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Effects of bilingualism on goal representation and maintenance

Amina Saadaoui

EFFECTS OF BILINGUALISM ON GOAL REPRESENTATION AND MAINTENANCE

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ABSTRACT

Bilingualism is an increasing interest to contemporary research in cognitive psychology. Various cognitive tasks that involve attention and inhibition have been used to identify the differences between monolinguals and bilinguals in terms of cognitive control. The present thesis reviewed the literature on bilingualism mainly in regards to how it affects cognitive control from both cognitive and neuroscience aspects. It also utilized a continuous performance task (AX-CPT) to examine the differences between monolinguals and bilinguals in how they represent and maintain goal information when having to select appropriate responses and disregard inappropriate responses. Performance on the AX-CPT was compared between monolinguals and bilinguals in both short and long cue-probe delay conditions on four trial types (AX, AY, BX, BY). It was predicted that bilinguals are better at inhibiting the tendency to make a target response on trials in which the cue is invalid, thus, would perform better than monolinguals in BX trials. It was also predicted that bilinguals would expect valid cues ("A") to be followed by target probes ("X"), thus, would perform worse than monolinguals in AY trials. The findings partially supported

the predictions such that bilinguals outperformed monolinguals on BX trials reflecting improved inhibition. However, there were no differences on AY trials, indicating that monolinguals and bilinguals are not different in their attentional processes.

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CHAPTER ONE

INTRODUCTION

In many parts of the world, being proficient in at least two languages is not an option, but a must. People in many countries learn two languages since birth or from a very young age. They are called bilinguals for their rich linguistic repertoire and their ability to master two languages. A great deal of research has indicated that these individuals are better than their monolingual peers at performing cognitive tasks that require high level of cognitive control (e.g., Ben-Zeev, 1977; Cummins & Swain, 1986; Colzato et al., 2008; Rodrigues-Fornells et al., 2006; Hernandez, 2009). Cognitive control, also referred to as executive control, is the ability to inhibit one cognitive task while executing another task (Casey, Durston, and Fossella, 2001). A key mechanism often associated with cognitive control is the ability to represent and maintain goal information in working memory (e.g., Braver et al., 2001; Braver & Barch, 2002; Javitt, Rabinowicz, Silipo, & Dias, 2007; Paxton, Barch, Racine, & Braver, 2008; Lorbach & Reimer, 2010). The primary focus of this study was to examine whether the bilingual advantage in cognitive control is due to bilinguals' ability to represent and maintain this goal information. This question was addressed through the use of an experimental paradigm referred to as AX-CPT (Braver et al., 2001; Braver & Barch, 2002).

Bilingualism and General Cognitive Ability

Some of the earliest research on the effects of simultaneous bilingualism on cognition was conducted by Ben-Zeev (1977) who demonstrated that bilingualism positively affects cognitive development. Ben-Zeev compared the performance of English-Hebrew speaking children to monolingual English and monolingual Hebrew speaking children on various cognitive tests. These tests were designed to examine flexibility in using syntactic rules, semantic knowledge, and nonverbal system understanding. Flexibility in using syntactic rules reflects the extent to which bilingual children know which syntactic rules apply to each language. Many languages have different syntactic rules. Thus, bilingual children must learn to adapt the syntactic rules they use, depending on the language that they are currently using. As a result, bilingual children are more analytical of syntax than monolingual children. Semantic knowledge tests examine the degree to which children understand that words are simply arbitrary symbols that do not carry meaning in themselves. Because bilingual children must in most cases learn two separate words for one concept, they often score better on semantic knowledge tests than monolinguals. The nonverbal system understanding test involves assessing the performance of bilinguals on a nonlinguistic cognitive task. Ben-Zeev demonstrated that bilingual children are not only more analytical of verbal structures, but are also more analytical of nonverbal structures as well. This suggests that bilingual children develop better attentional strategies than monolingual children.

Since Ben-Zeev's initial studies, Cummins and Swain (1986) have pointed out that being exposed to two languages may result in either positive or negative consequences. According to Cummins and Swain, the level of linguistic competence is an essential element in determining whether or not bilingualism positively affects cognitive processes. In order to account for both the positive and negative effects of bilingualism, Cummins and Swain proposed the threshold theory. According to this theory, two threshold levels are responsible for the impact of bilingualism on cognition. Bilinguals who are below the first threshold are less proficient in both first and second language than monolinguals are in either language. When this is the case, bilinguals are said to experience semilingualism. Once the first threshold is reached, bilinguals have already developed a decent level of competence in one of the two languages, but not in both. This allows them to avoid the negative effects associated with bilingualism, but do not outperform monolinguals. When bilinguals reach the second threshold, they are considered "balanced" bilinguals and can benefit from the positive effects of bilingualism. For instance, they can benefit from high levels of linguistic skills, divergent thinking, and cognitive development associated with bilingualism. They are also more sensitive to feedback cues and possess meta-linguistic awareness such as understanding that the relationship between the word and its referent is random and arbitrary. However, in order to avoid the negative effects associated to bilingualism, bilinguals need to reach a high level of competence in the second language. That occurs only when the bilingual spends more time learning the second language (Cummins & Swain, 1986).

More recently, Bialystok (2010) conducted a study on bilingualism and cognitive ability that examined bilinguals' performance on the global-local and the trial making tasks. Performance on these tasks requires the processing of stimuli in such a way that some elements are attended to while others are actively ignored. Which elements of the stimuli are to be attended or ignored depends on a frequently changing rule. In the global-local task, a fixation cross is presented in the center of the screen for 500 ms, followed by a global stimulus to which the participants must respond. The global level stimulus is represented by a large letter or a shape (such as circle or square), which itself is composed of smaller letters or shapes. These smaller letters or shapes represent the local level stimuli (see Figure 1). For example, on some trials, participants were presented with a large letter H which was composed of identical small H letters. Such trials were labeled as congruent trials. On other trials, the stimulus consisted of a large letter H composed of different small letters such as S or X. Such trials were labeled as incongruent trials. With incongruent trials, there is conflict between local and global levels. Usually, in the case of incongruent trials, participants process the global level faster with fewer errors than the local level because the global stimulus interferes with the local level. In both congruent and incongruent trials, Bialystok found that bilinguals have faster response times than monolinguals. Better performance in congruent trials, which did not require resolution of conflict, suggested that other cognitive processes, other than inhibition are involved in the bilingual advantage.

Bialystok (2010) also used the trial making task. This task contains two critical conditions. The first condition involves numbers that are displayed on different locations of a page. Using a pencil, participants were required to connect the numbers in order, starting with the number one. The second condition involved both numbers and letters displayed on different locations of a page and participants had to connect them according to their order, but by switching between numbers and letters such as "1, A, 2, B, 3, C…. etc." In this task, bilinguals performed better than monolinguals in both conditions. According to Bialystok, the superior performance of bilinguals in this task reflected better attentional control. Combined findings of both the global-local and the trial making tasks suggest that bilinguals possess advanced cognitive control that goes beyond only inhibition and conflict resolution, but extends to updating and switching as well. Bialystok also indicated that extensive research is needed in this area to examine all processes involved in the overall advanced cognitive control in bilinguals.

Bilingualism and Cognitive Control

Although cognitive control has been one of the main focuses of cognitive research, there is not much consensus on how it is defined. According to Casey, Durston, and Fossella (2001), cognitive control is characterized by one's ability to inhibit one cognitive task while executing another one, which often involves suppressing competing information and avoiding conflict when processing. Such inhibition occurs at the three phases of cognitive processing, stimulus selection, response selection, and response execution. Furthermore, Casey et al. (2001) suggested that two different brain areas are involved in this process. The basal ganglia are responsible for suppression of unnecessary information whereas the frontal cortex, specifically the PFC, is responsible for representing and maintaining target information. On the other hand, Miyake et al. (2000) defined cognitive control as the set of interconnected processes in the frontal lobes that consist of three main elements: inhibition, cognitive flexibility, and working memory. Inhibition involves suppressing unnecessary (non target) information, cognitive flexibility allows switching from one cognitive task to another, and working memory serves to represent and maintain information. Consistent with Miyake et al. (2000), Shimamura (2000), proposed that there are four processes of cognitive control. These processes are: selecting, maintaining, updating, and rerouting. Selecting is described as a mechanism that directs attention so that one may focus on target stimuli. Maintaining involves keeping selected stimuli active in working memory. Updating refers to modulating and constantly adjusting information in working memory depending on task goal and contents. Rerouting refers to switching one's focus from one cognitive process to another, such as from word naming to color naming in the Stroop task.

The existing research strongly supports the idea that being raised as a bilingual improves the inhibitory control system and suggests that there are at least two different mechanisms that are involved in this system: an active inhibition mechanism (Green, 1998) and a reactive inhibition mechanism (Logan & Cowan, 1984). When bilinguals select the words that need to be communicated, they have to select between the target word (i.e. the word in current language), and noise (i.e. the word in the alternative language). Both target and noise compete for selection, which creates competition which the speaker has to resolve in order to select the target and inhibit the noise. Green (1998) suggested that because bilinguals have to actively inhibit the noise in order to select the target word, their inhibitory mechanisms become well-developed and generalize to nonlinguistic tasks. As a result, bilinguals possess better overall cognitive control. Other researchers such as Logan and Cowan (1984) have identified another mechanism involved in bilinguals' selection of target words. This mechanism is referred to as reactive inhibition which states that bilinguals do not actively inhibit noise in order to select the target word, but they keep the target as their primary focus, which indirectly inhibits the noise. This indicates that bilinguals are not necessarily active inhibitors but they are better than monolinguals in maintaining their task goal.

Colzato et al. (2008) examined whether bilinguals are better than monolinguals at ignoring irrelevant information in nonlinguistic tasks. Colzato et al. (2008) tested bilinguals using the stop signal task in which participants were presented with a green arrow and had to press a key using their left or right index finger depending on the direction of the arrow. When the green arrow changes to a red arrow, participants have to try however to keep from pressing the key. Two processes are believed to be involved on successful performance on this task: A go process and a stop process. Participants can successfully inhibit their responses when the stop process finishes before the go process, but are incapable of inhibiting their responses when the go process finishes before the stop process. Colzato et al. (2008) found that on only half of the trials, both monolingual and bilingual participants were able to inhibit their responses when they were instructed to stop. The similarity in performance between monolinguals and bilinguals implies that the advantage that bilinguals have is not due to active inhibition.

Since the possibility of active inhibition was excluded by the stop signal task, Colzato et al. (2008) also used the attentional blink task. The attentional blink is a phenomenon that happens when participants are presented with two target stimuli that are presented sequentially with only a very brief temporal cue-probe delay between them. If the second target is presented 500 ms or less after the first target, multiple studies have found that participants have difficulty reporting the second target. This is the case because the participant is fully focused in processing the first target and cannot process the second target. In this task, bilinguals experienced larger attentional blink and performed worse than monolinguals at processing the second stimulus when it was presented while they were still processing the first stimulus. The larger attentional blink reflected better reactive inhibition which occurs when participants focus on processing the first stimulus and inhibit any competitors (i.e., the second stimulus). These findings demonstrate that the advantage that bilinguals have over monolinguals in cognitive control is not due to active inhibition, but rather that bilinguals are constantly trying to keep their two languages separate (reactive inhibition). This results in an enhancement in choosing goal-relevant information from goal-irrelevant information. This is consistent with Logan and Cowan (1984) findings that bilinguals use reactive inhibition mechanism when processing a target whether linguistic or nonlinguistic. Therefore, according to Colzato et al. (2008), bilinguals are better than monolinguals in creating, keeping, and transforming goal representations in order to maintain goal-relevant behavior (i.e., one language and not another). Also, Colzato et al. (2008) found it necessary to differentiate between the different types of inhibition and consider both goal maintenance and reactive inhibition in future research on bilingualism.

To determine whether it is bilingualism per se that affects cognitive control or the extensive training that bilinguals experience by speaking two languages, Bialystok and Depape (2009) compared the performance of bilinguals and musicians to monolinguals and non-musicians on the auditory Stroop and the Simon tasks. Whether it is to be proficient at two languages or to master a specific musical instrument, both bilinguals and musicians have to go through extensive training and spend time and cognitive resources in order to perform well. The similarity between musicians and bilinguals, therefore, is that they both have special experience with music or language. Bilinguals have special experience with language more than monolinguals as they use two different active language systems. Musicians also have special experience with musical instruments more than non musicians because they spend considerable amount of time playing a specific musical instrument. It was also suggested that the musical experience requires high levels of control, selective attention, inhibition, switching, and updating. Therefore, the cognitive processes involved in the musical training are also involved in the bilingual experience (Bialystok & Depape, 2009). This was also supported by Patel, Gibson, Ratner, Besson, and Holcomb (1998) who found that violating syntax in a sentence and violating harmony in musical sentence both elicit the same ERP component. Therefore, the degree to which the task performed is similar to musical experience in terms of using musical component will reflect the extent to which the effect can be generalized. For instance, if extensive musical training influences cognitive control, then performance of musicians at the auditory Stroop task can be considered a direct observation of how musical experience affects cognitive control since this task requires auditory judgments. Performance in the Simon task will reflect the generalized effects by indicating whether experience in music or language can be generalized to domains, other than music or language.

The Auditory Stroop task measures response times when there is a conflict between a word's meaning and its pitch. In this task, participants are presented with an auditory stimulus and must determine whether its pitch is high or low. In the control condition, the stimulus is the word "ahh" presented in a high or low pitch voice. In addition to the control condition, there are two conflict conditions in which the words "high" and "low" were presented in either low or high pitch. In the pitch conflict condition, participants had to determine the pitch and ignore the word, whereas in the word conflict condition, participants had to determine the word and ignore the pitch. Unlike the auditory stroop task, the Simon task is a nonverbal spatial task in which the stimuli are black arrows displayed on a white background. In the control condition, an arrow is presented in the center of the screen and participants must indicate the direction that the arrow by pressing one of the two buttons. In the position condition, arrows were presented on the far right or left side of the screen, and participants had to determine the spatial position of the arrow but ignore the direction of the arrow. A conflict is present when the arrow points in the opposite direction to its position.

In their study, Bialystok and Depape (2009) found that musicians completed the Auditory Stroop task faster than non musicians, monolinguals, and bilinguals with better performance in the pitch conflict conditions in which they had to determine the pitch of the word but ignore the word's meaning. This suggests that musical experience enhances cognitive control in tasks that are specific to the area of expertise. The Simon task was completed faster by bilinguals and musicians than non musicians and monolinguals with better performance in conditions where they had to determine the direction of the arrow and ignore its position. This pattern of data suggests that cognitive control is affected mainly by intensive training in a specific area such as speaking two languages or playing a specific instrument. The effect is evident in all activities that require executive control, even those that are not directly related to the experience itself. The findings of this study, therefore, demonstrate that increased cognitive control is not linked to language only, but experience in general. The high levels of cognitive control found in musicians and the high levels of control found in bilinguals are both related to the extensive experience of musicians and bilinguals. (Bialystok & Depape, 2009).

In a related study, Bialystok, Craik, and Luk (2008) assessed working memory, lexical retrieval, and cognitive control in bilinguals and monolinguals using a variety of different tasks. Working memory was examined using the forward and backward Corsi block span task and the self-ordered pointing test. Lexical access was examined using the Peabody picture vocabulary test, the Boston naming task, and the category/letter fluency task. Cognitive control was examined using the Simon arrows task, the Stroop color naming task, and the sustained attention to response task. In the working memory tasks, there was not a significant difference in performance of monolinguals and bilinguals. However, in the verbal tasks, monolinguals performed better than bilinguals. Bialystok et al. (2008) argued that because monolinguals have access to only one language, they have more experience in retrieving words in their language. In contrast to monolinguals, bilinguals are always challenged by competing responses from two different languages. This competition causes a cue-probe delay in their responses. In the cognitive control tasks, bilinguals performed better than monolinguals suggesting that this advantage is due to the constant need to inhibit interference from the unwanted language. More importantly, Bialystok, Craik, and Luk (2008) suggested that bilinguals' poor performance in lexical access tasks and enhanced performance in cognitive control tasks were related. Bilinguals suffer from lexical conflict caused by activation of words from both languages. Bilinguals constantly try to avoid this conflict by inhibiting the unwanted language, which leads to improved cognitive control.

In summary, it seems that the way researchers define cognitive control affects how they study its relationship to bilingualism. Most of the research indicates that not only active inhibition is involved in bilinguals' enhanced cognitive control, but other mechanisms such as reactive inhibition and the ability to create, maintain, and transform goal relevant information are also responsible for this bilingual advantage (e.g., Bialystok, 2010; Green, 1998; Colzato et al., 2008; Miyake et al., 2000).

Neurological Bases for the Cognitive Control of Two Languages

Neuroscience research supports the findings of behavioral research that bilingualism affects cognitive control. Much of the neuroscience research also demonstrates that in order to cope with the constant interference of one language over the other, bilingual speakers recruit executive functions to control the two languages. Using the event related potential (ERP) and Functional Magnetic Resonance Imaging (fMRI), Rodrigues-Fornells, De Diego Balaguer, and Munte (2006) examined the cognitive mechanisms involved in regulating two or more languages. Rodrigues-Fornells et al. (2006) found that code switching is regulated by the brain's executive system. Specifically, Rodrigues-Fornells et al. (2006) found that the prefrontal cortex is responsible for cognitive control in bilingual speakers through the interaction of a top-down selection suppression mechanism, and a local inhibitory mechanism that monitors the extent to which the different lexicons are selected or suppressed. Rodrigues-Fornells et al. (2006) believed that a neural network is created by the brain to execute three functions. These functions are: separating the first language and the second language, creating the proper activation and inhibitory lexical, morphological, and syntactic connections, and also selecting the correct word and applying its syntactic rules in the target language.

According to Rodrigues-Fornells et al. (2006), cognitive control occurs when we are able to suppress irrelevant external information and inhibit inappropriate thoughts and actions. Since cognitive control is needed to monitor the processing of two languages, bilingual children develop enhanced cognitive control mechanisms relative to monolingual children. This is due to their need to switch between the two languages and ignore distracting information from early on in life. Rodrigues-Fornells et al. (2006) used both ERP and fMRI methodologies to determine bilinguals' brain areas activated during the cognitive control of language processing and to assess the effects of response inhibition. By combining both methodologies, Rodrigues-Fornells et al. (2006) were able to measure both the brain areas involved in language production as well as the interference effects associated with it. Rodrigues-Fornells et al. (2006) found that the non-target language interferes with the target language phonologically in bilinguals. This is associated with activation in the left dorso-lateral prefrontal cortex (DLPFC) and the supplementary motor area. Therefore, bilinguals appear to manage the second language interference by using the left DLPFC and anterior cingulate cortex (ACC), which are basic executive brain areas. The ACC is important in cognitive control as it detects conflict and signals it to the DLPFC to get activated (Rodrigues-Fornells et al., 2006). Activation of the DLPFC, therefore, depends on the detection of conflict by the ACC.

Rodrigues-Fornells et al. (2006) also acknowledged that switching between two languages is dependent on working memory, attention, and the bilingual's choice to perform in the target language. For instance, highly proficient bilinguals are able to match a word's sound to its spelling in a target language while ignoring words in a non-target language. An fMRI study confirmed that bilinguals have superior executive control by showing greater activation in the left DLPFC, the anterior inferior frontal region, and the ACC. In this model, the ACC is responsible for detecting conflict and instantiating processing before response execution.

Furthermore, Rodrigues-Fornells et al. (2006) proposed two control mechanisms that are responsible for monitoring bilingual speech production. These mechanisms are: top down control mechanism and bottom up mechanism. The top down mechanism is used by the prefrontal cortex when language representations are activated. The bottom up mechanism is a more local inhibitory mechanism that monitors the availability of the non-target language representations. Both mechanisms interact to regulate the bilingual speech production such that top down modulations from the prefrontal cortex directly enable the language processing at posterior areas of the cortex and inhibit activity in areas that are non-relevant.

Similarly, Hernandez (2009) conducted an fMRI study to examine the neural associations of covert picture naming in the first language and the second language in early Spanish-English bilinguals. Hernandez was interested in this specific population because their dominant language is their second language (English), not their first language (Spanish). Hernandez found that switching between languages in bilinguals during picture naming shows greater activity in the left DLPFC and the superior parietal lobe. Also, there were differences in several regions when completing the task in English versus Spanish. More specifically, differences were found in the superior temporal gyrus which is responsible for language processing. Differences were also found in brain areas that are responsible for other nonlinguistic cognitive functions such as the hippocampus, amygdala, and post central gyrus. The hippocampus is responsible for memory. Hernandez found that greater activation in the right hippocampus when naming pictures in Spanish, and a greater activation in the left hippocampus when naming the picture in English. The amygdala is responsible for emotion. Bilinguals showed larger activity in the amygdala when performing the task in Spanish than in English. The post central gyrus is responsible for somatosensory processing. Bilinguals showed larger activity in the post central gyrus when performing the task in English than in Spanish. This indicates that neural systems that are usually associated with general cognitive functions are also responsible for bilinguals' representation of the two languages. These results indicate that processing both languages requires recruiting a larger neural network.

The primary findings of recent neuroscience research, therefore, suggest that coping with interference of one language over the other and exerting cognitive control result primarily in activation in the left DLPFC. As cognitive control increases, the activation of the DLPFC increases. This brain area is also cited in many studies that examine cognitive control using the AX-CPT paradigm.

Cognitive Control as Context Processing

Context processing is defined as the mechanism involved in representing and maintaining relevant goal information in working memory. Context processing, therefore, plays the role of working memory by keeping the relevant information active, by inhibiting irrelevant information, and also by directing attention to specific stimuli (Braver et al., 2001; Braver & Barch, 2002). A more specialized term of context information, specific to planning and overt behavior, is called goal information. Many researchers argue that the representation and maintenance of goal information are key elements in cognitive control (Braver et al., 2001; Braver & Barch, 2002; Lorsbach & Reimer, 2010). Goal information, therefore, is any information that is relevant to the task, thus, it must be internally represented in a way so that the participant may perform the task correctly. An illustrative example of context processing is the Stroop task in which task instructions make up the context and have to be represented and maintained in order to select the ink color and inhibit the word (Braver et al, 2001; Braver & Barch, 2002). It is also important to note that context processing theory explains how attention, working memory, and inhibition are related. For instance, the degree to which goal information can be maintained over time influences performance in tasks that require information to be held in working memory. Also, tasks that require attention and inhibition depend on the representation of goal information to selectively process task relevant cues and ignore irrelevant task cues (Braver et al., 2001; Braver & Barch, 2002; Lorsbach & Reimer, 2010).

Braver et al. (2001) emphasized the importance of DL-PFC on both context processing and cognitive control. Many neuroimaging studies have shown that there is larger activity in the PFC when individuals are performing tasks that require cognitive control (Braver et al., 2001). Also, larger activation is apparent in the PFC when individuals are maintaining goal information to perform a specific task, which suggests that PFC is responsible for context processing and cognitive control. Braver et al. (2001) also suggest that the PFC cannot perform its role without projections of the dopamine (DA) which control access of information by actively maintaining only task relevant information. This connection between the PFC and DA plays a gating role. An open gate allows access of incoming information to the context unit. On the other hand, a closed gate does not allow access which protects goal representations from irrelevant task information. Therefore, the interaction between the PFC and DA system is essential in cognitive control (Braver et al, 2001; Braver & Barch, 2002).

A simple version of the classic Continuous Performance Test (CPT), known as the AX-CPT is one of the most widely adopted cognitive tasks used to examine Braver's theory of cognitive control (Braver & Barch, 2002; Lorsbach & Reimer, 2010). This task was developed to examine context representation and maintenance of goal information (Braver et al., 2001). Braver and Barch (2002) indicated that the importance of contextual representations is greater when the inappropriate response is stronger than the appropriate response and interferes with the appropriate response. In any task, contextual cues play both mnemonic and control roles in working memory because they are present throughout the task and can be accessible at any time. Therefore, as suggested by Javitt, Rabinowics, Silipo, and Dias (2007), a main factor when performing the AX-CPT is the ability to transform the cue into a representational form that maintains that information regarding the cue and use it as an indicator for future stimulus assessment and response. This representation, is often called, context representation (Javitt, Rabinowicz, Silipo, & Dias, 2007).

In the AX-CPT, sequences of single letters are displayed on the center of a computer monitor one at a time. Participants are instructed to positively respond to a probe ("X") when it is preceded by a cue ("A") and to negatively respond in all other situations. The positive response is called a target response and a negative response is called a non-target response (see Figure 2). The sequences of letters are such that an ("A") cue is followed by an ("X") probe on 70% of the trials. Such trials are referred to as "target" trials. In the AX-CPT, there are three types of non-target trials: BX, AY, and BY. Each type of non-target trial is presented 10% of the time. In the BX trial, a ("B") non valid cue is followed by an ("X") valid probe. In the AY trial, an ("A") valid cue is followed by a ("Y") non valid probe. In the BY trials, ("B") non cue is followed by a ("Y") non valid probe.

Because the frequency of AX trials is high (70%), the representation and maintenance of contextual cues helps inhibit an incorrect target response on BX trials, but creates an expectancy bias in the AY trials as participants' attention is directed to a specific response by expecting an ("X") after ("A") valid cue. In the AY condition therefore, participants' expectation about the target creates a bias toward making an incorrect response. In the BX condition, the response bias is inhibited because of the internal representation of the ("B") non valid cue, which enhances performance. Therefore, in both AY and BX conditions, participants need to resist making an incorrect response (Paxton, Barch, Racine, & Braver, 2008). As a result, good goal representation should lead to improved performance of BX but poorer performance on AY trials. This is exactly what had been found in many studies that have utilized the AX-CPT (Braver et al., 2001; Braver & Barch, 2002; Lorsbach & Reimer, 2010). More specifically, situations where there is an invalid cue ("B") and an invalid probe ("Y") serve as control condition because of the absence of contextual cues and expectancy bias. Indeed, performance in the AX, BX, and AY conditions compared to the control condition BY is what reflects the degree to which context representation and maintenance are present the AX-CPT task. Both good representation and good maintenance are reflected by increased performance in the BX condition and decreased performance in the AY condition in terms of both reaction times and error rates. On the other hand, poor context representation is reflected by decreased performance on the BX and AX conditions and increased AY performance (Paxton, Barch, Racine, & Braver, 2008). For instance, when participants see a valid cue ("A"), they expect the probe to be an ("X") and tend to make an incorrect response. However, when participants see non-valid cue ("B"), they automatically know what response to make whether or not the probe is valid.

Braver et al. (2001) made a distinction between goal representation and goal maintenance. Goal representation simply means to internally represent and direct attention to the selected task relevant information. Goal maintenance means maintaining goal information active in working memory and available to impact processing. The AX-CPT tests both goal representation and goal maintenance by manipulating the delay between the cue and the probe. The AX-CPT tests goal representation through the use of short cue-probe delay conditions (i.e., 1,000 ms between the cue and the probe) and goal maintenance with long cue-probe delay conditions (i.e., 5,000 ms between the cue and the probe). Enhanced representation is reflected by good performance in the short cue-probe delay conditions, whereas, impaired representation is reflected by decreased performance in the short cue-probe delay conditions. Also, increased maintenance indicates good processing with long cue-probe delay conditions, whereas, impaired maintenance indicates decreased performance in the long cue-probe delay conditions (Braver & Barch, 2002).

The AX-CPT has mainly been used in studies that examine cognitive aging, cognitive development, and schizophrenia. For instance, in a study by Braver et al. (2001), the AX-CPT has been used to examine cognitive aging by comparing performance of older adults and younger adults on the AX-CPT. The task was performed in three different conditions: baseline, interference, and degraded. The baseline condition is the classical AX-CPT. In the interference condition, three distractors were presented between the cue and the probe. In the degraded condition, some letters were visually degraded so that only 85% of the pixels compose the letter. In the baseline condition, older adults performed worse than younger adults. This was reflected by more errors on the BX trials and fewer errors on the AY trials. In the interference condition, older adults performed much worse than younger adults, relative to the baseline condition. That is because the three distractors added made it more difficult for older adults to represent and maintain goal information. Also, in the degraded condition, older adults performed much worse than younger adults, relative to the baseline condition. That is because the difficulty of recognizing the letters made it more difficult for older adults to represent and maintain goal information. Overall, Braver et al. (2001) found that older adults' performance on the AX-CPT indicates that they possess a deficit in the ability to represent and maintain contextual information than younger adults. Braver et al. (2001) explained this poor performance by impairment in the dopamine (DA) function in the left dorso-lateral prefrontal cortex (DLPFC). DA and DLPFC are negatively affected by age. Also, the deterioration in context processing leads to decline in other cognitive tasks that require attention, working memory, and inhibition of response (Braver et al., 2001, Braver & Barch, 2002).

In a recent study by Lorsbach and Reimer (2010), the AX-CPT was used to examine the development of children's ability to represent and maintain contextual information by comparing performance of third grade and sixth grade children. The task was performed on two different cue-probe conditions: short cue-probe delay condition (1,000 ms) and long cue-probe delay condition (5,500 ms). Also, the color of letters was manipulated such that color red was the valid color and green was the invalid color. Older children outperformed younger children at representing and maintaining contextual information at the 5,500 ms cue-probe delay. Older children performed better on the AX and BX conditions, but performed worse on the AY conditions. When the cue-probe delay was reduced to 1,000 ms and the color and type of letters were manipulated, older children outperformed younger children when the cue features (type and color) were incongruent. Lorsbach and Reimer concluded that older children are better than younger children at representing and maintaining contextual information when expecting certain probes, especially in conditions that required them to be able to represent and maintain those contextual cues.

Research on schizophrenia is another area that heavily relied on the use of AX-CPT to explain the cognitive deficits of schizophrenic patients especially in relation to working memory. Lee and Park (2006) suggested that the deficits in working memory for schizophrenia patients are caused by their inability to encode stimuli. Lee and Park indicated that the importance of contextual cues makes a difference at the encoding phase and affects performance in the AX-CPT task. Consistent with Lee and Park, Javitt et al. (2007) suggested that schizophrenia patients are unable to correctly respond to a valid probe preceded by a valid cue (the "AX" condition) and also to a valid probe preceded by an invalid cue (the "BX" condition), but they are able to correctly respond when the probe is invalid and preceded by a valid cue (the "AY" condition). Javitt et al. (2007) explained this by suggesting that schizophrenia patients have greater difficulties at encoding and maintaining the contextual cue, than recognizing the target probe. Also, Javitt et al. (2007) manipulated the ease of the cue using three different contextual cues (letters, colored circles, and colored letters). This difference affected the overall performance in the task. Schizophrenia patients performed similarly to the control group when the contextual cues were solid colored circles. Also, schizophrenia patients performed better and made fewer errors when the cues were simple letters than when the cues were colored letters.

This means that performance of schizophrenia patients improves as the contextual cues are easy to interpret and that deficits in the AX-CPT task occur at the sensory decoding stage. Also, Javitt et al. (2007) indicated that inability to perform well in the AX-CPT is due to dysfunction in the prefrontal cortex.

CHAPTER TWO

THE PRESENT STUDY

As demonstrated above, previous research has demonstrated that bilingualism is associated with improved cognitive control. For example, Colzato et al. (2008) demonstrated that because bilinguals are constantly trying to keep their languages separate, they are better than monolinguals in choosing goal-relevant information from goal-irrelevant information. Also neuroscience research has demonstrated that DL-PFC plays a role in bilinguals' cognitive processing. Recent theories of cognitive control have emphasized the role of goal representation and maintenance in working memory, and that such processes are also linked to DL-PFC functioning. Such theories are based on the premise that three processes, the maintenance of goal information active in working memory, the inhibition of irrelevant information, and the direction of attention to goal related stimuli, underlie cognitive control (e.g., Braver et al., 2001; Braver & Barch, 2002; Javitt et al., 2007; Paxton, Barch et al., 2008). Given that bilinguals possess better cognitive control than monolinguals and that cognitive control has been related to goal representation and maintenance, it is possible that the advantage that has been found in cognitive control with bilinguals is due to an enhanced ability to represent and maintain goal information. To present, no study has used the AX-CPT paradigm as a way to examine bilinguals' ability to represent and maintain contextual cues, and how this ability makes them different than monolinguals in terms of cognitive control. Therefore, the present study was designed to examine whether the cognitive control advantage that has been found with bilinguals is the result of improved goal representation and/or goal maintenance. Thus, in the present study, performance on the AX-CPT was compared between bilingual and monolingual participants in both short (1,000 ms) and long (5,000) cue-probe delay conditions.

In general, if the ability to represent and/or maintain goal information is better for bilinguals than monolinguals, bilinguals should expect valid cues ("A") to be followed by target probes ("X"). This expectation should lead to poorer performance (i.e., more errors and/or slower RTs) on the AY trials relative to monolinguals. Additionally, if bilinguals have superior ability in representing and/or maintaining goal information, they should be better at inhibiting the tendency to make a target response on trials in which the cue is invalid (i.e., BX trials). Thus, compared to monolinguals, bilinguals should perform better (i.e., fewer errors and faster RTs) on BX trials.

Furthermore, by comparing the performance of bilinguals and monolinguals using both a short and long cue-probe delay within the AX-CPT, it is possible to determine whether the bilingual advantage that has been found in cognitive control is specifically due to an enhanced ability to represent goal information, maintain goal information, or represent and maintain goal information in working memory. In the short cue-probe delay condition, performance is largely dependent upon the participants' ability to represent the goal information (i.e., cues) in working memory. Because of the relatively short cue-probe delay, the demands placed upon goal representation are high while the demands on goal maintenance are relatively minimal. On the other hand, in the long cue-probe delay condition, because participants must maintain the cue for 5,000 ms, relatively greater demands are placed upon goal maintenance. If the bilingual advantage is due only to the ability to represent goal information, bilinguals should perform better than monolinguals at both the short and long cue-probe delay conditions. On the other hand, if the bilingual advantage is due only to the ability to maintain goal information, bilinguals should perform better than monolinguals at the long, but not the short, cue-probe delay condition. Finally, if both representation and maintenance of goal information are enhanced for bilinguals they should perform better than monolinguals at both the short and long cue-probe delay conditions; however, the difference in performance between bilinguals and monolinguals should be larger in the long than the short cue-probe delay condition.

Participants

Thirty-three English speaking monolingual and twenty-eight Spanish-English speaking bilingual participants participated in the present study. Two bilingual participants and two monolingual participants were left-handed. All participants were undergraduate students attending California State University, San Bernardino between 18 and 55 years of age. Participants were given course credit for their participation in the study. The bilingual participants were assigned to the bilingual group based on self-identification as bilinguals and reported their language use and competence by completing a language history questionnaire. All participants signed an informed consent as required by the Institutional Review Board. See Appendix D for informed consent.

Materials and Stimuli

Language History Questionnaire

This self report questionnaire, shown in Appendix C, was completed by participants prior to the experiment in order to rate their linguistic proficiency in terms of speech, reading, writing, and comprehension as well as length of exposure and use of all known languages. Responses on proficiency were answered on a scale of 1 to 7 and only responses of 6 and higher were considered. Responses on use were answered on a scale of 1 to 3 and only responses of 2 or higher were considered. Also, only the participants who indicated that they use both languages daily were considered in the bilingual group. The language history questionnaire was completed in English and took approximately 10 minutes to complete.

E-Prime Software

The present study was programmed using E-Prime software that presented stimuli and also served as a tool to record each participant's response and determine the accuracy and response latency (Schneider, Eschman, & Zuccolotto, 2002). The software displayed the letters in sequence on the center of 15 inch monitor screen. Letters were all be capitalized and presented in color red displayed on black background. The font type was Calibri and the font size was 36. The two letters K and Y were excluded from the experiment because they are similar to the letter X (target probe). Each letter was displayed for 500 ms. Also, the amount of time between the cue and the probe varied (1,000 ms or 5,000 ms). Therefore, the task was administered in 5 blocks of which the order of 1,000 ms and 5,000 ms cue-probe delay was counterbalanced across participants. Each block consisted of thirty trials and the first block was considered as practice trials and excluded from the analysis.

Design

A 4 (Trial type: AX, BX, AY, BY) x 2 (Language: monolingual, bilingual) x 2 (Cue-Probe Delay: 1,000 ms, 5,000 ms) mixed design was used. Language served as a between-subjects variable. Trial type and cue-probe delay served as the within subject variables. The dependent measures consisted of reaction time (RT) and error rate (ER).

Procedure

All participants were tested individually in single sessions in which they were seated in front of a computer screen. Before performing the AX-CPT task, participants completed the language history questionnaire. Only bilinguals with scores 6 or higher on proficiency and 2 or higher on use were included in the study.

Each participant performed the same AX-CPT in two cue-probe delay conditions (1,000 ms and 5,000 ms). Each condition consisted of five blocks and each block consisted of 30 trials. The first block in both conditions was considered a practice block and was administered to confirm that participants understood the instructions correctly. In each condition, sequences of letters were displayed one at a time on the center of a computer screen as a series of cue-probe pairs. The order of the trials was random. Also, the sequences of letters were such that an ("A") cue was followed by an ("X") probe on 70% of the trials. Such trials were referred to as "target" trials. In the AX-CPT, there are three types of non-target trials: BX, AY, and BY. Each type of non-target trial was presented 10% of the time. Instructions were provided verbally to participants and also appeared on the screen prior to the experiment. Right-handed participants were required to make a positive response on target trials by pressing the keyboard key "J" using their index finger and a negative response otherwise by pressing the keyboard key "L" using their middle finger. The left-handed participants were requested to make a positive response on target trials by pressing the keyboard "G" using their index finger and a negative response otherwise by pressing he keyboard key "J" using their middle finger. The goal of the task was to make a target response to an AX sequence by responding to an "X" (the target probe) but only when it follows an "A" (the valid cue) and to make a non-target response in all other cases (AY, BY, BX). Each cue appeared for 500 ms and then, after either 1,000 ms or 5,000 ms (depending on the cue-probe delay condition), the probe appeared for 500 ms. After the probe was presented, the participant was asked to respond as quickly but as accurately as possible. If the participant did not respond within 1,500 ms, a message appeared on the screen indicating that participants should respond faster. Since the experiment was administered in blocks, participants had to press the space bar between blocks. Participants were allowed a short break before pressing the space bar to proceed to the next block. The order of 1,000 ms and 5,000 ms cue-probe delay blocks was counterbalanced across participants. Half of the participants performed the 1,000 ms cue-probe delay condition first and then perform the 5,000 ms cue-probe delay condition second. The other half of participants performed the 5,000 ms cue-probe delay condition first and then performed the 1,000 ms cue-probe delay condition second. After performing the first condition, participants were allowed a short break before performing the second condition. Performing both conditions lasted about 40 minutes. Participants had the right to leave the experiment at any time.

CHAPTER THREE

RESULTS

Performance of monolinguals and bilinguals in each trial type and cue-probe delay was examined using a 4 (Trial type: AX, BX, AY, BY) x 2 (Language: monolingual, bilingual) x 2 (Cue-probe delay: short, long) mixed-design analysis of variance (ANOVA). Language served as a between-participants variable while trial type and cue-probe delay were varied within-participants. Table 1, shown in Appendix B, presents the mean RTs and ERs of monolinguals and bilinguals for each trial type and cue-probe delay condition. RTs were used to assess the speed of correct responses and ERs were used to assess the accuracy of performance. In addition, accuracy of performance was assessed using a signal-detection measure (*d'*) for target (AX) trials. Responses on target trials and non-target trials were analyzed separately because each had a different frequency of occurrence such that target trials occurred 70% of the time and each of the non-target trial types occurred 10% of the time. Also, different keyboard keys were used for target and non-target responses. Trials in which RTs were less than 200 ms or greater than 1,200 ms were eliminated and excluded from any subsequent analyses because they reflected that the participant was not properly attending to the task. An alpha level of 0.05 was used for all statistical tests.

Performance on Target Trials (AX)

The first set of analyses examined the accuracy and speed of performance of monolinguals and bilinguals on target trials (AX). There was a significant main effect of cue-probe delay on RTs, $F(1,59) = 68.127$, $MSE = 2556.716$, $p < 0.05$. Overall, participants performed significantly faster when the cue-probe delay was short ($M = 446$ ms) than when it was long ($M = 521$ ms). The main effect of language on RT was not significant ($F < 1$), however, the interaction between cue-probe delay and language approached significance, $F(1.59) = 3.329$, $MSE = 2556.716$, $p = 0.073$.

The main effect of cue-probe delay on ERs approached significance, $F(1,59) = 3.23$, $MSE = 0.00028$, $p = 0.077$, such that participants made fewer errors on the short cue-probe delay ($M = 1.1\%$) than the long cue-probe delay ($M = 1.7\%$). There was not a significant main effect of language on error rates ($F < 1$), but there was a significant interaction between cue-probe delay and language in the ER data, $F(1,59) = 5.693$, $MSE = 0.00028$, $p < 0.05$. Post-hoc test revealed no difference between monolinguals and bilinguals at the short cue-probe delay condition ($F < 1$). However, monolinguals made more errors than bilinguals on the cue-probe long delay condition $F(1,60) = 2.982$, $MSE = 0.001$, $p = 0.089$. See Figure 3 for means, shown in Appendix A.

The *d'*context measure also was used to assess accuracy on target trials. Previous research on context processing indicates that measuring *d'*context is a more focused indicator of sensitivity to context (e.g., Braver et al., 2001; Barch et al., 2004; Paxton, Barch, Racine, & Braver, 2008; Lorsbach & Reimer, 2010). This is because it reflects the extent to which participants were proficient at using context cues (A or non-A) when trying to distinguish target and non-target probes (X or non-X). It compares the proportion of correct responses in the AX condition (hits) to the proportion of incorrect responses in the BX condition only (false alarms) instead of all types of false alarms (i.e., AY, BX, and BY). Before computing *d'*context scores, a correction factor was applied to the hit and false alarm rates such that 0.5 was added to each frequency and then the result was divided by N + 1, where N represents the number of AX or BX trials (Snodgrass & Corwin, 1988; Lorsbach & Reimer, 2010). In the present study, the *d′*context measure was assessed using a two-way ANOVA with language as a between-participants factor and cue-probe delay as a within-participants factor. The main effect of cue-probe delay on *d′*context score was significant, $F(1,59) = 4.054$, $MSE = 0.277$, $p < 0.05$. A larger *d′*context score was produced for the short cue-probe delay condition ($M = 3.78$) than the long cue-probe delay conditions ($M = 3.59$). This main effect indicates that when presented with the probe (X or non-X), participants were better at recalling whether the cue was valid or invalid when the cue-probe delay was short than when it was long. The main effect of language on *d′*context score was not significant ($F < 1$) indicating that the ability of monolinguals and bilinguals to discriminate whether the cue was valid or invalid was comparable. The interaction between cue-probe delay and language on *d′*context score was not significant ($F < 1$).

Performance on Control Trials (BY)

The second set of analyses examined performance in the control trials (BY). The cue-probe delay (short, long) was used as a within-participants factor and language (monolingual, bilingual) was used as a between-participants factor. There was a significant main effect of cue-probe delay on RTs, $F(1,59) = 32.236$, $MSE = 4523.823$, $p < 0.05$. Overall, participants performed significantly faster when the cue-probe delay was short (M = 410 ms) than when it was long (M = 481 ms). For RTs, neither the main effect of language nor the interaction between cue-probe delay and language were significant (both Fs < 1). In the ER data, neither the main effect of cue-probe delay nor the main effect of language was significant (both Fs < 1). Also, the interaction between cue-probe delay and language on ERs was not significant ($F < 1$). Since there was no main effect of language and it did not interact with the other variables in either the RT nor ER data, data for the BY trials was not included in subsequent analyses of non-target trials.

Performance on Non-target Trials (BX, AY)

The third set of analyses examined performance on the non-target trials (AY and BX). The cue-probe delay and trial type were used as the within-participants factors and language was used as the between-participants factor. The main effect of cue-probe delay on RTs was significant,

$F(1,59) = 44.407$, $MSE = 7099.955$, $p < 0.05$. Responses in the short cue-probe delay condition were faster ($M = 493$ ms) than responses in the long cue-probe delay condition ($M = 565$ ms). The main effect of trial type on RTs was also significant, $F(1,59) = 303.552$, $MSE = 5535.648$, $p < 0.05$. Responses on the BX ($M = 445$ ms) trials were faster than responses on the AY ($M = 612$ ms) trials. The main effect of language was not significant ($F < 1$). The Cue-probe delay x Language, $F(1,59) = 8.376$, $MSE = 7099.955$, $p < 0.05$, and the Cue-probe delay x Trial type , $F(1,59) = 7.297$, $MSE = 2138.953$, $p < 0.05$, interactions were significant. However, these interactions were qualified by the presence of a significant three way interaction between cue-probe delay, trial type, and language, $F(1,59) = 4.003$, $MSE = 2138.953$, $p = 0.05$. Simple main effect tests were used to further examine the three way interaction by examining the interaction between language and cue-probe delay separately for AY and BX trials. For AY trials, the interaction between language and cue-probe delay only approached statistical significance, $F(1,59) = 3.391$, $MSE = 3376.458$, $p = 0.071$. See Figure 4 for means, shown in Appendix A. However, for BX trials, the interaction between language and cue-probe delay was statistically significant, $F(1,59)$

= 9.651, $MSE = 5862.450$, $p < 0.05$. See Figure 5 for means, shown in Appendix A. Post hoc tests revealed that for trials with a short cue-probe delay, there was no difference in RTs between monolinguals ($M = 404$ ms) and bilinguals ($M = 431$ ms). In contrast, for trials with a long cue-probe delay, bilinguals ($M = 444$ ms) responded faster than monolinguals ($M = 503$ ms), however, this effect was only marginally significant ($p = 0.087$). No significant effects were found in the ER data for the non-target trial trials.

CHAPTER FOUR

DISCUSSION

Previous research has demonstrated a bilingual advantage in a variety of cognitive processes that are related to cognitive control (e.g., Ben-Zeev, 1977; Cummins & Swain, 1986; Colzato et al., 2008; Rodrigues-Fornells et al., 2006; Hernandez, 2009). Braver et al.'s theory of context processing considers attention, inhibition, and working memory to be sub-served by a single mechanism, called context processing (Braver et al., 2001; Braver & Barch, 2002). The context processing mechanism represents and maintains goal information in working memory which leads to the inhibition of irrelevant information and directs attention to target information. In this theory, the cognitive functions of attention and inhibition are not independent processes, but are dependent on the representation and maintenance of goal information in working memory (Braver et al., 2001; Braver & Barch, 2002; Lorsbach & Reimer, 2010).

Performance on Target and Non-target Trials

The primary purpose of the present study was to test the hypothesis that the bilingual advantage in cognitive control is due to improved goal representation and/or maintenance. In order to test this hypothesis, the performance of monolingual and bilingual participants was compared on the AX-CPT. If the bilingual advantage in cognitive control is due to enhanced goal representation and/or maintenance, bilinguals were expected to perform better than monolinguals on target (AX) trials. On the non-target trials (AY, BX), bilinguals were expected to perform worse than monolinguals on AY trials and better than monolinguals on BX trials. This is because enhanced context processing of bilinguals should lead to an enhanced ability to represent and/or maintain the invalid cue ("B"), and use it to make a correct "non-target" response upon seeing the valid probe ("X"). In contrast, bilinguals' enhanced ability to represent and/or maintain the cue on AY trials should lead to poorer performance because they should have an increased expectation that the probe will be valid ("X") when they see a valid cue ("A"). Thus, for "BX" trials, bilinguals should produce faster RTs and/or fewer ERs than monolinguals, while for "AY" trials bilinguals should produce slower RTs and/or more ERs than monolinguals.

Additionally, in order to determine whether the bilingual advantage in cognitive control is due to an enhanced ability to represent or maintain goal information, the performance of bilinguals and monolinguals on the AX-CPT was compared at two cue-probe delays: a short (1,000 ms) and a long (5,000 ms) delay. If the bilingual advantage in cognitive control is due to an enhanced ability to represent goal information, differences between monolingual and bilingual participants should emerge at the short, but not the long, cue-probe delay for both target and non-target trials. On the other hand, if the bilingual advantage is due to an enhanced ability to maintain goal information, language differences should be found at the long, but not short, cue-probe delay for both target and non-target trials.

The findings partially supported these predictions. For target (AX) trials, monolinguals and bilinguals performed faster at the short than the long cue-probe delay in the RT and d' data. There was also a significant interaction between cue-probe delay and language in the ER data such that monolinguals made more errors than bilinguals on the long, but not the short, cue-probe delay trials. Thus, although the ER and *d′* data indicate that it was more difficult to recall whether the cue was valid or invalid at the long than the short cue-probe delay condition for both language groups, monolinguals' performance was affected more than bilinguals' performance at the long delay. In order to perform correctly on AX trials, one has to represent the cue on the short cue-probe delay condition, and also maintain it on the long cue-probe delay condition. The finding that monolinguals and bilinguals performed similarly on the short delay condition, suggests that the language groups are comparable in terms their ability to represent the cues. However, the difference in performance between the two language groups at the long cue-probe delay condition suggests that bilinguals are better than monolinguals at maintaining goal information across a relatively long delay. This pattern of results is consistent with Colzato et al.'s (2008) notion that the bilingual advantage in cognitive control is related to the ability to maintain relevant information in working memory. Based on the fact that the language groups did not differ at the short delay, it does not appear, at least based on data from target trials, that monolinguals and bilinguals differ in representational ability.

For non-target trials, both language groups responded faster on BX than AY trials. Finding this main effect of non-target trial type in the present study is important because it is consistent with multiple studies that have examined context processing using the AX-CPT (e.g., Braver et al., 2001, Braver & Barch, 2002, Lorsbach & Reimer, 2010). According to Braver et al.'s theory, young adults perform better on BX trials than AY because they have good context processing due to an intact prefrontal cortex (Braver et al., 2001, Braver & Barch, 2002). More importantly, the three-way interaction between language, trial type, and cue-probe delay was significant. This three-way interaction was further investigated by examining the interaction between language and cue-probe delay separately for AY and BX trials. The interaction for AY trials showed that there are no differences between monolinguals and bilinguals on short and long delay conditions. However, the interaction between language and cue-probe delay was significant for BX trials indicating better performance of bilinguals at the long delay condition. Better performance on BX trials can be considered evidence that bilinguals were able to maintain the invalid cue ("B") across the long cue-probe delay better than monolinguals. Thus, according to the context processing framework, bilinguals were in better position to use the context representation of the invalid cue ("B") to inhibit the response bias that is created by the high frequency of AX trials. Performance on AY trials is related to attentional processing. Since ("A") is followed by an ("X") 70% of the time, instances where ("A") is not followed by an ("X") also receive positive responses. Attention to the valid cue ("A") makes it hard not to make a positive response to a non-target probe ("Y"). If the attention of bilinguals is better than monolinguals, it should be measured by poorer performance on AY trials by bilinguals. However, no differences were found between the two groups in terms of RT's and ER's in this condition.

The pattern of results that were found with non-target trials are difficult to account for using Braver et al.'s context processing framework (Braver et al., 2001; Braver & Barch, 2002). According to this framework, inhibition and attention are not independent cognitive functions, but are sub-served by a unitary context processing mechanism. Performance on both AY and BX trials are dependent upon goal representation and maintenance. If BX performance was due to improved goal representation and maintenance, then differences should have been found in AY as well. That is, in Braver et al.' framework, superior performance of bilinguals on BX trials must be accompanied by a poorer performance on AY trials. However, this was not the case in the present study.

Challenges to the Unitary Notion of Cognitive Control

The idea that cognitive control, defined in this paper as context processing, is a unitary process has been challenged by multiple researchers who study cognitive development. According to this view, cognitive control is composed of a set of multiple constructs that are independent and develop at different rates as children grow older. For instance, Hughes (1998) believes that attention, inhibition, and working memory are three separate cognitive processes that work independently. Other researchers such as Miyake et al. (2000) consider inhibition, working memory, and cognitive flexibility to be the major components of cognitive control. According to Miyake et al. (2000), these cognitive processes are dissimilar, but interconnected. In addition, Best and Miller (2010) argue that both the neural development of inhibition and the neural development of working memory involve changes in the prefrontal cortex. However, the rate at which these two cognitive abilities develop is divergent. Specifically, inhibition develops at a faster rate during the preschool years, and then it develops linearly through adolescence. On the other hand, working memory develops gradually from preschool through adolescence. Consistent with Best and Miller (2010), Shing et al. (2010) examined how memory maintenance and inhibitory control are organized throughout development. They administered multiple cognitive tasks specific to how children maintained the rules in mind and also how they inhibit prepotent response. The findings of their study suggest that memory maintenance and inhibitory control are not functionally different in children younger than nine. However, after the age of nine, memory maintenance and inhibitory control become differentiated and two distinct cognitive functions. Furthermore, Bartgis, Thomas, Lefler, and Hartung (2008) studied the cognitive development of attention and inhibition. They found no age differences in inhibition between younger and older children, suggesting that inhibition does not change throughout childhood. However, attention is more developed in older children, as opposed to younger children. This suggests that attention, inhibition, and working memory do not develop at the same rate, and therefore, should be considered as independent, as opposed to unitary, processes.

If one assumes that attention and inhibition are independent processes, the pattern results found with AY and BX trials in the present experiment are more straightforward. Specifically, the results on the BX trials are compatible with a recent study that examined how bilingualism improves cognitive control (Colzato et al., 2008). Colzato et al. (2008) suggest that the bilingual advantage in cognitive control is not due to active inhibition. Active inhibition was first introduced by Green (1998) who claimed that bilinguals decide not to process the irrelevant information by actively suppressing it. Instead, Colzato et al. (2008) suggest that bilinguals suppress the irrelevant information indirectly by maintaining the relevant information. Therefore, goal maintenance facilitates the mechanism of inhibition such that bilinguals cognitively invest more on maintaining the relevant information active in working memory, which indirectly facilitate the process of inhibiting any irrelevant information. According to Colzato et al. (2008), because bilinguals are trained to regularly separate their two languages, they acquire an improved maintenance of goal relevant information, thus, improved inhibition on language- based tasks, as well as non-linguistic tasks. The results found on BX trials are consistent with Colzato et al.'s explanation. Because only representation is required at the short delay condition, no differences were found between language groups in the present study. In contrast, because the long delay placed increased demands on cue maintenance bilinguals performed better than monolinguals on long delay trials.

If one assumes that attention and inhibition are independent processes, the pattern results found with AY trials suggests that bilinguals' advantage in cognitive control is not due to enhanced attentional skills. Unfortunately, this finding is not consistent with existing research on bilingualism. Most research on bilingualism and attention indicates that bilinguals have better attention than monolinguals. For instance, Ben-Zeev (1977) suggested that the development of attentional strategies is easier for bilingual children than monolinguals. Bialystok (2010) also indicated that bilinguals possess better attentional control than monolinguals. In addition, a very recent study by Stafford (2011) examined attention in bilingual adults. Their results suggested that bilingualism improves the switching of attention, as well as inhibition in verbal and nonverbal tasks. The fact that previous studies found differences in attention with monolinguals and bilinguals, however, might be due to the way in which attention has been defined and measured. For instance, Bialystok and Martin (2004) defined control of attention as a process of directing focus to some features of the stimulus and inhibiting attention to these features if focus on other features is needed. Also, Bialystok and Martin (2004) used the terms attention and inhibition synonymously. In addition, they used the dimensional change card sort (DCCS) task to measure attentional control. In the DCCS task participants are required to sort cards based on a specific feature for a number of trials, and then sort them based on a different feature. For instance, if cards are sorted based on color the first time, they need to be sorted based on shape the second time. Performance on this task requires participants to inhibit either the color or the shape dimension, depending on the current goal. This task, therefore, measures inhibition, not attention. Future research on bilingualism and attention needs more clearly defined ways to operationalize attention, and use experimental tasks that disentangle attention and inhibition.

In conclusion, with regard to whether the bilingual advantage in cognitive control is due to enhanced goal representation and maintenance, the findings of the present study were mixed. First, it was found that the bilingual advantage in cognitive control is due to improved inhibition resulting from enhanced goal maintenance. Second, it was found that bilinguals and monolinguals are not different in terms of attention. Finally, with the fact that language differences were found with BX trials, but were not found with AY trials, suggests that attention and inhibition might not compose a single mechanism, but are two distinct cognitive processes.

Limitations of the Study

There are multiple limitations of this study. These limitations are sample size, self-reported data, and length of study. The sample size might have been too small for this study. Results for the AY condition might have been different if the number of participants was larger. It may have been possible to find differences between monolinguals and bilinguals with larger number of participants. The second limitation is self-reported data. Participants were assigned either to the monolingual or bilingual group based on self-report language history questionnaire. Responses on the language questionnaire primarily reflect the perception of the participant being a bilingual. Although daily use of both languages was considered as a main criterion in determining whether the participant is actually proficient in both languages, some of the participants might have categorized themselves as balanced bilinguals when in fact they were not. Exposure to two languages does not make the individual bilingual. The experience of bilingualism is beneficial only when the person reaches a high proficiency level in both languages, resulting in positive consequences such as divergent thinking and enhanced cognitive development (Cummins & Swain, 1986). Thus, the findings may have been affected by failure to form two separate language groups. It is important to note, however, that most research on bilingualism assesses bilingualism using a language questionnaire similar to the one used in the present study. The third limitation of the study is the length of the experiment. Each participant had to take the same experiment at the short and long cue-probe delay conditions. Completing both conditions requires forty minutes. This might have been too long and exhausting for some participants leading to responding without properly attending to the task, especially in the last twenty minutes. For instance, research has shown that students do not pay attention more than twenty minutes (Bunce, Flens, & Neiles, 2010).

APPENDIX A

FIGURES

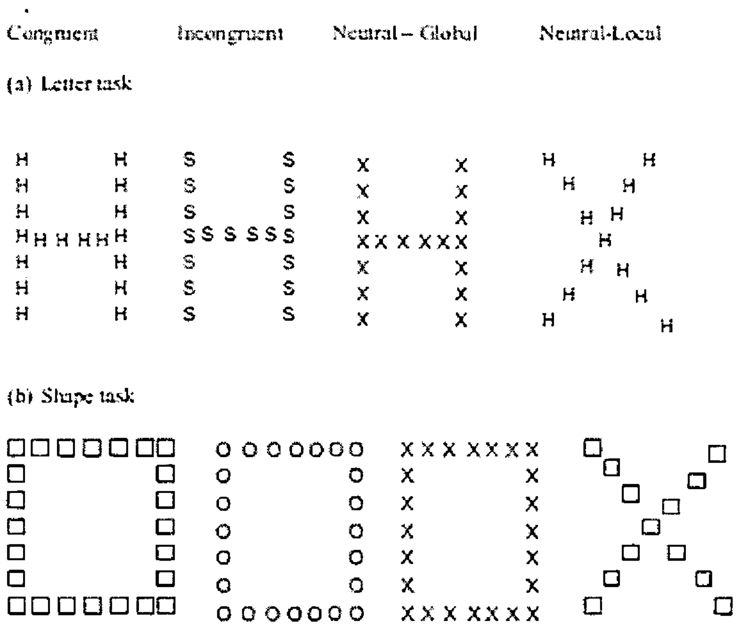

Figure1. Sample of stimuli used in the global-local paradigm as used by Bialystok (2010). *Note.* From "Global-Local and Trail-Making Tasks by Monolingual and Bilingual Children: Beyond Inhibition" by Bialystok, E. (2010), Developmental Psychology, 46, 93-105. Copyright 2010 by the American Psychological Association

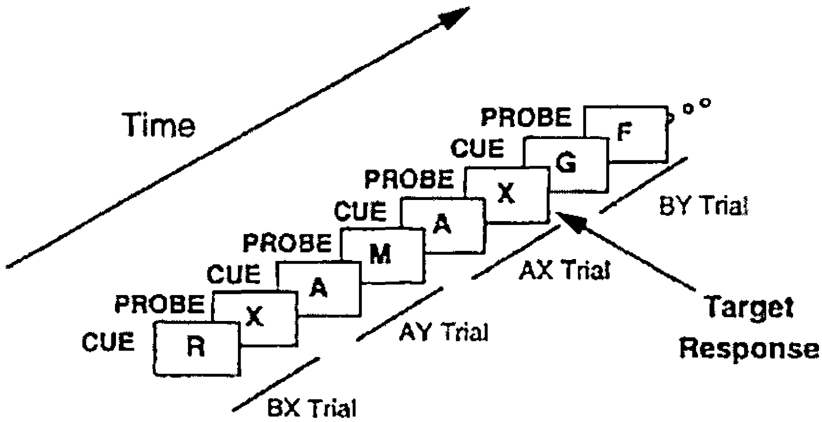

Figure 2. Schematic of AX-CPT as displayed by Braver et al (2001). *Note.* From "Context Processing in Older Adults: Evidence for a Theory Relating Cognitive Control to Neurobiology in Healthy Aging" by Braver, T. S., Barch, D. M., Keys, B. A., Carter, C. S., Cohen, J. D., Kaye, J. A., et al. (2001), Journal of Experimental Psychology, 130, 746-763. Copyright 2001 by the American Psychological Association

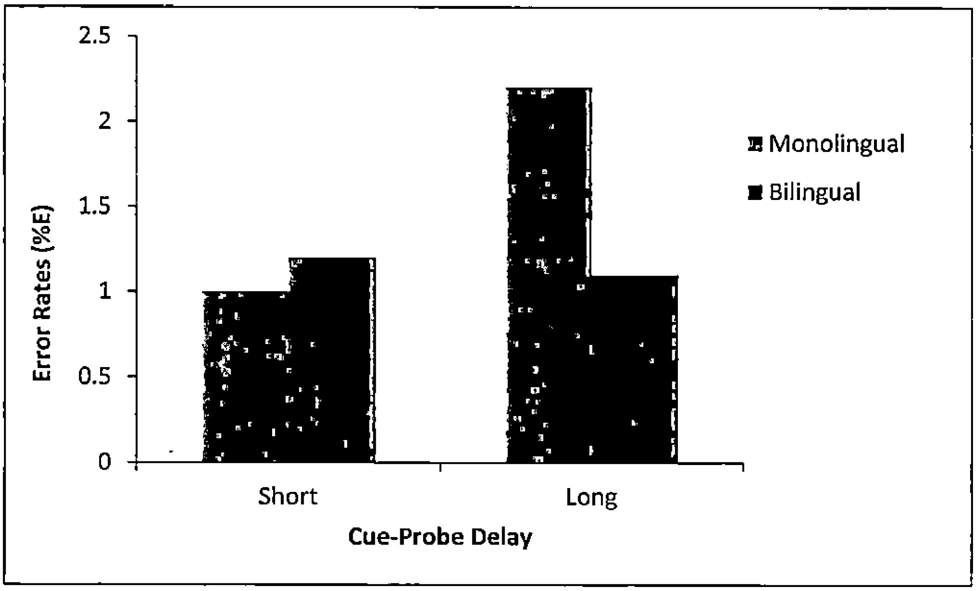

Figure 3. ERs as function of language and cue-probe delay (AX)

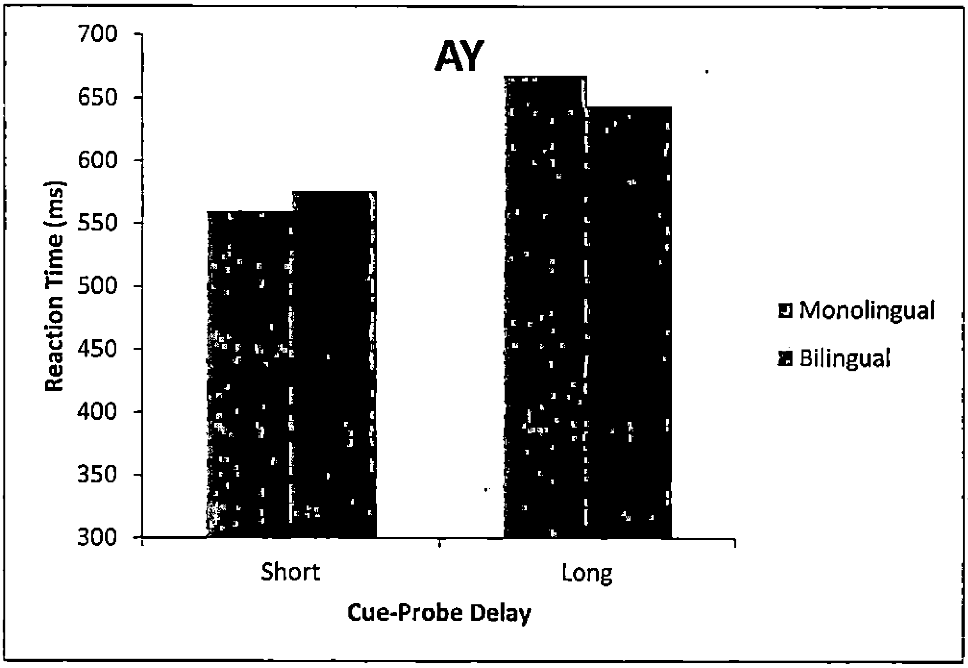

Figure 4. RTs as function of language and cue-probe delay (AY)

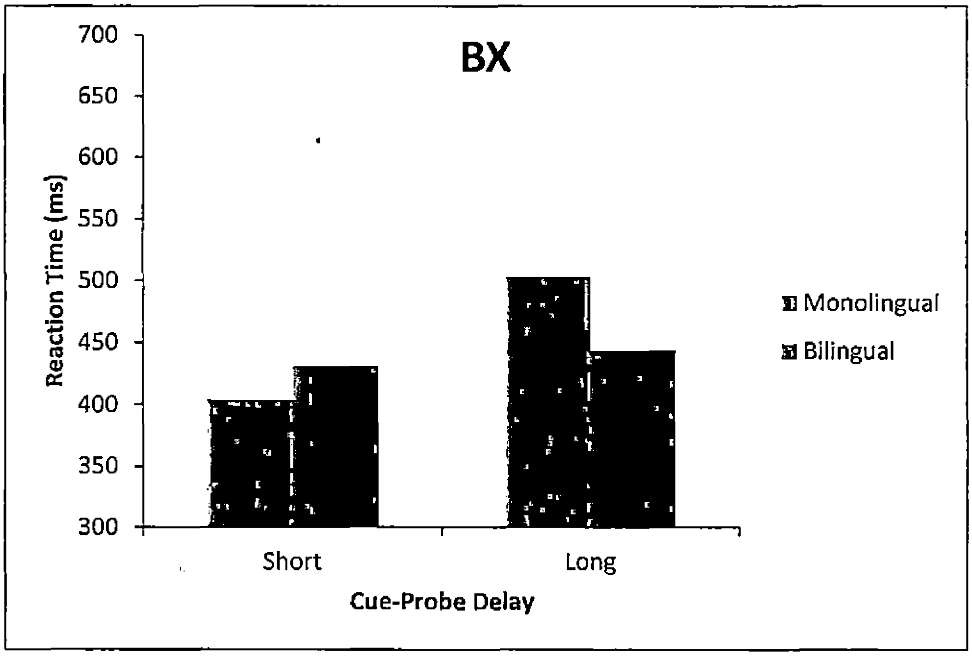

Figure 5. RTs as function of language and delay (BX)

APPENDIX B

TABLE

Table 1

Mean Reaction Times (RT; in ms) and Error Rates (%E)

Trial Type	Language Group			
	Monolinguals		Bilinguals	
	RT	%E	RT	%E
Short Cue-Probe Delay				
AX	435 (68.5)	1.00 (0.015)	457 (89.1)	1.29 (0.017)
AY	560 (62.8)	10.82 (0.118)	576 (85.6)	9.89 (0.197)
BX	404 (97.9)	3.91 (0.087)	431 (112.9)	10.18 (0.262)
BY	396 (88.7)	2.24 (0.077)	427 (119.9)	0.32 (0.017)
Long Cue-Probe Delay				
AX	527 (101.3)	0.27 (0.033)	516 (91.5)	1.11 (0.015)
AY	668 (105.6)	10.97 (0.142)	644 (93.9)	7.32 (0.108)
BX	503 (151.9)	4.00 (0.075)	444 (101.9)	5.07 (0.190)
BY	483 (132.8)	1.03 (0.035)	478 (117.1)	0.32 (0.017)

Note. Standard deviations are in parentheses.

APPENDIX C

LANGUAGE HISTORY QUESTIONNAIRE

LANGUAGE HISTORY QUESTIONNAIRE

Name ______________________ Today's Date ______________
Birth Date ______________________ Gender __________

1. Do you have any known visual or hearing problem?

2. List the languages that were spoken in your home before you reached the age of 10.

3. What is your native language? i.e. language first spoken (if more than one, please indicate):

4. Please list all the languages you know, from the most to the least proficient, and indicate the age which you were first exposed to each.

5. What languages do you use on a daily basis? If more than one, on a daily basis, which one do you use more?

6. How proficient are you currently in each of your languages? Please rate them using the following scale:

1= almost none 2= very poor 3= fair 4= functional
5= good 6=very good 7= like a native speaker

	Language	Speech	Reading	Writing	Comprehension
1	________	________	________	________	________
2	________	________	________	________	________
3	________	________	________	________	________

7. How many years have you formally studied (in a classroom or other structured situation) each of your languages except your first?

Language	Years of Study
1.	
2.	
3.	

8. Estimate how often you use your two best languages, using the following scale:

1= never 2= sometimes 3=always

	Language ________	Language ________
a. Employers/teachers	________	________
b. Mother/father	________	________
c. Brothers/Sisters	________	________
d. Friends	________	________
e. Yourself	________	________
f. Classmates/peers	________	________
g. Pets	________	________

9. In which language do you usually:

a- add, multiple, etc? ________

b. dream? ________

c. express affection? ________

d. swear? ________

Note. Language history questionnaire was developed at the cognitive lab at California State University San Bernardino by Dr. Jason Reimer.

APPENDIX D

INFORMED CONSENT FORM

Informed Consent
Context Processing Study

You are invited to participate in a study designed to investigate cognitive processing. This study is being conducted by Dr. Jason Reimer, professor of Psychology. The University asks that we obtain your consent before your participation in this study. This form should bear the official Psychology Department IRB Sub-Committee stamp of approval. The stamp verifies that this study is approved by the Institutional Review Board Sub-Committee of the Psychology Department of California State University, San Bernardino.

In this study, you will be presented with a series of letters on a computer screen. You are asked to respond to specific sequences of letters with either target or non-target response. The task should take no longer than 40-50 minutes of your time. Since no identifying information is collected on the survey, all your responses will be completely anonymous. Data will be reported in group form only. All data will be reported in group form only. Results from this study will be available from Dr. Jason Reimer (909) 537-7578 after July 1, 2011.

Your participation in this study is voluntary. You are free not to answer any question and to withdraw at any time during this study without penalty. This study involves no risks beyond those routinely encountered in daily life, nor any direct benefits to you as a participant other than extra credit for one of your psychology courses. When you have completed the task, you will receive a debriefing statement describing the study in more detail. In addition, you will receive 4 units of extra credit, to be used at your instructor's discretion in a Psychology class of your choice. In order to ensure the validity of the study, we ask that you not discuss this study with other participants.

If you have any questions or concerns about this study, please feel free to contact Dr. Jason Reimer at (909) 537-7578.

By placing an X in the space below, I acknowledge that I have been informed of, and that I understand, the nature and purpose of this study, and I freely consent to participate. I also acknowledge that I am at least 18 years of age.

Participant's X _______

Date: __________

CALIFORNIA STATE UNIVERSITY, SAN BERNARDINO
PSYCHOLOGY INSTITUTIONAL REVIEW BOARD SUB-COMMITTEE
APPROVED 02 / 10 / 11 VOID AFTER 02 / 10 / 12
IRB# H-08WI-03 CHAIR

APPENDIX E

INSTITUTIONAL REVIEW BOARD

APPROVAL LETTER

Human Subjects Review Board
Department of Psychology
California State University,
San Bernardino

PI:	Reimer, Jason, and Saadaoui, Amina
From:	Donna Garcia
Project Title:	Effects of Bilingualism on Goal Representation
Project ID:	H-08WI-03
Date:	Thursday, February 10, 2011

Disposition: Renewal Review

Your IRB proposal is approved. This approval is valid until 2/10/2012.

Good luck with your research!

Donna M. Garcia, Chair
Psychology IRB Sub-Committee

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