The Effects of Bilingualism on Attention and Memory: Do Bilingual Advantages in Attention Lead to Disadvantages in Memory?

by

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Abstract

Recent evidence suggests that the task of managing a bilingual individual’s two languages is carried out by general attentional mechanisms. Researchers have found evidence for bilingual advantages in attention, specifically on tasks that involve inhibiting irrelevant information, which are believed to stem from lifelong practice at inhibiting the language system not currently in use. In the present study we hypothesized that, since bilinguals are better at inhibiting irrelevant information, they should show memory disadvantages if previously irrelevant information becomes relevant. 12 bilingual and 12 monolingual participants (age range: 19-27) were tested in an eye tracking paradigm where the relational manipulation effect (the tendency to direct more viewing to manipulated regions of previously viewed scenes) was used to access memory for scenes that had been presented as distractors during a study block. No differences in memory were observed. However, we observed a significant difference in general viewing patterns between the two language groups, such that bilinguals made significantly shorter fixations.
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# Table of Contents

Acknowledgments ................................................................................................................................. iii

Table of Contents ................................................................................................................................. iv

List of Tables ........................................................................................................................................ v

List of Figures ........................................................................................................................................ vi

List of Appendices ............................................................................................................................... vii

1 Introduction ........................................................................................................................................ 1

1.1 The Internal Lexicon ...................................................................................................................... 3

1.1.1 The Internal Lexicon of Bilinguals .......................................................................................... 6

1.2 Eye Tracking Paradigms and the Study of Attention ....................................................................... 9

1.3 Bilingualism, Attention and Memory ............................................................................................. 12

1.3.1 Bilingualism and Attention ....................................................................................................... 12

1.3.2 Recent Findings on Bilingualism and memory ......................................................................... 17

1.3.3 Memory for Irrelevant Information .......................................................................................... 18

1.4 The Present Study .......................................................................................................................... 20

2 Methods ............................................................................................................................................ 21

3 Results ................................................................................................................................................ 27

4 Discussion .......................................................................................................................................... 36

4.1 Attention: Following the maze ....................................................................................................... 36

4.2 Language and Memory: Does bilingualism affect memory for scenes? ..................................... 36

4.3 General viewing patterns ............................................................................................................... 39

4.4 General conclusion and future directions ...................................................................................... 40

References ............................................................................................................................................. 42

Appendix 1 ............................................................................................................................................. 46
List of Tables

Table 1 ............................................................................................................................................. 21
Table 2 ............................................................................................................................................. 28
Table 3 ............................................................................................................................................. 30
Table 4 ............................................................................................................................................. 32
List of Figures

Figure 1 ................................................................................................................................. 4
Figure 2 ................................................................................................................................. 5
Figure 3 ................................................................................................................................. 7
Figure 4 ................................................................................................................................. 10
Figure 5 ................................................................................................................................. 12
Figure 6 ................................................................................................................................. 24
Figure 7 ................................................................................................................................. 26
Figure 8 ................................................................................................................................. 29
Figure 9 ................................................................................................................................. 31
Figure 10 .............................................................................................................................. 33
Figure 10 .............................................................................................................................. 34
Figure 11 .............................................................................................................................. 35
List of Appendices

Appendix 1 ........................................................................................................................................ 46
1 Introduction

Bilingual individuals face unique challenges as compared to their monolingual counterparts. Apart from the challenges involved in being immersed in two cultures, these individuals must juggle two language systems and accomplish efficient monitoring and switching between languages without compromising fluency. Current evidence suggests that general attentional processes, as opposed to language-specific mechanisms, mediate smooth communication and efficient switching between languages in a bilingual system (Green, 1998). Furthermore, there is robust evidence that the unique demands involved in managing two languages produce certain processing differences between bilinguals and monolinguals that reach beyond language and extend into other domains (e.g. Bialystok, Craik, & Luk, 2008; Bialystok, Craik, & Ryan, 2006). Various bilingual advantages and disadvantages have been observed in diverse aspects of general cognitive processing.

The cause of these processing differences is believed to stem from the fact that a bilingual individual’s languages, call them L1 and L2, are active simultaneously. In other words, a picture of a duck would simultaneously activate the word for ‘duck’ in L1 and in L2 (Golan & Kroll, 2001). It is evident that, when one converses in L1, the language representations from L2 are irrelevant and, if not blocked, would decrease the efficiency and fluency of communication. Therefore, it has been a dominant theory that the executive control component of attention is heavily involved in inhibiting the irrelevant language representations (Abutalebi & Green, 2008). This observation is believed to be the link to the processing differences that were found in non-linguistic domains, and led to a proliferation of research into the relationship between bilingualism and various aspects of attention. It has been hypothesized that, since bilinguals must constantly inhibit irrelevant language representations, they must, in a lifetime of practice, develop general advantages on tasks that require focusing attention in the face of distracting stimuli (Green, 1998). Such effects have been observed in many studies and across various age groups. In fact, bilingualism has been found in several studies to modulate age-related decline in general attentional processing (e.g. Bialystok et al, 2004; Bialystok et al, 2006) However, the literature is still unresolved as to the precise attentional mechanisms that bring about this bilingual advantage. In particular, while some researchers believe that bilinguals exhibit superior
inhibition of task-irrelevant stimuli (active inhibition; Bialystok et al, 2006), other studies provide evidence that the bilingual advantage might stem not from direct inhibition of certain stimuli, but from a superior ability to maintain action goals and to bias the attentional system towards goal-relevant information (reactive inhibition; Colzato et al, 2008).

While much research has been directed at the interaction between lifelong bilingualism and attentional processes, few studies have looked at the implications of these findings for memory. Considering that the purpose of attention is to select stimuli for further processing and retention, the absence of studies in this area is an unfortunate gap in our understanding of bilingualism. Furthermore, by studying how information is retained in memory it might be possible to come closer to resolving some of the debates regarding the precise attentional components that are enhanced in bilingual individuals.

The current study will use an eye-tracking paradigm similar to the one used in Ryan, Althoff, Whitlow and Cohen (2000) to compare memory for task-irrelevant information in young bilingual and monolingual participants. Participants will be instructed to follow a maze with their eyes as accurately as possible. The maze will be overlaid on top of a photograph depicting fairly common rooms or outdoor scenes, and containing certain objects appropriate to the setting. In subsequent test trials we will switch the location of certain objects in the photographs and study the participants’ eye movements to determine whether they noticed the change, indicating that they formed a memory representation of the task-irrelevant background picture. Note that unlike other similar studies (ex. Ryan, Leung, Turk-Browne, & Hasher, 2007), which gave explicit instructions for participants to ignore certain late-onset stimuli and found evidence for memory for the ignored stimuli in younger, the participants in the current study are never instructed to ignore any aspect of the scene – their task is simply to try and follow the maze as closely as they can. Clearly, the background is a distracting element, but, akin to real-world situations, the task is not to ignore the distracting element, but rather to accomplish some goal in a sub-optimal environment. If the bilingual advantage stems from superior inhibition of irrelevant stimuli, bilinguals should show poorer memory for the background image than age-matched monolinguals. However, if the bilingual advantage stems from superior goal maintenance, bilinguals will not necessarily show poorer memory for the background. This assumption is based on the finding that robust memory representations can be formed even without directly
fixating the object to be remembered. For instance, one study found that younger adults are quite capable of forming implicit memory representations of objects that they had demonstrably ignored (as per the experimenter’s instructions) during the study blocks (Ryan et al, 2007).

In the review that follows I will first describe current findings about the arrangement of the bilingual lexicon, and the implications of these findings for attention and memory. Next, I will briefly describe eye-tracking paradigms as they apply to the study of attention, and certain findings that will be relevant to the present experiment. I will then focus on current findings and controversies in the study of language effects on attentional processes. Finally, I will outline the premises of the current study and its potential theoretical contributions.

1.1 The Internal Lexicon

Before there can be meaningful discussion about the lexical structure in bilingualism, it is important to review current theories regarding lexical access, and the structure of the internal lexicon in general.

The current view is that the lexicon is set up as a semantic network. That is, the lexicon is a network of nodes corresponding to different words, or even separate aspects of words (ex. syntactic category, sound), connected to one another by virtue of being related to one another in specific ways (Carrol, 2008). The earlier models assumed that words are organized in a hierarchical structure such that ‘cat’ is a subcategory of ‘mammal’, which is itself a subcategory of ‘animal’. Proponents of this model assumed that words that are separated by more nodes have a weaker association than words that have fewer nodes between them (Collins & Quillian, 1969). For example, assuming a simplified model for clarity, they predicted that ‘cat’ and mammal’, which are connected directly, are more closely associated then ‘cat’ and ‘animal’, which have one node between them (refer to Fig. 1).
Figure 1. The lexicon as a hierarchical network

Although this model is intuitively appealing, some of its predictions fail. Smith, Shoben and Rips (1974) tested the predictions of this model using the Semantic Verification task. They predicted that, since ‘cat’ is closer to ‘mammal’ than to ‘animal’, it should be easier to verify the sentence: ‘a cat is a mammal’, rather than the sentence: ‘a cat is an animal’. However, it took participants more time to respond to the first statement, which clearly cannot be explained by a purely hierarchical model. The researchers hypothesized that this result is due to the fact that ‘animal’ is a more basic and familiar category, and people are more accustomed to working with it. Furthermore, the researchers found that people need less time to verify that a cat is a mammal as compared to verifying that a whale is a mammal. The hierarchical model again fails to explain this finding, since ‘cat’ and ‘whale’ should be an equal distance away from the node corresponding to ‘mammal’ (refer to Fig. 1). Another criticism of the hierarchical model is that it fails to account for the fact that words have attributes other than meaning, such as grammatical categories, and sound.

The most widely accepted model of lexical organization is the Spreading Activation model proposed by Bock and Levelt in 1994 (refer to Fig. 2).
As shown in Fig. 2, this model consists of three levels. The conceptual level is the level at which various concepts are organized into a network. This network however, is not a hierarchy. Instead, concepts at various nodes are connected based on some algorithm that takes into account various types of information, such as the taxonomic relationship between the two concepts, the likelihood of encountering the two concepts together, the idiosyncratic experiences the individual has had with respect to these concepts, and so on. The strength of the relationship between two nodes can vary, and is represented in figure 2 by the varying distances between the nodes. Once a certain node is activated, activation spreads to adjacent nodes, such that the smaller the distance between two nodes, the more activation spreads between them. Referring to Figure 2, if ‘whale’ becomes activated, the activation will spread to ‘mammal’, and also, to a smaller extent, to ‘mouse’. An important feature of this model is that it accounts for the grammatical and phonetic aspects of lexical organization. Thus, when one hears the first ‘g’ in the word ‘goat’, activation spreads to multiple words beginning with this sound. As the speaker produces the rest of the word, sound representation /gout/ receives even more activation, while the other “g words” do not. Eventually, activation spread from the sound representation ‘/gout/’ to the concept ‘goat’, and the listener perceives the message communicated by the speaker. Looking at this from the
opposite direction, if one is the speaker, and one wants to express a certain idea involving a goat, the concept ‘goat’ spreads activation until the sound representation of this concept is retrieved.

1.1.1 The Internal Lexicon of Bilinguals

When an individual is fluent in two languages and uses both regularly, an interesting question arises: To what extent does activation spread across languages? To use the previous example, if one is bilingual in English and another language, L2, when he hears the first ‘g’ of the word ‘goat’, does activation spread to words in L2 that begin with that sound? Conversely, when one wants to communicate the word ‘goat’, to what extent do related L2 representations get activated?

In terms of language production, some theorists have assumed that no interference exists between L1 and L2. For instance, La Heij (2005) has proposed that language identity (i.e. whether it is in L1 or L2) is just a regular word feature, just as the feature “slang” belongs to the word ‘pal’, while the feature “proper English” belongs to the word ‘friend’. He points out that no interference exists between ‘friend’ and ‘pal’, because, in a sense, these two words do not refer to the same concept – they correspond to two different concept nodes with different features. By the same token La Heij argues that two words that are translations of each other in L1 and L2 do not interfere because they are activated by different concept nodes. While this model is appealing, its weakness lies in the fact that it approaches the problem from a purely top-down, unidirectional point of view. La Heij assumes that during language production activation simply spreads down from the conceptual level to the sound level without feedback. A closer look at the patterns of spreading activation paints a different picture. One study used the lexical bias effect to demonstrate that activation spread to the language representations of the language that is not being used. The lexical bias effect is the tendency for phonological speech errors to produce real words, rather than nonsense words. For example, after reading a long list of word that all begin with the letter ‘B’ (beak, bit, bill, bob) if one were asked to pronounce the word ‘pin’, one would be likely to say ‘bin’, but not quite so likely to misread ‘clay’ as ‘blay’. In terms of the spreading activation model, this effect is explained by the premise that the repeated exposure to words starting with ‘b’ spreads activation to other “b words”. However, since ‘blay’ is not a real word, it does not have a corresponding node in the model, and activation cannot spread to it. Costa et al. (2006) designed an experiment to test whether activation can spread from words in L1 to
words in L2. Their participants were Spanish-Catalan bilinguals. Their goal was to test whether, when testing was conducted in Spanish, participants would show the lexical bias effect if the resulting word was a real word in Catalan, but not in Spanish. Costa et al indeed found activation across languages, providing strong evidence that words from L1 and L2 are activated simultaneously. A simplified schematic of the bilingual lexicon is presented in Fig. 3, with pink circles representing L2.

Figure 3. The bilingual lexicon

Further evidence in favour of the simultaneous activation hypothesis is provided by the fact that bilinguals perform more poorly than monolinguals on the semantic fluency task, which gives participants a specified amount of time to produce as many words as possible that belong to a particular category (ex. barn animals). Supposedly, this disadvantage occurs because bilinguals face the additional challenge of sifting through words for barn animals in both of their languages, and making sure that only words in the correct language are used (Golan, Montoya & Werner, 1992).

The fact that bilinguals have two active language systems implies that they must somehow control their output if they wish to maintain fluency. Currently, the dominant theory is that bilinguals use general executive mechanisms, and specifically inhibitory control, to suppress the
system not in use (Green, 1998). Some evidence for this theory is provided by experiments that look at the cost of switching between two languages in individuals who are not equally fluent in L1 and L2, such that L1 is their dominant language. Surprisingly, it has been found that such individuals take longer to switch back to their dominant language, as opposed to their second language (Meuter & Allport, 1999). This finding has been taken to support the theory that inhibitory control is the key mechanism active in language suppression in bilinguals. That is, it is believed that when a non-fluent bilingual speaks in L2, he must constantly inhibit L1. On the other hand, when speaking L1, it is not necessary to inhibit the less dominant L2 to the same extent, because L2 is not as active to begin with. Thus, more effort is required when one wants to “unblock” L1 as compared to L2 (Costa & Santesteban, 2004). The assumption is that in fluent bilinguals both L1 and L2 are equally active, and one must block the language not in use in order to communicate effectively in either of his languages (Green, 1998).

While Green’s general reasoning has been retained in the literature, more recent studies offer some diverging evidence. Firstly, results have been obtained that suggest that the bilingual advantage goes beyond inhibitory control and spreads to other executive functions (Bialystok et al, 2006). Secondly, some studies suggest that the bilingual advantage may result from superior goal maintenance and reactive inhibition. That is, irrelevant information may not be directly inhibited, but rather processed to a lesser extent because bilinguals are able to direct more attentional resources to their goal. Since attentional resources are drawn from a limited pool, this would automatically mean that fewer resources are available to process irrelevant information (Colzato et al, 2008). Under this theory, if the task at hand is quite simple sufficient resources may in theory be left over to process irrelevant information (which is not directly inhibited) to ensure memory for it. Proponents of this theory could respond to the Green (1998) findings by pointing out that communicating in a language in which one is not entirely comfortable requires a great concentration of attention, simply because it is a difficult, non-automatic task. Therefore, to explain the finding that it takes longer to switch to the more dominant language rather than the less dominant one, it is not necessary to assume that the dominant language has been inhibited. It is possible that a person simply needs more time to reorient after a more difficult task because one’s cognitive resources have been taxed more heavily. It is quite possible, for instance, that participants would also take longer to solve simple arithmetic equations after exerting themselves in the use of a language in which they are not entirely fluent.
In the following sections I will review the accumulating results on the interrelation of bilingualism and executive function, as well as findings suggesting that the experience bilinguals acquire in exercising executive control generalizes to nonverbal domains. Before I launch into this discussion, however, I will briefly review eye-tracking paradigms and their contributions to the study of attention in general. These concepts are discussed here because various pivotal findings on attention and aging relate in important ways to the study of bilingualism, and because some important results on bilingualism have been obtained using an eye-tracking paradigm similar to the one that will be used in the current experiment.

1.2 Eye Tracking Paradigms and the Study of Attention

Let us firstly take a brief look at what we mean by the term ‘attention’. The brain possesses a limited amount of processing resource and a limited capacity to generate responses to stimuli. Our effective interaction with the world therefore depends on our ability to select certain stimuli for further processing, while ignoring competing stimuli. In the visual domain, this task is mediated by visual attention (Posner & Peterson, 1990). The attentional system itself is thought to be an aggregate of several related, but distinct processes (refer to Fig. 4). According to Posner (1990), the main functions of attention, which are modulated by distinct neural networks, are alerting, orienting, and executive control. The alerting and orienting functions are responsible for detecting stimuli and selecting them for further processing. Executive control, on the other hand, is involved in conflict resolution. This function becomes important when one must choose between two salient stimuli, or ignore a salient stimulus in order to achieve a top-down goal. There is evidence that it is precisely this component of attention that is involved in resolving the competition between L1 and L2 in bilinguals (Green, 1998).
The eye-tracking paradigm has been a pivotal tool in the study of attention as well as memory. Although these two areas of study (attention and memory) have historically been somewhat separate, one of the important assets of the eye-tracking paradigm is that it allows to explore both, often within the same experimental setup. In this technique participants’ eye movements are tracked via specialized cameras, which provides a direct measure of their sampling behaviour. In terms of quantifying attention, the utility of this paradigm is obvious, at least for measuring overt attention: By tracking a participant’s eye movements it is possible to tell which areas of a display had captured his attention by noting where his/her eye movements had been directed. The utility of the paradigm for studying memory is less obvious. However, Ryan et al (2007) have been able to discover important patterns of eye movements that specifically indicate memory for a previously viewed scene. For instance, participants tend to direct more eye movements to manipulated areas of previously viewed scenes, which necessarily implies that they had formed memory representation for the scenes when they first saw them. Thus, within the same paradigm it is possible to study both an individual’s pattern of attention (e.g. which areas of a visual display had attracted his attention and which had not), and the resulting pattern of memory encoding (Ryan et al, 2007). This potential to simultaneously study memory and attention has made the eye-tracking paradigm particularly befitting for the present study, in which we explore the effects of bilingual attentional advantages on memory encoding. One additional advantage of this technique is that it does not rely on verbal responses, making it possible to gain access to subconscious processes. This is an important asset because not all

Figure 4. Processes of attention (Posner, 1990)
cognitive processes are accessible to conscious awareness. One can appreciate this by asking oneself how he goes about examining pictures of faces. One will realize that it is quite difficult to analyze one’s own viewing behaviour in this way, but eye-tracking experiments have revealed a definite trend: People tend to direct more fixations, and spend more time viewing the eye region of faces (Walker-Smith, Gale & Findlay, 1976). Furthermore, in some cases performance has been known to decline if participants are made aware that they are involved in a test of memory. For instance, older adults have been found to show poorer performance on tasks if they are told that their memory is being tested. Supposedly this occurs because they have negative expectations due to societal stereotypes linking old age with poor memory (Hess et al, 2003).

Eye-tracking studies have revealed two memory effects (briefly discussed above) that will be of particular relevance to the current experiment. The first of these is the repetition effect: Participants tend to direct fewer saccades, and spend less time examining previously viewed scenes. This effect occurs whether or not participants are consciously aware of the repetition, making it a valuable tool in studying memory for scenes. The second effect is the relational manipulation effect: Participants tend to increase viewing to manipulated regions of previously viewed scenes (Ryan et al, 2007). In summary, eye-tracking paradigms make use of information about participants’ eye movements to study their patterns of attention and subsequent memory for scenes. Attentional processes can be accessed by noting the elements in a visual display that attract saccadic eye movements, and memory for scenes can be studied by observing eye-movement patterns on previously viewed displays.

Of relevance to the current experiment, eye-tracking paradigms have been used to study attention and memory as they relate to the process of aging. Even though the current study will not be testing older individuals, I will mention these results briefly, because some parallels exist between attentional advantages of younger adults compared to older adults, and the advantages of bilingual compared to monolingual individuals. Additionally, the design of the current study was greatly influenced by the paradigm used in comparing younger and older adults.

Older adults have been found to have inhibition deficits. In a 2007 study by Ryan et al, younger and older participants were instructed to view a display containing several abstract objects placed in neutral, real-life background. The participants were informed that an additional object will
appear after a short delay, and they are to ignore it. Older participants directed more saccades and spent more time overall looking at the late-onset objects than their younger counterparts. This finding suggests that older participants have difficulty inhibiting attending to irrelevant information, even under direct instructions to do so. The observation helps explain the memory deficits that have been consistently associated with older age: If older adults spend their limited attentional resources on irrelevant information, they have fewer resources available to process important information, which is what is usually tested in memory tests.

In summary, it has been established that attentional, as well as memory performance declines with age (Winocur, Moscovitch & Stuss, 1996), which has been linked both to inhibitory and binding deficits. As mentioned before, there is accumulating evidence that lifelong bilingualism may produce advantages in precisely those domains of performance that appear to decline with age. It is therefore a natural question whether bilingualism may be able to moderate age-related decline in these domains. Recent evidence in fact suggests such a moderating interaction between language and attention (Bialystok et al, 2006). The discussion that follows will discuss these, and other related findings.

1.3 Bilingualism, Attention and Memory

1.3.1 Bilingualism and Attention

It will be beneficial at this point to review fig. 4 and the mechanisms of attention.

![Figure 4. Mechanisms of attention (Posner, 1990)]
Recall that the alerting and orienting networks are responsible for maintaining a state of preparedness and choosing where to focus attention, based either on bottom-up features (e.g. salience), or top-down factors (e.g. task demands) (Posner, 1990). The executive control component comes into play when performance depends on the successful resolution of a conflict. In as much as conflict needs to be resolved when focusing and orienting attention, executive control mediates these networks as well. Various types of conflicts may affect performance. For instance, salient but task-irrelevant stimuli might compete with relevant stimuli for processing resources. This is precisely what happens when one is instructed to pick out a red square among red circles while the display contains, say, a yellow square. The differently coloured stimulus is very salient, but completely irrelevant to the task at hand, and successfully ignoring it is a task that relies on executive control (Smith & Kosslyn, 2007).

The executive control component of attention can be further subdivided into component processes. The inhibitory control network is responsible for ignoring irrelevant information, such as the yellow square from the example above. Response suppression is the process whereby automatic responses are blocked if they are not in line with current task demands. For example, the Stroop task (Stroop, 1935) requires that participants read color names (e.g. the word ‘green’) that are printed in colourful ink. When the word ‘green’ is printed in red ink, participants must resist the tendency to read the word, and instead they must respond by saying the color of the ink (red). Task switching refers to the ability to keep in mind more than one set of instructions and effectively switch between them as circumstances change (Smith & Kosslyn, 2007).

It is not difficult to see how all of these executive control subsystems may play a part in resolving the conflict between the two languages in a bilingual system. Inhibitory control might be involved when a bilingual individual suppresses the language representation for a certain concept in the language he is not currently using. Response suppression may ensure that one produces responses in the correct language in situations where his first instinct is to use the second language. For example, one might be used to naming certain household items in the language he uses at home, and yet be able to name them in the second language as the need arises. Task switching may be involved in effectively switching between different language environments. Indeed, there is evidence in the literature for bilingual advantage in all three subcomponents of executive control.
In one pivotal study bilingual and monolingual participants performed the Simon test. In this task, stimuli in one of two colors appear on either the left or the right side of the screen. Each color is associated with a key that is either on the left or the right side of the keyboard. In each trial participants must press the key that corresponds to the color of the stimulus. When the stimulus appears on the same side of the screen as its corresponding key (e.g. the stimulus is on the left side of the screen and the key is on the left side of the keyboard), the task is rather easy. However, when the stimulus appears on the opposite side from the key, reaction times grow longer, which reflects the added demands of suppressing the automatic tendency to respond based on stimulus location. This slowing of response times is called the Simon effect. Bilingual participants across different age groups demonstrate a smaller Simon effect than monolingual participants, which provides evidence for superior inhibition of irrelevant information (Bialystok, et al, 2004). One could argue that inhibition is confounded with response suppression in this task, since in order to be successful one must not only inhibit the irrelevant object location, but also resist the automatic tendency to respond on the congruent side. However, if one successfully suppressed the irrelevant information, there should be no trigger for the automatic response.

Further evidence comes from a study that found a larger negative priming effect in bilingual as compared to monolingual individuals. In this study, a location that was associated with distractor stimuli in previous trials became the target position in subsequent trials. Bilingual participants were more successful than monolinguals at ignoring the irrelevant locations, but showed longer reaction times on trials where previously inhibited locations became relevant. This finding is attributed to the fact that bilinguals were able to inhibit irrelevant locations to a greater extant and subsequently required more effort to “unblock” those locations (Treccani, Argyri, Sorace & Della Sala, 2009).

One innovative study set out to test whether the bilingual advantage effects task switching and response suppression, as well as inhibitory control. In this study the display consisted of a schematic representation of a human face and two boxes, to the right and left of the face. In each trial the eyes turned either green or red, after which the face disappeared and an asterisk flashed in one of the boxes. Participants were instructed that if the eyes turned green they were to respond by pressing a key on the side of the keyboard corresponding to the side of the screen on which the stimulus appeared (congruent condition). If the eyes turned red they were to press the key on the opposite side from the stimulus (incongruent condition). In addition, on some trials
the eyes gazed either to the same or the opposite side from the direction of correct response. On trials where the gaze was in the opposite direction from the direction of response participants faced the additional challenge of inhibiting this irrelevant information. The researchers found that bilingual participants were significantly better at inhibiting irrelevant gaze than monolingual participants, providing additional evidence that bilinguals have superior inhibitory control (Bialystok et al, 2006). In addition, the researchers grouped the trials in sets, some containing only congruent or only incongruent trials, and others containing mixed trials. In the mixed sets participants had to switch between task instructions and decide whether they must respond to the same or opposite side from the flashing stimulus. On the other hand, in blocked sets no rule switching was involved. The average difference in response times between blocked and mixed sets was taken as a measure of the cost of task switching, which was found to be significantly smaller in bilingual participants. Since the natural tendency is to respond on the same side as a flashing stimulus, the difference in response times between congruent and incongruent trials was taken as a measure of the cost of response suppression. This too was found to be significantly smaller in bilingual individuals. On the whole, this study provided evidence that bilingual individuals show significant advantages in all three components of executive attention: inhibition, response suppression, and task switching. Furthermore, this study compared performance of groups of younger and older bilingual and monolingual participants. The results indicate that older participants show weaker overall performance on all executive control tasks. However, the gap in performance between older and younger individuals is reduced in the bilingual group. Therefore, there is evidence that the lifelong practice associated with bilingualism attenuates age-related decline in attention (Bialystok et al, 2006).

Not all studies, however, support these findings. One study used a somewhat different paradigm and found no difference between bilingual and monolingual participants on a task requiring inhibitory control. This study employed the stop signal task. Participants were presented with arrows pointing left of right, and were required to press a key with their left hand if the arrow pointed left, and press a key with their right hand if the arrow pointed right. However, in some proportion of the trials the arrow changed color, in which case participants were to abort the normal response and make no response at all. The researchers reasoned that in order to perform this task successfully, participants had to inhibit a pre-determined response, and therefore they took the proportion of successfully aborted trials to be a measure of inhibitory control
performance. They found no significant difference in performance between bilingual and monolingual participants. The researchers therefore concluded that there might not be a bilingual advantage in inhibitory control, or, to use their term, active inhibition (Colzato et al., 2008). To explain the results obtained previously (ex. Bialystok et al., 2004), they proposed a model whereby bilinguals have better reactive inhibition. According to this model, there are two ways to inhibit a response. One way is to inhibit it directly, which is the view shared by Bialystok et al. (2004), Costa et al. (2006), Treccani et al. (2009), and others. The second way to produce what manifests as inhibition of an irrelevant response is to maintain a stronger representation of the goal, thereby diverting more resources to the required responses. Since resources are limited, more resources diverted to the target may manifest as fewer resources spent on irrelevant stimuli. The authors call this process reactive inhibition. One criticism that can be directed at this experimental design is that it is unclear whether the stop signal paradigm in fact measures inhibitory control. In particular, this paradigm does not create interference between two competing stimuli. Rather, this paradigm creates interference between two rules: The one that applies to regular trials and the one that applies to those trials where the arrow changes color.

To further test the reactive inhibition theory, the researchers devised an experiment based on the attentional blink phenomenon. An attentional blink occurs when participants fail to process a second target stimulus in a string if it occurs too close to the first target stimulus (Raymond, Shapiro & Arnell, 1992). There is evidence that the blink occurs because once the first target is detected attentional resources remain concentrated on it for some length of time, preventing processing of signals that occurs too close to it (Shapiro et al., 2006). Indeed, there is evidence that a more relaxed general attitude toward the task reduces attentional blink, suggesting that it in fact reflects the strength of the goal, and is thus a good measure of reactive inhibition (Olivers & Nieuwenhuis, 2005). In this experiment, participants were asked to identify and report two numbers in a string of letters. The researchers found that bilingual individuals had a larger attentional blink. Since it makes no sense in this setup to actively inhibit the stimuli occurring after the first target (in fact, it is counterproductive, as participants knew that a second target could appear at any position), these results were taken as evidence that the bilingual advantage stems from better goal maintenance (Colzato et al., 2008). Together, the stop signal paradigm and the attentional blink paradigm provide compelling evidence in favour of the reactive inhibition hypothesis.
1.3.2 Recent Findings on Bilingualism and memory

Although the interaction of memory and bilingualism is not nearly as well-studied as the relationship of bilingualism and attention, some recent findings should be reviewed here. Recall that in the current study we predict that bilinguals will have a memory disadvantage for irrelevant information made relevant. Although no studies to our knowledge directly test memory for irrelevant information in bilinguals, some studies do find certain memory disadvantages in bilingual participants. One study (Fernandes, Craik, Bialystok & Kreuger, 2007) had younger and older bilingual and monolingual participants memorize lists of 20 words under 3 categories of experimental conditions: Full attention, divided attention at encoding and divided attention at retrieval. Previous studies show that attention plays a more critical role for subsequent memory performance during encoding as compared to retrieval (Fernandes & Moscovitch, 2000), and indeed, better memory performance was observed for all groups of participants when attention was divided during retrieval as opposed to encoding. In terms of the effects of bilingualism, in keeping with the previously discussed findings on the bilingual advantages in suppression of irrelevant information the authors predicted that bilinguals would recall more words than age-matched monolinguals under divided attention at encoding. Surprisingly, this was not the case. In fact, the authors found a memory disadvantage for bilinguals, such that they were able to recall fewer words. One potential explanation for this unexpected finding is that bilinguals generally perform more poorly on tasks requiring lexical access, supposedly because they must juggle two separate lexicons (Gollan, Montoya & Werner, 2002). Thus, it is possible that the memory disadvantage arose because the memory task required retrieval of verbal materials. This lexical access disadvantage, among other considerations, led us to devise a completely non-verbal paradigm for the present study.

By contrast, a different study, which focused on different aspects of memory, did find a certain memory advantage for bilinguals (Wodniecka, Craik, Luo & Bialystok, 2010). In this very recent study the researchers drew on the distinction between familiarity and recollection – two separate measures of memory. It is generally believed that these two processes are separate and that while familiarity is a relatively automatic process, recollection relies on executive control functions (Yonelinas, 2002). The authors therefore hypothesized that bilinguals, due to their executive control advantages, will show superior performance in recollection, but not in familiarity. To test this hypothesis the authors used a variant of the Process Dissociation Procedure (PDP) first
proposed by Jacoby (1991). Participants were instructed to memorize a list of items for a subsequent memory test. During the test phase participants were presented with a long list of items belonging to three categories: Items from the study list, new items (not from the study list) seen only once and new items seen more than once in the test phase. In the verbal version of this study the items were words, while in the non-verbal variant the items were abstract objects. The study had two sets of instructions: ‘Inclusion’ and ‘exclusion’. Under inclusion instructions participants were instructed to say ‘yes’ both to items from the original study list and to repeated new items. Performance on this task is a measure of familiarity because the response criterion is simply that an item is familiar from somewhere. Under exclusion instructions participants had to respond ‘yes’ only to items that they recognized as being part of the original study list. Performance under these instructions is a measure of recollection, since the participants had to specifically recollect learning the items. In keeping with the original prediction, the researchers found a bilingual advantage in recollection, particularly for older adults and on non-verbal tasks.

The experiments described here have produced somewhat contradictory results, and have tested various aspects of memory for information directly studied. In the study proposed here we will look at yet another aspect of memory: Memory for information not studied directly and indeed for information that served as distracting background at study. Although such studies have not been conducted with bilinguals, memory for irrelevant information has been considered in relation to aging. As was mentioned previously, some parallels exist between the way in which younger adults relate to older adults and the way bilinguals relate to monolinguals. Therefore, I will briefly review some important finding from the aging literature with respect to memory for irrelevant information.

### 1.3.3 Memory for Irrelevant Information

As mentioned previously, old age is accompanied by decline in the same attentional mechanisms that are considered to be involved in the management of two language systems in bilinguals, namely, components of executive control. There is evidence that the bandwidth of attention is greater for older adults such that they absorb more information from their environment, even when this information is extraneous to the task at hand (Hasher, Zacks & May, 1999), in other words, older adults show poorer performance when they are required to inhibit irrelevant information. As the reader will recall, this is precisely the finding when monolinguals are
compared to bilinguals: Monolinguals are less able to suppress irrelevant information than bilinguals. Therefore, it is reasonable to assume that any memory results found when comparing older and younger adults might be replicated in studies of bilingualism.

In one study (Rowe, Valderrama, Hasher & Lenartowicz, 2006) older and younger participants were shown line drawings and had to respond whether two identical drawings occurred in sequence. The drawings were superimposed with irrelevant letters. During a later test participants were presented with a fragment-completion task and older adults showed a significantly larger priming effect from the distractors then did younger adults. This finding demonstrates that older adults, who find it more difficult to inhibit irrelevant information, seem to actually form better memory representations for this irrelevant information. This is encouraging: If the parallel between bilingualism and aging holds in memory this finding is directly equivalent to our predictions in the present experiment.

In a follow-up experiment (Campbell, Hasher & Thomas, 2010) the researchers asked whether the memory advantage that was observed for older adults was only for the distractor stimuli themselves, or whether older adults also bound the distractors to their simultaneously presented targets. The paradigm was similar to the one described above: Participants viewed pictures with superimposed distractor words and had to press a button if two identical pictures appeared in a row. Ten minutes later participants were given a paired-association task where some of the pictures were paired with the words that had been superimposed on them as distractors in the previous task. Older adults showed a memory advantage for preserved picture-word pairs, demonstrating that not only do they form memory representations for task-irrelevant information, but they are also better able to encode co-occurrences.

Again, in as much as parallels exist between aging and bilingualism research, findings in the aging literature provide support to the prediction that bilinguals should show poorer memory for irrelevant information because they are better able to suppress it. In the next section I will introduce the current experiment and demonstrate its potential in bringing us a step closer to understanding language effects on attention and memory.
1.4 The Present Study

While many studies have looked at effects of bilingualism on attentional processes, no one has yet tested the implications of the bilingual attentional advantage on memory. This is an unfortunate gap, especially in light of the fact that a better understanding of memory, valuable in its own right, could help us adjudicate between the competing theories of bilingualism and inhibitory control. The present experiment will build on the eye-tracking paradigm employed in Ryan et al (2000). Participants will view a series of photographs depicting ordinary everyday environments and containing an assortment of location-appropriate objects. A maze will be overlaid on top of the photographs and participants will be instructed to track the maze with their eyes as accurately as possible. Following the maze trials, participants will be exposed to the background pictures again under free viewing instructions. In this free viewing block some trials will be intact and some manipulated. In manipulated trials the location of two objects will be switched relative to the maze block. We will then study participants’ viewing behaviour focusing on the nature, proportion and number of fixations directed to manipulated regions as compared to non-manipulated regions. As per the relational manipulation effect, we will be looking for an increased number and proportion of fixations to manipulated areas as an indication that the image had been effectively coded in memory and the manipulation detected. An important feature of this paradigm is that at no point are participants instructed to ignore any of the stimuli on the display. Rather, akin to real-world challenges, participants are simply instructed to accomplish some goal to the best of their ability and in the manner they see fit. This will allow us to come closer to understanding the strategies that bilingual and monolingual individuals choose naturally. Furthermore, this paradigm will allow us to study attention and binding (memory) within the same experimental setup. In the maze trials we will obtain a measure of attention by comparing viewing behaviour of bilingual and monolingual participants with respect to their ability to keep their eyes on the maze. In the free viewing trials we will measure the participants’ memory for scenes based on their ability to detect changes to the location of objects. Recall that the relational manipulation effect refers to the tendency to increase viewing to regions of scenes that have been manipulated.

In line with previous results, we predict that, if bilinguals are in fact better at directly inhibiting irrelevant information, they should show poorer memory for aspects of the background scenes than monolingual participants. However, if the bilingual advantage results from better reactive
inhibition, or improved goal maintenance, bilingual participants will not necessarily show poorer memory for the background scenes. It is important to point out here that our paradigm relies on the assumption that it is possible to form memory representations for incidental information: Information not directly fixated. This assumption is justified in light of a study (described earlier) that showed a robust relational manipulation effect in younger adults in response to changes to a region of the visual scene they were instructed to ignore, even when it could be demonstrated that they had ignored that region successfully (Ryan et al, 2007).

In summary, the present paradigm promises to increase our understanding of language effects on attention and memory.

2 Methods

Participants

Twenty four healthy participants (16 Females, age range: 19-28 yrs.) with normal or corrected to normal vision participated in the present experiment. Participants were recruited through the Rotman Research Institute participant database and compensated at a rate of $10/h for their participation. These participants came from two language groups: Twelve were monolingual English speakers and twelve were bilinguals who had immigrated to Canada from various countries and learned English as a second language. There was neither a significant age difference nor a significant education difference between the two groups.

Table 1. Demographic information for the two language groups: Means and summary of statistics

<table>
<thead>
<tr>
<th></th>
<th>Monolinguals</th>
<th>Bilinguals</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td>M = 22.6</td>
<td>M = 23.2</td>
</tr>
<tr>
<td></td>
<td>SD = 0.85</td>
<td>SD = 0.76</td>
</tr>
<tr>
<td><strong>Total Years of Education</strong></td>
<td>M = 16.3</td>
<td>M = 16.4</td>
</tr>
<tr>
<td></td>
<td>SD = 0.58</td>
<td>SD = 0.60</td>
</tr>
<tr>
<td><strong>Years of University Education</strong></td>
<td>M = 3.8</td>
<td>M = 3.9</td>
</tr>
<tr>
<td></td>
<td>SD = 0.56</td>
<td>SD = 0.50</td>
</tr>
</tbody>
</table>
There is evidence in the literature that the full cognitive affects of bilingualism are more salient in fluent, balanced bilinguals (Kroll & Stewart, 1994). That is, not only do individuals need to show high proficiency in their two languages, they also need to have learned their second language at a young age, and to be using both of their languages in fairly equal proportion in their daily lives in order to fully display language-related cognitive effects. In particular, individuals must use their two languages such that the use of one language does not outweigh the use of the other by more than 20%. The ideal candidate would use his/her two languages in a proportion of 50:50, and we disqualified participants who reported proportions larger than 60:40. The Language and Social Background Questionnaire (Luk, 2008) was used to assess language proficiency in the bilingual group of participants. In keeping with the criteria outlined above, the bilinguals in our study, all of whom have English as their second language, have started using English actively at the age of 6.9 years on average. Their average daily use of English was 40% at home and 87% at work, and all reported being comfortable conversing in either of their two languages.

The monolingual English participants were born and lived in Canada and had no functional knowledge of any language but English. To qualify as monolingual, participants had to have never taken any language classes beyond regular high school level. Specifically, individuals who were involved in immersion and/or language exchange programs were disqualified even if they reported no functional knowledge of a second language. All monolinguals identified themselves as ‘not bilingual’ in the global self-assessment section of the Language and Social Background Questionnaire. Participants provided written informed consent, and verbal debriefing was provided upon completion.

Stimuli and Design

The stimuli consisted of 40 photographs of fairly ordinary everyday environments, both indoor and outdoor (1024 × 768 pixels). Each of the 40 photographs exists in two versions (version A and version B), such that the only difference between the two is in the switching of the location of two objects, referred to hereafter as the ‘manipulated objects’ (refer to figure 6).
The study block consisted of 40 trials corresponding to the 40 photographs, which were presented in random order. Each photograph was displayed for 6500ms with a maze overlaid over the image. Participants were instructed to follow the maze with their eye as accurately as possible. The mazes were created in Adobe Photoshop and had the following specifications:

<table>
<thead>
<tr>
<th>Color</th>
<th>Red</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width</td>
<td>20 pixels</td>
</tr>
<tr>
<td>Length</td>
<td>2160 – 2376 pixels</td>
</tr>
<tr>
<td>Number of Corners</td>
<td>12</td>
</tr>
</tbody>
</table>

A separate maze was designed for each photograph to eliminate learning effects as well as to make sure that the mazes did not obstruct any of the manipulated objects.

In the test block participants viewed 40 images (4000ms/trial) with no overlaid maze, under free viewing instructions, and in random order. In half of the trials participants viewed intact versions of the images they had seen in block 1. In other words, if version A of a picture appeared in block 1, they now saw version A of that picture again. In the remaining half of the trials participants viewed manipulated versions of the images from block 1, such that if version A of a pictured appeared behind the maze, they now saw version B of that picture (refer to Figure 6).

The third block was a repetition of block 2, but this time participants were instructed to press a button indicating whether they thought each image was intact or manipulated relative to way it had appeared in the first (maze) block. Stimuli were counterbalanced such that each version of each picture appeared as either intact or manipulated, and in either the study of the test blocks.
Figure 6. Examples of Stimuli (a) A block 1 (study) stimulus with an overlaid maze (b) Intact and (c) manipulated stimuli from block 2 (eye movement test).

Procedure

The present study consisted of three blocks with 40 trials per block. Refer to Figure 7 for concrete examples.

Block 1

Following initial setup and equipment calibration, participants viewed an instruction screen, supplemented with verbal explanation. They were told that they will see a set of photographs with overlaid mazes and their task will be to follow those mazes as accurately as possible. They were specifically instructed not to skip any corners or cut across any sections of the maze. A printed sample photograph with an overlaid maze was presented to all participants prior to the
commencement of the experiment and they were told that all mazes begin at the bottom of the screen and must be followed to the top of the screen. Each picture was then presented for 6500ms and was followed by a black screen with a fixation dot in the center. The onset of the next picture was controlled by the participant and was triggered by a button press. Thus, participants could take a moment between trials if they needed to blink, rest their eyes, etc.

**Block 2**

The procedure was similar to the one described above, but this time participants were instructed to freely view the images, and the mazes were removed. Each picture remained on screen for 4000ms and was replaced by a black screen. The participant triggered the onset of the next picture. Images were presented in random order such that half of them were manipulated relative to block 1 and half were intact.

**Block 3**

Block three was a repetition of block two. However, this time participants were explicitly instructed to try and compare the images they see to those same images as they appeared in block 1 behind the maze. Participants were instructed to indicate via button press (left, right) whether the image is intact or manipulated. These trials were not timed, allowing participants to examine and compare the images at their own pace. A black screen separated the images similarly to the first two blocks.
Figure 7. (a) Trial progression, block 1 (b) Trial progression, block 2.
Apparatus and Eye Movement Data Analysis

Stimuli were presented on a 19-inch monitor that subtended approximately 33.4° of visual angle from a distance of 25 inches. Eye movements were measured with an Eyelink II eye-tracking system (SR Research, Ltd., Mississauga, Ontario, Canada) and sampled at a rate of 500 Hz with a spatial resolution of 0.1°. A 9-point calibration was performed at the start of the experiment followed by a 0-point calibration accuracy test. Calibration was repeated if the error at any point was more than 1°.

Eye movements were analyzed with respect to experimenter-drawn interest areas corresponding to the maze and the manipulated objects. Various measures were derived from the eye movement data, such as the number and percentage of fixations to the aforementioned areas of interest. The main object of analysis was to compare viewing patterns to the manipulated objects in intact and manipulated trials.

3 Results

Please refer to Appendix 1 for definitions of eye tracking measures.

Block 1: Study

Recall that during the study block participants viewed photographs with overlaid mazes and were instructed to follow the mazes with their eyes. The main object of analysis then was to compare the accuracy with which the two participant groups (bilinguals and monolinguals) were able to perform this task. For this purpose, we calculated the distance (in pixels) of each fixation from the closest point on the maze, such that fixations falling within the maze were assigned a value of zero. Both bilinguals (M=9.7, SD=0.85) and monolinguals (M=8.7, SD=1.2) showed nearly perfect performance on this task and no significant difference was observed between the two groups, t(22)=0.66, p=0.52.
Block 2: Eye Test

Viewing Patterns of manipulated objects on intact and manipulated trials

Mixed two-factor ANOVAs were conducted to compare the viewing patterns of bilingual and monolingual participants to manipulated areas of the display on intact, as compared to manipulated trials. As per the relational manipulation effect (Ryan et al., 2007), if participants had successfully coded the scenes presented to them at study, they were expected to direct more viewing to manipulated areas of the display when a manipulation had occurred, as compared to the amount of viewing to the same areas on intact trials. In other words, increased viewing to manipulated areas on manipulated trials was to be taken as an indication of implicit memory for the scene. Furthermore, we predicted that bilinguals would show poorer memory for the scenes than their monolingual counterparts, due to their purported improved ability to inhibit the task-irrelevant scenes during the study phase. To quantify viewing patterns we studied two parameters: Average Interest Area (IA) fixation percent (figure 8a) and average IA dwell time percent (figure 8b). IA fixation percent is the percentage of the total number of fixations in a trial that fell with a certain area of interest, while the IA dwell time percent gives the proportion of time within a trial spent within a certain interest area. Contrary to our predictions, there was neither a trial type effect, nor a language effect, nor an interaction between the two for either of the two parameters studied. In other words, we observed an equal absence of any memory effects in both groups of participants. Relevant statistics are summarized in Table 2.

Table 2.
Summary of statistics: Viewing of manipulated objects by language group on intact and manipulated trials.

<table>
<thead>
<tr>
<th></th>
<th>Trial Type (Intact/Manipulated)</th>
<th>Language (Bilingual/Monolingual)</th>
<th>Trial Type × Lang. Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave. IA Fixation %</td>
<td>F(1,22) = 0.4, p = 0.53</td>
<td>F(1,22) = 1.0, p = 0.32</td>
<td>F(1,22) = 0.8, p = 0.38</td>
</tr>
<tr>
<td>Ave. IA Dwell Time %</td>
<td>F(1,22) = 0.8, p = 0.37</td>
<td>F(1,22) = 0.7, p = 0.40</td>
<td>F(1,22) = 0.4, p = 0.54</td>
</tr>
</tbody>
</table>
Figure 8. Viewing of manipulated objects by language group on intact and manipulated trials. (a) Ave. IA Fixation %: The average of the proportion of the total number of fixations in a trial that fell within the manipulated areas. (b) Ave. IA Dwell Time %: The Average of the proportion of time in a trial spent with the manipulated areas.
There is some indication in previous research that the relational manipulation effect may take place only in the absence of explicit awareness of the manipulation (Ryan et al, 2007). We therefore analyzed separately those trials on which participants had incorrectly identified the trial as either intact or manipulated during subsequent behavioral testing (see the following discussion of block 3). Table 9 summarizes the performance of the two language groups on intact and manipulated trials. As before, we did not observe any memory or language effects, or interactions. Relevant statistics are summarized in Table 3. Note that the present experiment did not contain study trials without an overlaid maze.

Table 3.

Summary of statistics: Viewing to manipulated areas on trials where an incorrect behavioural response was provided in subsequent behavioural testing

<table>
<thead>
<tr>
<th></th>
<th>Trial Type (Intact/Manipulated)</th>
<th>Language (Bilingual/Monolingual)</th>
<th>Trial Type × Lang. Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ave. IA Fixation %</strong></td>
<td>F(1,22) = 0.06</td>
<td>F(1,22) = 0.3</td>
<td>F(1,22) = 0.3</td>
</tr>
<tr>
<td></td>
<td>p = 0.81</td>
<td>p = 0.61</td>
<td>p = 0.61</td>
</tr>
<tr>
<td><strong>Ave. IA Dwell Time %</strong></td>
<td>F(1,22) = 0.2</td>
<td>F(1,22) = 0.05</td>
<td>F(1,22) = 0.06</td>
</tr>
<tr>
<td></td>
<td>p = 0.65</td>
<td>p = 0.83</td>
<td>p = 0.81</td>
</tr>
</tbody>
</table>
Figure 9. Viewing to manipulated areas on trials where an incorrect behavioral response was provided in subsequent behavioral testing. (a) Ave. IA Fixation % (b) Ave. IA Dwell Time %
Overall viewing patterns

Further analysis was conducted to examine the general viewing patterns of the two language groups. Whereas previous analyses looked specifically at manipulated areas of the display, here the question was whether there is any difference in the way bilingual and monolingual individuals move their eyes across scenes in general, and not with respect to any particular interest area. For this purpose mixed two-factor ANOVAs were conducted to analyze the following parameters, averaged across trials: Fixation duration, run count, fixation count, and saccade count (refer to Figure 9). As before, no significant memory effects were observed. In other words, general viewing patterns did not differ between manipulated and intact trials. However, language effects were observed (refer to figure 9). Specifically, monolinguals displayed significantly longer fixation durations, while bilinguals showed higher Run, fixation and saccade counts, all three parameters showing a trend toward significance. In other words, there is some indication that bilinguals tend to view scenes more actively, while monolinguals tend to spend longer periods of time fixated in one spot. Relevant statistics are summarized in Table 4.

### Table 4.
**Summary of statistics: General viewing patterns across trials**

<table>
<thead>
<tr>
<th>Trial Type</th>
<th>Language</th>
<th>Trial Type × Lang. Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave. Fixation Duration</td>
<td>F(1,22) = 0.06 p = 0.81</td>
<td>F(1,22) = 4.5 ** p = 0.046</td>
</tr>
<tr>
<td>Ave. Run Count</td>
<td>F(1,22) = 0.0 p = 0.98</td>
<td>F(1,22) = 2.6 * p = 0.12</td>
</tr>
<tr>
<td>Ave. Fixation Count</td>
<td>F(1,22) = 0.3 p = 0.58</td>
<td>F(1,22) = 1.8 * p = 0.19</td>
</tr>
<tr>
<td>Ave. Saccade Count</td>
<td>F(1,22) = 0.2 p = 0.63</td>
<td>F(1,22) = 1.9 * p = 0.18</td>
</tr>
</tbody>
</table>

** Significant
* Trend towards significance
a) Ave. Fixation Duration

<table>
<thead>
<tr>
<th>Fixation Duration (ms)</th>
<th>Bilinguals</th>
<th>Monolinguals</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>Intact</td>
<td>Manipulated</td>
</tr>
<tr>
<td>210</td>
<td></td>
<td></td>
</tr>
<tr>
<td>220</td>
<td></td>
<td></td>
</tr>
<tr>
<td>230</td>
<td></td>
<td></td>
</tr>
<tr>
<td>240</td>
<td></td>
<td></td>
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<tr>
<td>250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>260</td>
<td></td>
<td></td>
</tr>
<tr>
<td>270</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b) Ave. Run Count

<table>
<thead>
<tr>
<th>#Runs/Trial</th>
<th>Bilinguals</th>
<th>Monolinguals</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5</td>
<td>Intact</td>
<td>Manipulated</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 10. General scene viewing patterns. (a) Average length of a fixation in a trial. (b) Average number of runs per trial. (c) Average number of fixations per trial. (d) Average number of saccades per trial.
Block 3: Behavioural Test

In this block the stimuli from block 2 were repeated and participants were instructed to indicate via a button press whether they believed a manipulation had occurred relative to the study block. As participants displayed an obvious bias toward identifying trials as intact (refer to figure 10), we derived a corrected response rate (CRR) in order to arrive at a less biased estimate of explicit memory for the scenes. We defined a “hit” as a manipulated trial that was identified correctly (i.e. Trial type = manipulated, participant’s response = manipulated). Accordingly, a “false alarm” was defined as an intact trial that was identified incorrectly (i.e. Trial type = intact, participant’s response = manipulated). The CRR was calculated by subtracting the “false alarms” from the “hits”. The CRR gives the deviation from chance performance, such that a CRR of 5 would indicate that the participant performed 5% better than chance. No significant difference was found in behavioral responses (and consequently explicit memory for the scenes) between bilingual and monolingual participant, $t(22) = 0.9, p = 0.36$. While neither group performed significantly better than chance (bilinguals: $t(12) = 1.5, p = 0.17$; monolinguals: $t(12) = 0.43, p = 0.68$), bilinguals showed a slight trend toward significance.

![Behavioural Responses: % Correct](image-url)

**Figure 11.** Proportion of correct responses for bilingual and monolingual participants on intact and manipulated trials.
4 Discussion

4.1 Attention: Following the maze

As discussed previously, many recent findings indicate that bilingualism confers advantages on tasks requiring executive control (Bialystok, Craik & Ryan, 2006; Colzato et al, 2008). In accordance with these findings we hypothesized that bilingual participants will find it easier than their monolingual counterparts to stay focused on the maze. However, it was not our goal to make the task of following the mazes so difficult as to induce frequent overt gaze shifts away from the mazes (which could be easily achieved by introducing periodic flashes in locations outside of the mazes, or making the mazes faint and hard to separate from the background). Since our main purpose was to study memory for the background scenes and not the study of attention in itself, we reasoned that such a design would introduce too much noise and necessitate a separate analysis of the actual amount of time different participants spent looking at the background images. Instead, the mazes were designed to be trivial for younger participants, and in fact we found that both bilinguals and monolinguals followed the mazes almost perfectly, straying by no more than a few pixels. Thus, we relied mostly on covert shifts in attention. In other words, we hypothesized that, although both groups should be able to keep their eyes on the mazes equally well, monolinguals would take in more details about the background images through covert shifts in attention. This assumption is justified as other studies indicate that covert attention (at least in younger adults) can be enough to produce a memory trace (Ryan et al, 2007).

4.2 Language and Memory: Does bilingualism affect memory for scenes?

Remember that memory was defined here through the relational manipulation effect, which is the tendency to increase viewing to manipulated regions of previously viewed scenes. A greater relational manipulation effect indicates better memory for studied scenes subtending an improved ability to notice differences (Ryan et al, 2007). Contrary to our hypothesis we observed neither a language, nor a trial type effect, nor an interaction between the two. These results go beyond a simple absence of language group differences, and demonstrate that in the current paradigm there was no relational manipulation effect at all: All participants, bilingual and
monolingual alike, made the same proportion of their fixations and spent the same amount of time viewing the manipulated objects on manipulated and intact trials.

Recall that in the introduction two separate theories were presented of the origin of the bilingual executive control advantage. Several groups (ex. Bialystok et al, 2004; Costa et al, 2006; Treccani et al, 2009) have produced evidence that bilinguals are better at directly inhibiting irrelevant information, while other researchers (ex. Raymond et al, 1992) believe that bilinguals are instead better at reactive inhibition. That is, their advantage stems from superior active goal maintenance and superior diversion of resources to task-relevant details without active inhibition of any competing details. One of the original goals of the current study was to investigate these two theories. We reasoned that if active inhibition is the source of the bilingual advantage, bilinguals should show poorer memory for study scenes, since those background scenes are distracting and irrelevant to the task of following the maze and thus should be actively inhibited. If, on the other hand, superior reactive inhibition is the cause of the advantage, corresponding disadvantages in memory for irrelevant information should only be seen when the task (the goal) is sufficiently complex to divert all available resources, which was purposely avoided in this study by keeping the mazes trivial. Thus, we proposed that no significant effects of language may be taken as support for the reactive inhibition theory. Unfortunately, the results we obtained do not allow us to draw any conclusions about these two theories. The fact that we found no significant effects of language is obscured by the fact that we found no memory effects at all, either implicit or explicit: It appears that participants in both groups simply did not remember the scenes at all, as indicated by the absence of a relational manipulation effect and by chance performance in the behavioural response block.

The fact that the relational manipulation effect, which had been found in previous eye tracking studies, and is in fact emerging in one study currently in progress that uses the same stimuli (Dr. Jennifer Ryan, Personal communication: September 1st, 2010), leads us to believe that paradigm flaws have led to the pattern of performance described here. Therefore, in the following discussion I will outline several improvements that might lead to a more informative future experiment.
First and foremost, the absence of a relational manipulation effect needs to be addressed, as the whole study is premised on it. The most likely reason for the floor effect in memory performance is that the task was too hard: Participants simply did not have enough time to form a memory representation of the scenes. Recall that each trial in the study block was 6500ms long, which is approximately the length of time required to finish the maze. Therefore, if the trials had been made significantly longer participants will have had time to finish the maze and begin exploring the background image, which is undesirable. One way to let people spend more time viewing images without prolonging the trials is to repeat study trials several times. The precise number of repetitions required for a memory effect to emerge will need to be determined through piloting. It should be mentioned here that in a pilot version of the present experiment, which had only 10, instead of 40 trials, the relational manipulation effect was in fact observed. It appears that the increase in the number of trials placed excessive demands on cognitive resources.

Assuming that the paradigm can be modified so as to produce general memory effects, it would be worthwhile to repeat the experiment with older, instead of younger participants. Previous studies have generally found that the bilingual advantages in attention are most robust in older individuals, supposedly due to the fact that young participants are the pick of their cognitive performance and are prone ceiling effects on tasks requiring attention (Bialystok et al, 2004). In older individuals, bilingualism has been found to attenuate the attentional decline associated with aging, widening the gap in performance between bilingual and monolingual individuals (Bialystok et al, 2006). In fact, recent evidence has found bilingual advantages in the recognition component of memory retrieval, and these advantages too appear to be more robust in older adults (Wodniecka, Craik, Luo & Bialystok, 2010). Thus, it appears that if in fact there is a difference in memory for irrelevant information between bilingual and monolingual participants it would be more likely to be detected with older participants. However, considering that the paradigm in its present form appears to have been too complex even for younger individual, extensive piloting would be required to ensure that it does not overload the cognitive capacities of older adults. It is likely that the number of stimuli would have to be reduced and the study stimuli may need to be repeated multiple times, as mentioned before. It is possible that a different set of stimuli, where the manipulated objects are made more conspicuous, would be preferable.
4.3 General viewing patterns

Although neither memory nor language effects were observed, a set of very interesting and unexpected general viewing patterns emerged. Recall that when we talk about general viewing patterns we are no longer focusing on any particular objects or interest areas. Rather, we target the scene as a whole. Accordingly, we analyze all saccades, fixations and runs within a trial regardless of their location. As demonstrated in Figure 9a-d monolinguals tend to make significantly longer fixations. On the other hand, bilinguals tend to make more runs, fixations and saccades, with all three parameters sowing a trend toward significance. In effect, these results indicate that whereas monolinguals show a tendency toward sluggish eye movements, staying riveted to one spot for a longer period of time, bilinguals explore scenes more actively, making more eye movements overall and entering and leaving various interest areas (areas containing objects) more frequently.

Explaining these results is not easy, as very few studies to date have used eye tracking paradigms in the study of bilingualism. Since such is the case, very the following discussion relies heavily on personal communication with Dr. Gigi Luk, who is a researcher at Rotman research institute. One of her studies, currently in its infancy, is proposing a new theory that might prove very relevant to the patterns uncovered here. The theory points out that traditionally studies of bilingualism have focused on endogenous cues and the ability of bilingual and monolingual participants to control their attentional resources in response to internal goals. As discussed previously, this line of research has uncovered certain bilingual advantages in executive control functions. Another type of cue, which might be relevant to the bilingual experience, but has scarcely been studied, is the exogenous cue generated by the environment. To illustrate this concept an example (derived from the author’s personal experience) might be useful: Being in command of a language not spoken by the majority carries certain benefits, such as the freedom to discuss private matters in public spaces. However, to do so safely one must quickly assess upon entering a new environment the likelihood that someone else in it understands the same foreign language. A plethora of implicit environmental information might bear on this decision and the decision process is not necessarily accessible to conscious awareness. Nevertheless such decisions are made routinely, quickly and, surprisingly often, correctly. Clearly, this is a situation where certain exogenous cues can cause the bilingual speaker to switch between his language systems. It is also clear that there is an entire set of exogenous cues implicit in the environment
that a bilingual person must look for, but a monolingual person would find entirely useless. In
line with these phenomenological observations the new theory proposes that bilingual
individuals may generally tend to search the environment more actively (Dr. Gigi Luk, personal
communication: September 8th, 2010). It is easy to see how the general viewing patterns reported
here may be explained by the theory outlined above: As the study block evidently did not give
participants enough time to encode the background images, we may assume that the viewing
patterns in the test block reflect the participants’ natural scene exploration patterns,
unencumbered by memory effects. It is possible that the active exploration we found in the
bilingual sample reflects a general tendency to search the environment more carefully for cues.
Monolinguals, for whom the subset of relevant environmental cues is smaller, do not tend toward
such active exploration, and therefore spend more time fixated in one spot.

4.4 General conclusion and future directions

It is clear from the discussion above that, as far as improving our understanding of memory and
bilingualism, our paradigm was not successful. No significant effects of either trial type, or
language nor an interaction were found, and it is therefore not possible to draw conclusions about
memory for irrelevant information in bilingual and monolingual individuals. Several
improvements upon the present paradigm were proposed and discussed at length in the previous
sections, and it is likely that if the experiment is repeated with older participants and multiple
repetitions of study trials a more informative pattern of results will emerge. There is also a
possibility that a deeper flaw underlies our lack of results. For instance, it is possible that our
fundamental assumption that it is generally possible to pick up incidental information while
following the maze is wrong. As mentioned previously, this assumption was based on a study
where participants were able to encode stimuli that they had actively ignored (Ryan et al, 2007).
However, in that study, which compared younger and older individuals, participants showed
memory for one ignored object, which was conspicuous and part of a display that they otherwise
explored freely. Successful detection of manipulations in the current study required the ability to
encode a rather detailed and rich environment. Moreover, the two objects that switched were not
necessarily the most conspicuous items in the display (for instance, they may have been smaller
than some non-manipulated objects). In conclusion, it is possible that the absence of significant
results was due to a faulty underlying premise, but recall that a memory effect for the same
stimuli was observed in a pilot, which was different from the final experiment only in that it had 10 trials per block instead of 40. It appears that abandoning this paradigm might be premature: Quite apart from adjusting it so that it may serve as a tool in language studies, important information about covert attention and memory encoding may be gleaned by determining the conditions necessary to elicit a relational manipulation effect for the background scenes.

Very interesting and unexpected differences in viewing patterns between bilingual and monolingual participants were observed. Our results provide evidence that bilinguals tend to engage in more active exploration of scenes than their monolingual counterparts. These results are especially interesting in light of a new emerging theory that the subset of relevant environmental cues is larger for bilinguals than for monolinguals, and therefore bilinguals tend to search for environmental cues more actively. This research is in its infancy and any findings may provide valuable clues and stepping stones for future studies. For example, since there is some evidence in the literature that eye movements may be instrumental in binding and storing spatial and temporal relationships among objects (Ryan & Villate, 2009), it would be interesting to see how the tendency of bilingual participants to make more eye movements affects their memory for spatial and temporal relations.
References


Appendix 1

Definitions of Eye-Movement Measures

Interest area specific:

**IA Fixation Percent**
The percentage of all fixations in a trial falling in the current interest area

**IA Dwell Time Percent**
The percentage of trial time spent within the current interest area

*Overall patterns:*

**Average Fixation Duration**
Average duration of all fixations in a trial

**Run Count**
Total number of runs in a trial, where a run refers to a group of consecutive fixations that fell within the same interest area

**Fixation Count**
Total number of fixations in a trial

**Saccade Count**
Total number of saccades in a trial