs of two trials in each language, Experiment 3 used sets of three trials in each language in order to build in a neutral stay trial before each switch. This neutral trial was included to further separate out the switch and stay trial types and to

reduce any potential carryover effects of the previous trial's conflict type. The details of the paradigm are described in more detail below.

Method

Participants. Thirty-two native English-speaking adults with intermediate proficiency in Spanish (currently or recently having taken intermediate to upper level college Spanish courses) were recruited from the University of Maryland and paid \$10 for their participation. One participant was excluded from analysis for not meeting the requirement of being a native English speaker.

Materials. The target pictures, sixteen black and white drawn images from the International Picture Naming Project (IPNP) database (Szekely et al., 2004), included many items from Experiment 1. The set of pictures was chosen to avoid pictures with cognate names in Spanish and English as well as to meet the requirements of the distractor words, as described below. (See Appendix C for target items, distractor words, and frequency information.)

Distractor words. All distractor strings were presented in capital letters, in red size 24 Helvetica font, in the center of the picture stimuli. These parameters were chosen to make the string highly visible. Related distractor words were selected from the online WordNet database (Miller, 1995; WordNet, 2010), to be a non-cognate sister term of the target picture item—that is, sharing a hypernym (e.g., “pet” for “cat” and “dog”) with the target item (Meyer & Schriefers, 1991; Schriefers et al., 1990)—and to have high frequency, as to ensure familiarity for participants. Unrelated distractor words were chosen to be non-cognates, matched in frequency and number

of syllables in both Spanish and English, and determined to be minimally related to the target (e.g., Target: “COW”/”VACA”, Related: “HORSE”/”CABALLO”, Unrelated: “RING”/”ANILLO”). Neutral distractors appeared during the second stay trials (stay2 trials) and acted as a resetting trial before the switch. These neutral “distractors” were a string of “#”s, which matched the number of characters of the unrelated distractor in the target language to match in terms of visual distraction, but remove potential for any lexical competition with the target word. For example, the neutral distractor for “VACA” (“ANILLO”) was “#####”.

Lists. Trials were set up in triads by language (L1 and L2), with a switch into the language (switch), a stay trial following the switch (stay1) and a second stay trial (stay2). Lists were created so that each picture showed up equally in each language, and equally in the related and unrelated distractor conditions. Additionally, each picture showed up equally in each of the switch, stay1, and stay2 positions in each language, and each switch trial was followed equally often by a related or unrelated stay trial. Finally, to reduce repetition-priming effects, a picture in a switch trial was never repeated in the following stay1 trial.

Procedure

Vocabulary practice. At the start of the experiment, participants were presented with the 32 distractor items (16 related, 16 unrelated) in a pre-determined randomized order for translation from Spanish to English. Each item was presented in capital letters, in size 24 black Helvetica font. Upon presentation, the participant was instructed to translate the item out loud into English and to guess if unsure. As soon as the voice key was activated, the correct response appeared in blue below the

written word. The participant was encouraged to verify the correct response and press the space bar to move on to the next item. The list appeared two times in the same order, to ensure the participant was comfortable with the distractor words and their meanings. Participants were informed that they would be tested on these words at the end of the experiment and encouraged to learn any words they did not yet know. If they received below 75% accuracy, they ran through the translation process in the same order again, at which point all participants successfully were able to translate with at least 75% accuracy.

Picture naming practice. Participants then practiced naming the 16 pictures, first in English, and then in Spanish. In the English block, each picture appeared with a square around the picture, as a cue to name the item in English. The picture remained on the screen until a voice key was detected, after which the correct response appeared below the picture in blue font. The participant was encouraged to verify the answer before proceeding to the next trial by key press. Following the English block, the same procedure occurred with the same items in the same order, but with a circle around the item, as the Spanish language cue, and instructions indicated to name the items in Spanish. Again, participants were encouraged to verify the response before moving on to the next trial. All participants were comfortable naming all items by the end of this trial.

Switching Practice. Following the blocked naming there was a set of 24 practice switch-naming trials. For a subset of the picture stimuli, randomly selected from the complete set of stimuli, each participant practiced switching between naming three items in Spanish followed by three items in English, each picture

appearing with its corresponding language cue. Before each trial, a fixation-cross appeared in the center of the screen for 1000ms, and the onset of each picture was delayed 500ms after the fixation disappeared. This longer ISI was chosen to reduce interference from errors made on previous trials. The participant practiced naming the pictures in the cued language; the picture disappeared when their naming response was detected.

Combined Task. Following the switching practice, the participants had 24 practice trials with the complete task; switching between languages with the same parameters as the switch-only trials, but with a distractor word superimposed on the center of the pictured item. These 24 trials were subset of the complete list of trials, randomly selected for each participant from the complete list of trials from the full task. The participant was instructed to name the pictures and to ignore the distractor word. After all practice was completed, participants began the full combined task followed the practice which consisted of 384 total trials with a scheduled, self-timed break halfway through.

Post-test questionnaires. After completion of the task, the participants were given a vocabulary test where all 32 Spanish distractor items were listed, in a pre-determined randomized order, for translation into English. The participants were given as much time as they needed to complete this task. After completing the vocabulary quiz, participants completed a shortened version of the language history questionnaire (as described in Experiment 2).

Design and Analysis

Response times were analyzed just as in Experiment 1, replacing arrow congruency with distractor relatedness. All trials with naming errors (349, 2.9% of trials) or voice key errors (57, 0.5% of all trials) were removed from the reaction time data analysis. Additionally, for each participant, any trials in either English or Spanish for which the distractor item was not accurately translated on the vocabulary quiz were removed from analysis (621 trials, 5.4% of accurate naming trials). After removing the extreme 3% of accurate RT trials, RT's greater than 2 standard deviations from each subject's mean (530 trials, 5.04%) were removed from analysis. In total, these criteria led to the exclusion of 1062 trials (8.9% of total trials).

Results and Discussion

As shown in Figure 12 and Table 14a below, naming was slower in switch than stay trials, reflected in an expected main effect of switch condition. Additionally, naming was slower when pictures appeared with a related distractor word compared with an unrelated word, reflected in a main effect of relatedness. As shown in Table 14b, the error rates showed a similar pattern of results, with naming responses on switch trials being less accurate than on stay trials and less accurate when paired with related compared to unrelated distractors. There was an additional interaction between switch condition and language in the accuracy analysis, with increased errors on L1 switches reflecting a tendency to incorrectly remain in the L2 rather than switch (see Table 15b).

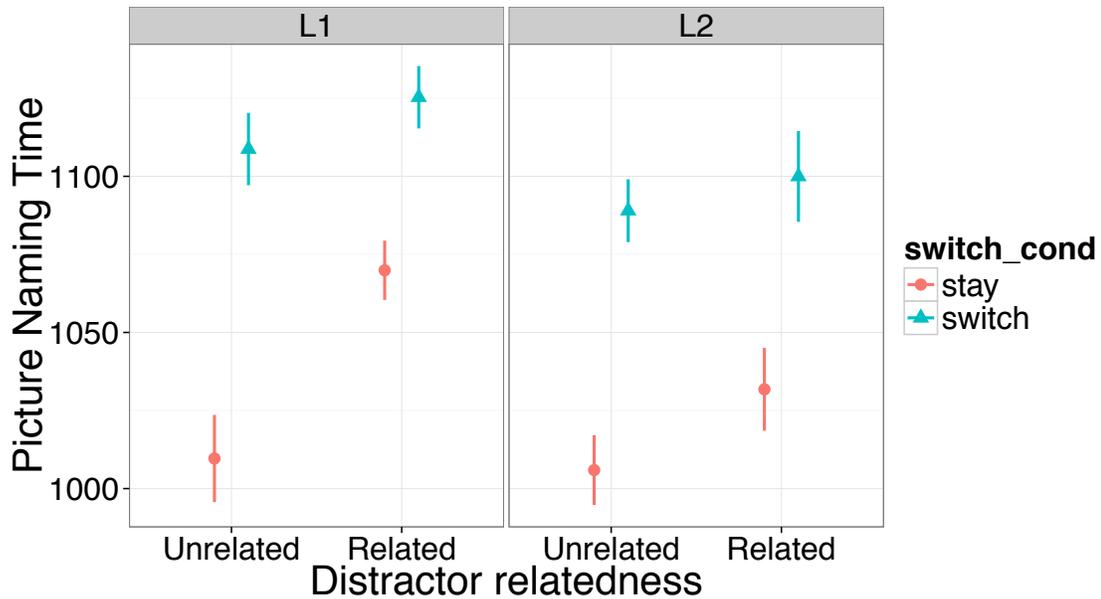


Figure 12. Experiment 3: Naming reaction time by distractor relatedness condition and switch condition, across languages. Plotted data are means of subject means. Error bars indicate standard error of the mean.

While there were no significant interactions between switch condition and distractor relatedness in the naming RT data (see Table 15a), the pattern of the relationship between distractor relatedness and switch condition is similar to the pattern of results in Experiment 1a. That is, the effect of a language switch was numerically smaller when the switch trial appeared with a related distractor compared with an unrelated distractor (see Table 14a for mean RT values and switch costs by condition). The finding that the same under-additive pattern is seen in two very different types of inhibitory control manipulations, in Experiments 1a and 3, but not in the others, suggests a similar process may be involved in bilingual switching and both linguistic and non-linguistic (but not perceptual) competition. Most importantly, the data clearly do not support the original predictions of an over-additive interaction.

The under additive interaction could be explained, in part, in terms of a bottleneck in processing (e.g., Ferreira & Pashler, 2002; Pashler, 1989) whereby some, but not all aspects of a given task require domain general, capacity-limited resources. When capacity-demanding tasks are presented simultaneously, they reach a bottleneck, and must be performed in sequence. Aspects of processing that do not require these ‘central’ resources are automatically processed and therefore do not contribute to, and are not affected by, the bottleneck. In the context of the PWI paradigm, Kleinman (2013) proposed that picture naming responses are subject to this attentional bottleneck, however word reading occurs as an automatic process and as such is unaffected by a secondary task. Thus, when the PWI task is paired with a secondary task, the distractor word is processed immediately while the picture naming task is delayed. As such, the two components of the PWI may become separated in time, and the PWI effect is reduced. In Experiment 3, the switch task, ostensibly requiring central resources, might effectively delay picture naming while allowing the distractor word to be read and processed, and no longer sufficiently active to induce interference at the point of lexical selection. On the other hand, picture naming should not be delayed during stay trials, when there is no additional conflict, therefore both picture naming and distractor word may be processed at the same time, where the interference is readily available to take its toll. This account does a relatively good job at explaining the Experiment 3 results: a trend towards reduced costs during switch trials, where the interference from the distracting word may have had ample time to decay. This explanation, in light of all experiments, will be further discussed in the general discussion.

Table 14a

Experiment 3 Mean Reaction Time as a Function of Language, Distractor Relatedness, and Language Switch Condition

Relatedness Condition	L1					L2					
	Stay		Switch		Cost	Stay		Switch		Cost	
	M	SD	M	SD	M	M	SD	M	SD	M	
Reaction time (ms)											
Unrelated	1009.63	77.72	1108.72	64.51	99.10	1005.92	62.11	1088.99	56.01	83.07	
Related	1069.90	52.85	1125.32	55.63	55.42	1031.79	73.78	1099.95	80.96	68.16	

Table 14b

Experiment 3: Mean Naming Accuracy As a Function of Language, Distractor Relatedness, and Language Switch Condition

Relatedness Condition	L1				L2			
	Stay		Switch		Stay		Switch	
	M	SD	M	SD	M	SD	M	SD
Mean Name Accuracy								
Unrelated	0.98	0.03	0.94	0.06	0.98	0.04	0.98	0.03
Related	0.96	0.04	0.91	0.06	0.98	0.03	0.98	0.03

Table 15a

Experiment 3: Fixed Effects naming RT

Naming RT Fixed effects	Estimate	Std.Error	t value
(Intercept)	6.93	0.03	239.69
Related Cond	0.02	0.01	3.70
Switch Cond	0.07	0.01	7.90
Lang	0.02	0.02	0.94
Related Cond*Switch Cond	-0.02	0.01	-1.51
Related Cond*Lang	0.02	0.02	1.40
Switch Cond*Lang	0.01	0.01	0.54
Related Cond*Switch Cond*Lang	-0.03	0.02	-1.21

Table 15b

Experiment 3: Fixed Effects Naming Accuracy

Naming Accuracy Fixed Effects	Estimate	Std.Error	z	p-value
(Intercept)	4.06	0.26	15.58	<.0001
Related Cond	-0.75	0.29	-2.58	0.01
Switch Cond	1.27	0.27	-4.68	<.0001
Lang	0.26	0.36	0.72	0.47
Related Cond*Switch Cond	0.39	0.34	1.15	0.25
Related Cond*Lang	0.49	0.46	1.07	0.28
Switch Cond*Lang	1.01	0.45	2.26	0.02
Related Cond*Switch Cond*Lang	-0.34	0.59	-0.58	0.56

Discussion and Conclusion

This study sought to define the role of domain general inhibitory control in dealing with competition in bilingual language production- using a dual-task approach to investigate this during a language switching paradigm. In Experiment 1 a concurrent Simon arrow task was performed during bilingual language switching. This paradigm was predicted to result in an over-additive interaction between an incongruent stimulus and a language switch, that is, an increased switch cost during incongruent, compared with congruent trials. Experiment 1 did find an interaction between language switching and the non-linguistic conflict task, however this interaction was under-additive, wherein switch costs were actually larger when performed on congruent trials compared with incongruent trials. Experiment 1b showed no difference between language switch costs as a function of concurrent *perceptual* difficulty, demonstrating that the pattern in Experiment 1a did not simply reflect the difficulty of the concurrent task (or an increased perceptual load), but was likely due to the inhibitory processes required to resolve interference in the Simon arrow task. To investigate the possibility that the under-additive pattern in Experiment 1 resulted from conflict adaptation occurring between the two tasks, Experiment 2 separated the two tasks in time to create a conflict adaptation paradigm (cf. Kan et al., 2014). This paradigm revealed both switch costs between naming trials and conflict adaptation between arrow trials, however there was no interaction between tasks; i.e., no difference in switch costs when naming trials were preceded by an incongruent arrow compared with a congruent arrow. Finally, Experiment 3 sought to both reduce explicit demands of a secondary task while maintaining the dual-task component of

Experiment 1, using a PWI task in a switching context. This paradigm reduced the task to a single response in order to eliminate effects of task prioritization. This task allowed manipulation of the level of conflict at lexical selection by including competing and non-competing distractors, which could be expected to more directly interfere with the language switching task. Experiment 3 showed no interaction between distractor type and switch condition; if anything, the data suggest a reduced switch cost in the high conflict condition (as in Experiment 1a). Together, these data give no evidence for over-additive interactions, as would be predicted by language switch models that propose inhibitory control as the underlying process necessary to make the switch. A summary of the results from all experiments is shown in Figure 13.

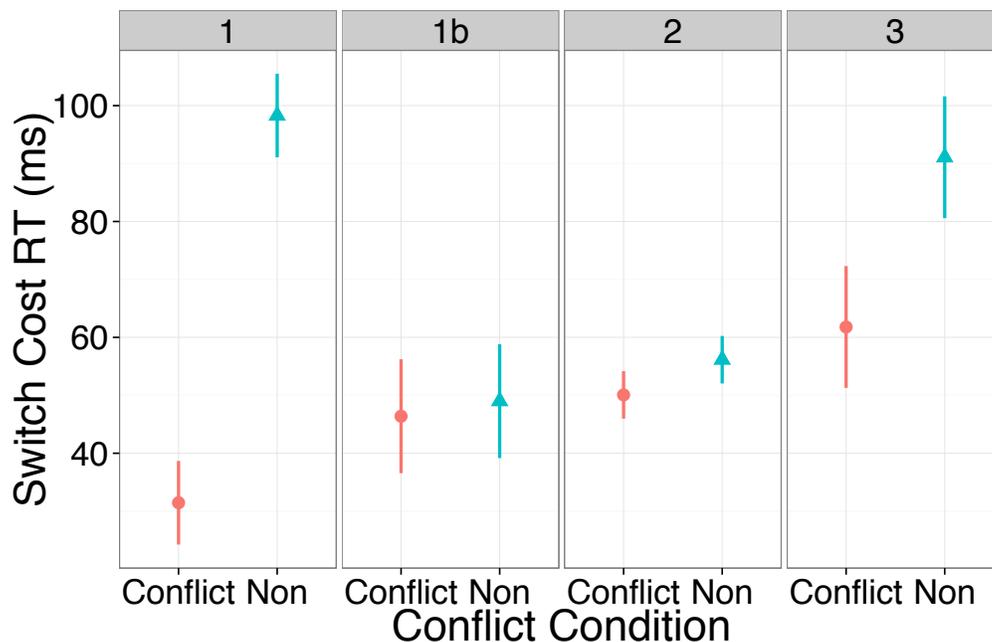


Figure 13. Mean switch cost (switch RT minus stay RT) by secondary task condition across all 4 experiments. Plotted data are means of subject means. Error bars indicate standard error of the mean.

The role of inhibition in language switching is made very clear in the inhibitory control model (Green, 1998). This model claims that inhibition is required in order to reduce competition from the non-target language, which allows for production in the target language. Therefore, on a switch trial, where this inhibitory control is required, concurrent use of inhibitory control by another inhibitory task, such as an incongruent arrow (Experiment 1a) or a highly competitive distractor word (Experiment 3) should interfere with successful inhibition of the non-target language. That is, the model predicts that conflict should increase switch costs. These predictions were not met in either Experiments 1a or 3, where the switch costs were in fact, increased on *stay* trials (albeit non-significantly in Experiment 3). These data are therefore inconsistent with predictions of the inhibitory control model.

Recall that in Experiment 3, the PWI paradigm used written distractors, which could be automatically processed, paired with a picture naming task that could have been differentially affected by the switch task which could account for the underadditive interaction found in the paradigm. This explanation, however, fails to explain the same under-additive interaction between the Simon arrow task, which is unlikely to be automatized, and the picture-naming task in Experiment 1a. It might also be argued that the relative timing of the tasks in Experiment 1a may be similarly shifted, due to task prioritization as a function of trial type. However, the similar pattern of results in Experiment 3, where there was not an opportunity for differential task prioritization, suggests that this is not the case.

Other models suggest that activation, rather than inhibition may better explain language access in switching. These accounts are based on evidence that counter the

requirement of inhibition of the non-target language in naming. To explain the asymmetric switch costs, which have been taken as evidence for involvement of inhibitory control, Finkbeiner et al. (2006)'s differential activation account posits that the more available a response is for selection (e.g. the dominant language), the more likely it is to be rejected in a switching context, which in turn would account for a larger switch cost into the dominant L1. This “ease of access” account is, in fact supported by Experiment 3, as the related condition of the PWI task is designed to make the target naming task more difficult, and therefore less accessible. By this account, these trials should be, and in fact were, easier during switch trials than on stay trials. This account cannot, however, explain the findings from Experiment 1. That is, if inhibition does not play a role in language access, then there is no reason that an incongruent arrow task (1a) or even the perceptually difficult arrow task (1b) should impact ease of access. Thus, while ease of access may, in part address our findings, it cannot be the complete story.

Other research has suggested that interference in switching tasks is not from inhibition of the dominant task, but is instead from activation of a non-dominant task (for review, see Kiesel et al., 2010). Additionally, there is some dispute about the interpretation of a switch cost asymmetry as a marker for inhibitory control (Bobb and Wodnieka, 2013). As such, task maintenance and activation may also need to be considered as playing an important role in switching. In light of this and our current findings, it is important to consider the other side of the coin: maybe there is more happening during the stay than the switch. That is, while switching effects are typically framed as costs, without a real baseline between switching and staying it is

hard to determine directionality, and thus it may be that the effect is a reduction in stay *benefit* rather than a switch cost. Accordingly, measures of neural activity during language switch and language stay trials (e.g., DeBaene et al., 2012; Verhoef et al., 2009) find support for a stay benefit. Verhoef et al., (2009) find that in a language switch task with a variable language cue-to-target interval, all but the extremely dominant L1-stay RTs can be reduced by increasing the cue-target interval, suggesting that L1 stay trials may be at ceiling. As such, they claim that typical switch cost findings, used as support for a key role of inhibitory control, are grounded in this L1 “repeat benefit”, rather than the typically discussed switch cost. Note that, similar to the discussion of the current study’s findings, they do not rule out inhibitory control as playing a role in language switching. Rather, they suggest that it can help efficient switching, but may not be the driving force of switch costs. Along these lines, De Baene and colleagues, (2012) looked at the possible role of adaptation across a number of stay trials. They claim that while adaptation might be expected to increase over trials, task-set reconfiguration, as a means of overcoming the previously performed task, should not. Behaviorally, reaction times were reduced over a number of stay trials, but not over a number of switch trials, supporting a benefit of staying within a task. Additionally, using Bayesian model selection methods, the authors compared two potential models of the neural activity recorded during the switching task: a model of reconfiguration during the switch and a model of activation occurring over successive stay trials. The pattern of neural activity was better explained by the activation, rather than the reconfiguration model, suggesting a stronger role for adaptation over stay trials rather than recruitment of additional

control processes on switch trials. The finding that there may be important action during the stay trials, rather than only during the switch trials, may help explain the unpredicted direction of the interactions found the current experiments.

With the caveat that directionality of the switch cost (that is, reduced cost on incongruent arrow trials vs. increased cost on congruent trials) cannot be confirmed without a neutral arrow condition as a baseline, in our experiments, the pattern of results found in Experiments 1a and 3 do *appear* to be driven by a change in the stay trials, rather than the switch. If this is true, it may be that the stay benefit is reduced on trials where conflict of a certain type (incongruent arrow, or related PWI distractor) is able to interfere. Again, based on the current experimental findings, the data do suggest that some form of inhibitory control is involved in language switching. However it seems that taxing inhibitory control may have disrupted the adaptation over stay trials, thereby reducing the stay benefit (which, without a baseline to determine directionality of the effect, would be indistinguishable from a reduced switch cost).

The findings presented here suggest a few conclusions about language control. First, there was in fact an interaction between language switching and Simon arrow conflict in Experiment 1, and a numerically similar pattern between language switching and PWI conflict in Experiment 3. As such, there does appear to be some role of domain general inhibitory control in language switching as when the manipulated task does not involve inhibitory control (Experiment 1b) the interaction is nearly eliminated. Thus, while inhibitory control may play a role in the switch task, the under additive interaction between tasks provides evidence against a

straightforward inhibitory account, wherein inhibitory control is applied during the switch. As discussed, it is possible that inhibition may have disrupted the adaptation over stay trials, thereby reducing benefits of continuing to use the same language rather than increasing the cost of switching between languages. The current data are thus inconsistent with the inhibitory control model (Green, 1998) and lend more support to activation-based models of language control (e.g. de Baene et al., 2012; Philipp & Koch, 2009). Additional work will be necessary to determine exactly how studies of language control reflect switch costs versus stay benefits, and exactly how these costs and benefits relate to inhibitory control processes more broadly. However, these experiments bring us closer to a more complete understanding of how bilinguals control lexical access across languages.

Appendices

Appendix A

L2 proficiency data from LEAPQ results for all experiments*

	Exp 1a		Exp 1b		Exp 2		Exp 3	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Proficiency Rating/10								
Speaking	6.91	1.70	6.91	1.40	6.15	2.02	6.48	1.50
Comprehension	7.13	1.58	7.09	1.76	7.01	2.09	7.35	1.56
Reading	7.52	0.99	7.45	1.48	6.81	2.05	7.34	1.22

**Note. Data from 14 participants are not included in table due to computer error in recording responses.*

Appendix B

Experiment 1: Name agreement scores in both Spanish and English for all items

Spanish Name	English Name	Spanish Agreement	English Agreement
brazo	arm	0.80	0.93
cama	bed	0.92	0.94
cinturón	belt	0.88	0.92
libro	book	1.00	0.87
pan	bread	0.92	0.92
mariposa	butterfly	0.90	0.99
gato	cat	1.00	0.96
silla	chair	0.93	0.96
queso	cheese	0.92	0.96
iglesia	church	0.94	1.00
reloj	clock	0.97	0.97
vaca	cow	0.97	0.99
perro	dog	0.96	0.98
puerta	door	0.88	0.96
ojo	eye	0.87	0.90
dedo	finger	0.93	0.97
fuego	fire	0.94	1.00
uvas	grapes	0.88	0.94
mano	hand	0.90	0.93
sombrero	hat	0.88	1.00
corazón	heart	0.90	0.98
casa	house	0.97	0.99
llave	key	0.88	1.00
rey	king	0.97	0.99
lechuga	lettuce	0.97	0.90
hombre	man	0.88	0.79
mono	monkey	0.90	0.97
nariz	nose	0.89	0.96
naranja	orange	0.90	0.94
pantalones	pants	1.00	1.00
lápiz	pencil	0.85	0.96
piña	pineapple	0.87	0.96
piscina	pool	0.93	0.92
zapato	shoe	0.96	0.94
sol	sun	1.00	0.96
mesa	table	0.94	0.92
diente	teeth	0.88	0.67
basura	trash	0.98	0.29
árbol	tree	0.94	0.94
ventana	window	1.00	0.97

Appendix C

Experiment 3: Picture-word interference task: Target picture and it's related and unrelated distractor words for both L1 (English) and L2 (Spanish) with its corresponding English frequency.

L1 Target	Target		Related Distractor			Unrelated Distractor		
	L2 Target	Target Freq	L1 Rel Dist	L2 Rel Dist	Rel Dis Freq	L1 Unr Dist	L2 Unr Dist	Unrel Dist Freq
arm	brazo	65.41	leg	pierna	56.51	nuts	nueces	53.51
bread	pan	28.33	cake	torta	45.06	mail	correo	36.84
cat	gato	66.33	dog	perro	192.84	blood	sangre	186.12
cheese	queso	39.04	milk	leche	42.53	skin	piel	44.04
church	iglesia	69.67	school	escuela	333.12	friends	amigos	305.45
cow	vaca	25.51	horse	caballo	92.88	ring	anillo	92.75
dog	perro	192.84	wolf	lobo	20.27	lake	lago	36.00
lettuce	lechuga	3.39	spinach	espinacas	2.55	olives	aceitunas	2.69
window	ventana	86.00	mirror	espejo	24.18	ticket	billete	45.57
tree	árbol	65.00	grass	hierba	16.78	toy	juguete	16.84
sun	sol	69.67	candle	vela	8.02	balloon	globo	8.67
bed	cama	187.12	nest	nido	11.10	nails	claves	11.04
house	casa	514.00	building	edificio	99.57	cover	cubierta	94.27
heart	corazón	244.18	star	estrella	81.35	seat	asiento	78.78
hand	mano	279.65	foot	pie	64.92	pigs	cerdos	13.29
boat	barco	95.78	raft	balsa	4.71	leaf	hoja	5.20

References

- Abutalebi, J., & Green, D. (2007). Bilingual language production: The neurocognition of language representation and control. *Journal of Neurolinguistics*, 20(3), 242-275.
- Abutalebi, J., Della Rosa, P. A., Green, D. W., Hernandez, M., Scifo, P., Keim, R., ... Costa, A. (2012). Bilingualism tunes the anterior cingulate cortex for conflict monitoring. *Cerebral cortex*, 22(9), 2076–86.
- Bates, D. Maechler, M., Ben Bolker & Walker, S (2014). lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1-7. <http://CRAN.R-project.org/package=lme4>
- Belke, E. (2013). Effects of working memory load on lexical-semantic encoding in language production. *Psychonomic Bulletin & Review*, 15(2), 357–363.
- Bialystok, E. (1999). Cognitive complexity and attentional control in the bilingual mind. *Child Development*, 70(3), 636–644.
- Bialystok, E., Craik, F. I. M., Grady, C., Chau, W., Ishii, R., Gunji, A., & Pantev, C. (2005). Effect of bilingualism on cognitive control in the Simon task: evidence from MEG. *NeuroImage*, 24(1), 40–9.
- Bialystok, E., & Martin, M. M. (2004). Attention and inhibition in bilingual children : evidence from the dimensional change card sort task. *Developmental Science*, 7(2), 325–339.
- Bloem, I., & La Heij, W. (2003). Semantic facilitation and semantic interference in word translation: Implications for models of lexical access in language production. *Journal of Memory and Language*, 48(3), 468–488.

- Bobb, S. C., & Wodniecka, Z. (2013). Language switching in picture naming: What asymmetric switch costs (do not) tell us about inhibition in bilingual speech planning. *Journal of Cognitive Psychology, 25*(5), 568–585.
- Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108*(3), 624–652.
- Caramazza, A. (1997). How many levels of processing are there in lexical access? *Cognitive Neuropsychology, 14*(1), 177–208.
- Caramazza, A., & Costa, A. (2001). Set size and repetition in the picture-word interference paradigm : implications for models of naming. *Cognition, 80*(2001), 215–222.
- Cohen J.D., MacWhinney B., Flatt M., & Provost J. (1993). PsyScope: A new graphic interactive environment for designing psychology experiments. *Behavioral Research Methods, Instruments, and Computers, 25*(2), 257-271.
- Compton, R. J., Huber, E., Levinson, A. R., & Zheutlin, A. (2012). Is “conflict adaptation” driven by conflict? Behavioral and EEG evidence for the underappreciated role of congruent trials. *Psychophysiology, 49*(5), 583–9.
- Costa, A., & Caramazza, A. (2000). Bilingualism : Language and Cognition
Language and Cognition: Is lexical selection in bilingual speech production language-specific? Further evidence from Spanish – English and English – Spanish bilinguals. *Bilingualism: Language and Cognition, 2*(3), 231–244.

- Costa, A., Alario, F.-X., & Caramazza, A. (2005). On the categorical nature of the semantic interference effect in the picture – word interference paradigm. *Psychonomic Bulletin & Review*, *12*(1), 125–131.
- 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*(2), 135–149.
- Costa, A., Miozzo, M., & Caramazza, A. (1999). Lexical Selection in Bilinguals : Do Words in the Bilingual's Two Lexicons Compete for Selection? *Journal of Memory and Language*, *41*, 365–397.
- Costa, A., & Santesteban, M. (2004). Lexical access in bilingual speech production: Evidence from language switching in highly proficient bilinguals and L2 learners. *Journal of Memory and Language*, *50*(4), 491–511.
- De Baene, W., Kühn, S., & Brass, M. (2012). Challenging a decade of brain research on task switching: brain activation in the task-switching paradigm reflects adaptation rather than reconfiguration of task sets. *Human Brain Mapping*, *33*(3), 639–51.
- de Bruin, A., Treccani, B., & Della Sala, S. (2015). Cognitive advantage in bilingualism An example of publication bias?. *Psychological Science*, *26*(1), 99-107.
- Damian, M. F., & Bowers, J. S. (2003). Locus of semantic interference in picture–word interference tasks. *Psychonomic Bulletin & Review*, *10*(1), 111–117.
- Damian, M. F., Vigliocco, G., & Levelt, W. J. M. (2001). Effects of semantic context in the naming of pictures and words. *Cognition*, *81*, 77–86.

- Dell, G. S., & O'Seaghdha, P. G. (1992). Stages of lexical access in language production. *Cognition*, 42(1-3), 287–314.
- Eriksen, Charles W. (1995) The flankers task and response competition: A useful tool for investigating a variety of cognitive problems. *Visual Cognition* 2.2-3: 101-118.
- Ferreira, V. S., & Pashler, H. (2002). Central bottleneck influences on the processing stages of word Production. *Journal of Experimental Psychology Learning Memory Cognition*, 28(6), 1187–1199.
- Finkbeiner, M., Almeida, J., Janssen, N., & Caramazza, A. (2006). Lexical selection in bilingual speech production does not involve language suppression. *Journal of experimental psychology. Learning, memory, and cognition*, 32(5), 1075–89.
- Gade, M., & Koch, I. (2005). Linking inhibition to activation in the control of task sequences. *Psychonomic Bulletin & Review*, 12(3), 530–534.
- Garrett, M. F. (1975). The analysis of sentence production. *Psychology of Learning and Motivation*, 9, 133-177.
- Gelman, A & Hill, J. (2007) Data Analysis Using Regression and Multilevel/Hierarchical Models. Cambridge University Press, Cambridge, UK.
- Glaser, W. R., & Dünghoff, F.-J. (1984). The time course of picture-word interference. *Journal of Experimental Psychology*, 10(5), 640–654.
- Gollan, T., Silverberg, B (2001). Tip-of-the-tongue states in Hebrew–English bilinguals. *Bilingualism: Language and Cognition*, 4(01), 63-83.

- Gratton, G., Coles, M. G., & Donchin, E. (1992). Optimizing the use of information: strategic control of activation of responses. *Journal of Experimental Psychology: General*, *121*(4), 480–506.
- Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and cognition*, *1*(02), 67-81.
- Guo, T., Liu, H., Misra, M., & Kroll, J. F. (2011). Local and global inhibition in bilingual word production: fMRI evidence from Chinese-English bilinguals. *NeuroImage*, *56*(4), 2300–9.
- Harley, T. A., & Macandrew, S. B. G. (2001). Constraints upon word substitution speech errors. *Journal of Psycholinguistic Research*, *30*(4), 395–418.
- Indefrey, P., & Levelt, W. J. M. (2004). The spatial and temporal signatures of word production components. *Cognition*, *92*(1-2), 101–44.
- Kan, I. P., Teubner-Rhodes, S., Drummey, A. B., Nutile, L., Krupa, L., & Novick, J. M. (2013). To adapt or not to adapt: The question of domain-general cognitive control. *Cognition*, *129*(3), 637–51.
- Kempen, G., & Huijbers, P. (1983). The lexocalization process in sentence production and naming: Indirect selection of words. *Cognition*, *14*, 185–209.
- Kerns, J. G., Cohen, J. D., MacDonald, A. W., Cho, R. Y., Stenger, V. A., & Carter, C. S. (2004). Anterior cingulate conflict monitoring and adjustments in control. *Science* *303*(5660), 1023–6.
- Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A. M., & Koch, I. (2010). Control and interference in task switching--a review. *Psychological Bulletin*, *136*(5), 849–74.

- Kleinman, D. (2013). Resolving semantic interference during word production requires central attention. *Journal of experimental psychology. Learning, Memory, and Cognition*, 39(6), 1860–77.
- Koch, I., Gade, M., Schuch, S., & Philipp, A. M. (2010). The role of inhibition in task switching: a review. *Psychonomic Bulletin & Review*, 17(1), 1–14.
- Kroll, J. F., Bobb, S. C., & Wodniecka, Z. (2006). Language selectivity is the exception, not the rule: Arguments against a fixed locus of language selection in bilingual speech. *Bilingualism*, 9(02), 119.
- Lavie, N. (2010). Attention, Distraction, and Cognitive Control Under Load. *Current Directions in Psychological Science*, 19(3), 143–148.
- Levelt, W. J. M., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences*, 22, 1–75.
- Linck, J. A., Schwieter, J. W., & Sunderman, G. (2011). Inhibitory control predicts language switching performance in trilingual speech production. *Bilingualism: Language and Cognition*, 15(03), 651–662.
- Marian, V., Blumfield, H., & Kaushanskaya, M. (2007). The Language Experience and Proficiency Questionnaire (LEAP-Q): Assessing language profiles in bilinguals and multilinguals. *Journal of Speech, Language, and Hearing Research*, 50(August), 940–967.
- MATLAB version 7.6. Natick, Massachusetts: The MathWorks Inc., 2008.
- McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review*, 88(5), 375–408.

- Mercier, J., Pivneva, I., & Titone, D. (2013). Individual differences in inhibitory control relate to bilingual spoken word processing. *Bilingualism: Language and Cognition*, 17(01), 89–117.
- Meuter, R. F. I., & Allport, A. (1999). Bilingual language switching in naming: Asymmetrical costs of language selection. *Journal of Memory and Language*, 40, 25–40.
- Meyer, A. S., & Schriefers, H. (1991). Phonological facilitation in picture-word interference experiments : Effects of stimulus onset asynchrony and types of interfering stimuli. *Journal of Experimental Psychology*, 17(6), 1146–1160.
- Miller, G. (1995). WordNet: A lexical database for English. *Communications of the ACM*, 38(11) 39-41.
- Miozzo, M., & Caramazza, A. (2003). When more is less: A counterintuitive effect of distractor frequency in the picture-word interference paradigm. *Journal of Experimental Psychology: General*, 132(2), 228–252.
- Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences*, 7(3), 134–140.
- Monsell, S., Yeung, N., & Azuma, R. (2000). Reconfiguration of task-set : Is it easier to switch to the weaker task? *Psychological Research*, 250–264.
- Novick, J. M., Trueswell, J. C., & Thompson-schill, S. L. (2010). Broca’s area and language processing : Evidence for the cognitive control connection, 10, 906–924.
- Papp, K., & Greenberg, Z. (2013). There is no coherent evidence for a bilingual advantage in executive processing. *Cognitive Psychology*, 66, 232-258.

- Pashler, H. (1989). Dissociations and dependencies between speed and accuracy: Evidence for a two-component theory of divided attention in simple tasks. *Cognitive Psychology*, 21, 469–514.
- Pashler, H. (1994). Dual-task interference in simple tasks : Data and theory. *Psychological Bulletin*, 116(2), 220–244.
- Philipp, A. M., & Koch, I. (2009). Inhibition in language switching: What is inhibited when switching between languages in naming tasks? *Journal of Experimental Psychology. Learning, Memory, and Cognition*, 35(5), 1187–95.
- Princeton University "About WordNet." WordNet. Princeton University. 2010. <<http://wordnet.princeton.edu>>
- R Core Team (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <http://www.R-project.org/>.
- Rogers, D., & Monsell, S. (1995). Cost of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology. General*, 124(2), 207–231.
- Scherbaum, S., Dshemuchadse, M., Fischer, R., & Goschke, T. (2010). How decisions evolve: The temporal dynamics of action selection. *Cognition*, 115(3), 407–16.
- Schriefers, H., Meyer, A. S., & Levelt, W. J. M. (1990). Exploring the time course of lexical access in language production : Picture-word interference studies. *Journal of Memory and Language*, 29, 86–102.

- Simon, J. R., & Rudell, A. P. (1967). Auditory SR compatibility: the effect of an irrelevant cue on information processing. *Journal of Applied Psychology*, 51 (3), 300.
- Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, 18(6), 643.
- Szekeley, A., Jacobsen, T., D'Amico, S., Devescovi, A., Andonova, E., Herron, D., ... Gerdjikova, I. (2012). A new on-online resource for psycholinguistic studies. *Journal of Memory and Language*, 51(2), 247–250.
- Van Casteren, M., & Davis, M. H. (2006). Mix, a program for pseudorandomization. *Behavior Research methods*, 38(4), 584–589.
- Verhoef, K., Roelofs, A., & Chwilla, D. J. (2009). Role of inhibition in language switching: Evidence from event-related brain potentials in overt picture naming. *Cognition*, 110(1), 84–99.
- Wylie, G., & Allport, A. (2000). Task switching and the measurement of “switch costs”. *Psychological research*, 63(3-4), 212–33.