# EXPLORING THE BILINGUAL ADVANTAGE IN EXECUTIVE CONTROL: USING GOAL MAINTENANCE AND EXPECTANCIES

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Abstract

Previous research has shown that bilingualism helps to offset age-related losses in certain executive processes such as inhibitory control, task switching and divided attention. The two studies presented in this dissertation investigated possible mechanisms underlying this bilingual advantage in executive control by examining the role of expectancies and goal maintenance in monolingual and bilingual younger (30 to 40 years) and older adults (60 to 80 years). In Chapter 2, the fadeout paradigm (Mayr & Liebscher, 2001) was used to examine differences in the ability to disengage from an irrelevant task cue. Testing began with single task blocks of shape and colour classifications presented separately, followed by a task switching block in which the two tasks alternated randomly. On trial 49, one of the tasks became irrelevant, leaving only a single task to perform. The critical variable was the point at which participants' performance reflected this change by examining the number of trials required to return to single task block speed. Results showed that both younger and older bilinguals returned to single task block speeds sooner than monolinguals. The results were interpreted as showing that bilinguals were better able to use task cues to improve task performance and that outsourcing control to task cues may be beneficial. In Chapter 3, a dual modality classification paradigm was used to determine the speed at which two tasks could be executed at the same time as a means of measuring the ability to sustain task goals. The task required participants to simultaneously respond manually to visual stimuli and verbally to auditory stimuli. Results revealed that younger and older bilinguals showed smaller costs in responding to two tasks whereas monolinguals experienced larger delays in making their responses. Proportion analysis of dual task costs and pairs of responses revealed a bilingual advantage and did not show any age-related increases in costs. The results were interpreted as demonstrating the strength in goal maintenance in bilinguals,

allowing them to establish a task goal, control interference from stimulus pairings in order to uphold the goal, and to manage multiple streams of information, and these abilities are sustained in aging.

Dedication

In memory of many of my older adult participants, and a few younger adult participants (including my grandpa S.A.R., my dad’s best friend V.P., and one of my close friends J.M.D.).

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TABLE OF CONTENTS

List of Tables

List of Figures

# Chapter 1

## Introduction

Research has consistently shown that with age, there is significant decline in cognitive functions (Cepeda, Kramer, & Gonzalez de Sather, 2001; Dempster, 1992; Reimers & Maylor, 2005). Research on cognitive reserve suggests that adults with higher cognitive abilities have a lower risk of dementia than those with less cognitive abilities (Stern, 2003). Active factors such as highest level of education, IQ, and engaging in regular tasks that require mental effort, as well as passive factors such as structural changes in the brain that result from these enhanced abilities, have been shown to improve cognitive reserve and protect against cognitive decline (see Tucker & Stern, 2011). It appears that this age-related decline can also be mediated through experience. One such active experience that may improve cognitive reserve is language experience, more specifically, bilingualism. A study by Bialystok, Craik, Klein, and Viswanathan (2004) was the first to show that bilingualism positively altered the trajectory of the well-documented age-related decline of inhibitory control, an executive function. Following this, the past decade has seen more research showing improved performance by bilingual adults than comparable monolinguals on tasks that measure working memory (Luo, Craik, Moreno, & Bialystok, 2013), and inhibitory control (Bialystok, Craik, & Luk, 2008; Bialystok, Poarch, Luo, & Craik, 2014). It is generally believed that the bilingual experience of suppressing one language in order to use another has translated into a more generalized ability to ignore distracting information in high conflict tasks, and that this ability results in an advantage for bilinguals over their monolingual counterparts on non-linguistic tasks (Green, 1998). Research with brain imaging, mainly using functional magnetic resonance imaging (or fMRI), has shown that when bilinguals engage in language switching tasks, the brain regions that are recruited are similar to the regions that are activated during non-linguistic executive function tasks for monolinguals (see meta-analysis in Luk, Green, Abutalebi, & Grady, 2012). Research also shows that there is more efficient brain activation in older bilinguals than in older monolinguals during task switching (Gold, Kim, Johnson, Kryscio, & Smith, 2013). These studies suggest that bilingual language experience enhances the brain's ability to monitor conflict and engage in effortful processing.

Green and Abutalebi (2013) proposed the Adaptive Control Hypothesis (henceforth ACH) to explain the relation between brain networks and bilingual experience. They argue that in dual-language situations when higher control is needed, neural circuits in the brain automatically adapt in order to avoid conflict. The authors suggest that this adaptive change is the reason for improved performance of bilinguals on non-linguistic cognitive control tasks. The ACH isolated eight processes involved in language control in bilingual speech production that include *goal maintenance*, *conflict monitoring*, *interference suppression*, *salient cue detection*, *response inhibition*, *task disengagement/engagement*, and *planning*. According to the ACH, maintaining the task goal is the key to successful language control. Maintaining this goal is a *proactive* process that is established at the onset of the interaction. In order to maintain this goal, conflict monitoring and interference suppression may be required depending on the language production demands. Cues from the environment such as overhearing the other language or knowing that the other speaker also knows the other language can interfere with this goal, so these cues need to be suppressed if they are irrelevant to the current goal. Conversely, if both languages are required in the conversation, then both languages need to remain active and used appropriately to maintain a flow in the conversation. The process of cue detection leads to adapting the goal based on the environment. For example, if language X is being used and a person who speaks both language X and Y enters the conversation, then the speaker needs to decide whether to continue in X, use Y, or use both if they are relevant. This process is *reactive* because the language goals have to be sustained or adapted based on what is happening around the speaker. A certain level of flexibility is required to change the language usage goals. The ACH proposes that the active maintenance of language goals, suppressing or inhibiting the irrelevant language, and adapting language goals results in bilinguals showing improved performance in non-linguistic cognitive tasks.

The ACH is derived from a cognitive framework proposed by Braver (2012) who distinguishes between *proactive control*, defined as establishing a task goal and controlling interference in order to uphold the goal before the onset of a task, and *reactive control*, the process of reactivating task goals when stimuli contain conflicting information. Generally, proactive control is more self-directed while reactive control is externally-driven. Braver's (2012) Dual Mechanisms of Control (henceforth DMC) framework proposes that goal activation needs to be sustained during varying task conditions and failure to do this proactively will result in stimulus-driven reactivation of the goals. The DMC framework is based on paradigms such as the Stroop task (Stroop, 1935), and the AX continuous performance task that is a memory updating task that requires the maintenance of a contextual cue to guide responses to probes (Barch, Braver, Nystom, Forman, Noll, & Cohen, 1997; Braver, Barch, & Cohen, 1999; Frank & O'Reilly, 2006). The DMC framework proposes that proactive control is sustained across trials while reactive control occurs on an "as needed" basis and is more likely to occur only on the difficult trials (e.g., when the stimulus is misleading, or contains irrelevant information). The constant and active representation of the goal provides top-down support, resulting in faster responses. Conversely, in reactive control, there is no sustained goal information during the task. Instead, task goals are activated on conflict trials resulting in delays in the time to identify the goal and selecting a response. The DMC framework proposes that in aging, older adults come to rely more on reactive control than proactive control due to the inability to maintain task goals over time.

Table 1. Differences between proactive and reactive control in the ACH and DMC frameworks and the implication for aging.

| | **Adaptive Control Hypothesis** | **Dual Mechanisms of Control** |
|---|---|---|
| **Proactive control** | Flexible<br>Sustainable | Rigid<br>Difficult to sustain |
| **Reactive control** | Helps adapt task goals to speed up reaction times | Slows down reaction times |
| **Aging** | Interaction between proactive and reactive control | Failure in proactive control results in use of reactive control |

Researchers generally view proactive control as a rigid process that is not as dynamic as reactive control (Braver, 2012; Goschke, 2000; Meiran, Cole, & Braver, 2012; Meiran, Pereg, Kessler, Cole, & Braver, 2015). However, the ACH suggests that proactive control is flexible because language usage goals need to be modified in response to changes in the environment (see Table 1 for differences between the ACH and the DMC). In the ACH, salient cue detection is a control process that leads to flexibility in shifting from the current language in use to the other language. This dissertation will examine the constructs of goal maintenance and cue detection proposed by the ACH to determine if task goals are managed similarly or differently in younger and older monolinguals and bilinguals. The aim is to further our understanding the extent to which dual-language experience changes cognitive control and if the inclusion of bilingual samples in cognitive aging research mitigates any discrepancies between theoretical explanations of specific kinds of task performance. The ACH and the DMC framework are mostly based on tasks that contain inherent conflict. This next section will examine existing research that uses conflict-based tasks to examine bilingualism and age-related changes, and how the results relate to the ACH and DMC framework.

**The impact of bilingualism and aging on conflict-based tasks**

The ACH and DMC frameworks focus on tasks that measure inhibitory control, defined as the ability to ignore distracting or irrelevant information in order to perform a task. Tasks that measure inhibitory control typically assess the ability to respond to one dimension of a stimulus while suppressing or ignoring the other. One such task that has been used often in the aging literature is the Stroop colour-word task, in which colour words are presented in an ink colour that may conflict with the word and participants are asked to name the colour of the ink (Stroop, 1935). If the word and the ink colour do not match (e.g., word is "RED" printed in blue), it is harder than naming the ink if it is the same colour as the word (e.g., word is "RED" printed in red). The difference in time between naming the ink colour when it is the same as the word (congruent trials) and naming the colour when it is different from the word (incongruent trials) is the *Stroop effect*. It is generally assumed that the Stroop effect reflects response selection processes that are part of executive functions (e.g., MacLeod, 1991). The premise of the Stroop task is that reading is automatized therefore making it difficult to ignore the word and identify the colour of the word. In other words, word reading interferes with colour naming. Older adults typically find it difficult to ignore reading the word because it is an automatic process, so older adults typically show larger Stroop effects than younger adults (Comalli, Wapner, & Werner, 1962). Research with bilinguals has shown that both younger and older bilinguals experience smaller Stroop effects than matched monolinguals, suggesting that bilinguals are faster at reconciling the conflict between word reading versus colour naming (Bialystok et al., 2008, 2014).

According to the DMC framework, in the Stroop task, proactive control would result in the task goal "name colour" being continuously active, leading to faster identification of the stimuli and faster reaction times (henceforth RTs). Proactive control does not reduce the amount of conflict but rather it improves the management of the conflict. Reactive control in a Stroop task is operationalized as the reactivation of the task goal only on incongruent trials. For example, when the ink colour conflicts with the word, both components of the stimuli are identified (ink colour and word) followed by the reactivation of the task goal "name colour". The framework suggests that reactive control is inefficient and results in slower RTs. In terms of bilingualism, the smaller Stroop effects found in younger and older bilinguals than comparable monolinguals suggests that bilinguals were more efficient in engaging in top-down proactive control rather than defaulting to reactive control.

Another well known task in the conflict literature is the Simon task (Simon, 1969). This task is a stimulus-response compatibility task that requires participants to ignore prepotent responses to spatial information and attend to the instructions that are provided (see review in Lu & Proctor, 1995). In the standard version of the task, participants are presented with coloured squares that appear on the left or right side of the screen and are required to respond to the colour and ignore the location. This paradigm yields two types of responses—congruent responses where the stimuli are presented on the same side as the required response, and incongruent responses where they appear on the opposite side of the correct response. A control condition where the stimuli appear in the centre of the screen is sometimes used to measure baseline RTs. As in the Stroop task, participants generally perform better when the location of the response is compatible with the stimulus location (Fitts & Seeger, 1953; Simon, 1990). The *Simon effect* is the mean RT difference between incongruent and congruent items. Also like the Stroop task, older adults experience larger Simon effects than younger adults indicating an age-related decline in the ability to ignore spatial location (Christ, White, Mandernach, & Keys, 2001; van der Lubbe & Verleger, 2002).

Bialystok et al. (2004) administered four conditions of the Simon task to younger and older monolingual and bilingual adults. The four conditions were—centre-2, in which blue and brown squares appeared in the middle of the screen, side-2, in which the squares appeared on the left or right side of the screen, centre-4, in which pink, yellow, red and green squares appeared in the centre of the screen, and side-4, in which these squares appeared on the left or right side. The centre-2 condition was a control condition to measure baseline RTs, side-2 was the standard Simon task, centre-4 measured simple working memory load and side-4 was an advanced Simon task measuring complex working memory load. The centre- and side- 2 conditions had two stimulus-response mappings whereas the centre- and side-4 conditions consisted of four stimulus-response mappings. In the side-2 and side-4 conditions, participants had to ignore the spatial location of the square in order to make the correct response. In the side-2 and -4 conditions, bilinguals of both age groups were faster on both the congruent and incongruent trials than monolinguals. The basic centre-2 condition yielded only age-related differences and no language group differences. In the centre-4 condition, even though there was no misleading information (the squares appeared in the centre of the screen), bilinguals outperformed their monolingual counterparts. These results indicate that the two additional response mappings that required participants to remember four stimulus-response mappings negatively affected the monolinguals only. The centre-4 condition was called a "working memory load" condition however, on standard measures of working memory there were no age group or language group differences. If the experience of being bilingual enhances the ability to ignore distracting information, why were bilinguals better than comparable monolinguals at reconciling four response mappings in a colour recognition task version of the Simon task that did not contain any conflicting information on the stimulus level?

One way to answer this question is to consider the environment of a bilingual. If a bilingual speaker of French and English were in a French environment, knowledge of English would need to be suppressed in order to use French (Green, 2005; Meuter & Allport, 1999). Having knowledge of two languages requires bilinguals to focus on two language networks and draw from the relevant language. A great deal of mental control is required to achieve these outcomes. The fact is that bilingual speakers do not switch from one language to the next word by word, and there are occasions where both languages are used within the same conversation or even the same sentence. Even in the case of dense code switching (alternating between two or more languages within a conversation), bilinguals do not alternate between language X and language Y word-to-word. Managing two languages is different from switching between languages. Similarly, in a multi-tasking situation, we do not execute one task after the other in a repetitive pattern. For example, when we are working on the computer and receive a phone call, we do not type one word and speak one word into the phone. It is likely that we talk and type at the same time with the goals of (a) completing the sentence that we are in the middle of typing, (b) to pay attention to the phone call, and (c) eventually end the phone conversation in order to continue typing. Managing multiple goals and handling possible conflict between these goals is required in order to complete both tasks. There needs to be an overall efficiency in proactive control in order to successfully engage in two tasks.

Results from studies that measure the effects of bilingualism on aging suggest that bilinguals show greater flexibility in proactive control and less reliance on reactive control than monolinguals as evidenced by smaller Stroop and Simon effects (Bialystok et al., 2004, 2008, 2014). There appears to be an overall increase in efficiency in performance by bilinguals that is not tied to the type of trial presented. The Inhibitory Control Model of bilingualism (Green, 1998) and the ACH describe this bilingual advantage in terms of language usage goals translating into task goals. While the Inhibitory Control Model and ACH suggest that language control leads to greater cognitive control, most of the research is still focused on inhibitory control and language switching studies. Research using language switching in bilinguals has shown that bilinguals who are equally proficient in both their languages experience no language switch costs (Costa, Santesteban, & Ivanova, 2006; Dalrymple-Alford & Aamiry, 1969; Kolers, 1966).

The focus of the majority of the research on the impact of aging on cognition is in trial-to-trial changes that occur during task performance. However, there are more than just these trial-to-trial changes that may provide a clearer picture of how bilingualism off-sets age-related decline in aging. The two experiments presented in this dissertation will attempt to further our understanding of how maintaining goals proactively and modifying task goals based on task demands (an interaction between reactive and proactive control) are impacted by aging and bilingualism. Green and Abutalebi (2013) claim that goal maintenance is a proactive process and salient cue detection is a reactive process that leads to the maintenance or modification of goals that were set proactively. In the cognitive aging literature, the interaction between proactive and reactive control and the sustainability of proactive control are considered to be taxing and problematic in aging (Braver, 2012; Goschke, 2000). The next section will examine research that lends support to how task goals are managed and to determine if existing research can demonstrate flexibility in proactive control, and if flexibility persists in aging.

## Flexibility in proactive control

The first process involved in task performance is maintaining the goals of the task (Fagot, 1994; Meiran, 2010; Paxton, Barch, Racine, & Braver, 2008). Based on the task goal, subsequent cognitive operations take place in order to process stimuli and eventually make a response. Task goals have been thought to create task rules in working memory (Carpenter, Just, & Shell, 1990; Duncan, Emslie, Williams, Johnson, & Freer, 1996). De Jong, Berendsen, & Cools (1999) proposed the notion of *goal neglect* to explain age-related decline in cognition. Goal neglect is defined as the inability to maintain the task requirement in working memory when distracted by irrelevant cues in the mental environment. De Jong (2000, 2001) proposed that age-related differences in saccadic eye movement RTs and Stroop effects are directly related to older adults' inability to maintain goals. Engle and colleagues (1999a, 1999b) introduced the specific term *goal maintenance* that they describe as the ability to keep goal-related information active as an important aspect of the controlled processing involved in working memory. The two terms are complimentary in that goal maintenance is the ability to keep the information active while goal neglect is the failure to do so. Goal maintenance is a top-down or proactive process that is considered to be a necessary step to success in tasks with overlapping task demands and response conflicts.

According to the DMC framework (Braver, 2012), age-related decline in cognitive control is caused largely by the inability to maintain goals and an increase in reliance on the stimuli or cues to reactivate the goals (Braver, Gray, & Burgess, 2007). In the goal maintenance context, the smaller Simon or Stroop effects in younger and older bilinguals than in monolinguals can be interpreted as successfully maintaining task goals proactively and not relying on reactivating task goals on difficult trials (Braver & West, 2007). Evidence for proactive control in the DMC framework is limited to tasks that rely on the inhibition or suppression of irrelevant cues. The Stroop and Simon tasks are based on *bivalent* stimuli in which the stimuli contain two pieces of information. In the Stroop task, stimuli consist of a word in an ink colour and in the standard Simon task stimuli contain information about the response (e.g., colour) and location. Bivalent stimuli are considered to be difficult to process because participants need to ignore one of the features. In the case of the Stroop and Simon tasks, the bivalent stimuli influence proactive goal maintenance. Proponents of goal maintenance argue that successful goal maintenance is characterized by the ability to suppress inappropriate/incorrect responses (see Kane & Engle, 2003). What happens when an explicit cue is presented? Does it reduce the need to maintain goals proactively because the cues give an indication of the response? Are task goals reactivated based on task cues? Answers to these questions may be found in the task switching literature and the measures calculated to determine efficient task switching performance.

**Task switching**

Task switching paradigms have been used to measure the ability to manage two task sets and alternate responses between them. In the standard task switching paradigm, bivalent stimuli are presented and a cue is used to indicate the relevant task to perform on each trial. This design enables two types of presentations—single task and task switch. In the single task condition, the cue indicates that only one task has to be performed. In the task switch condition, the cues alternate requiring participants to pay attention to both features of the stimuli. The occurrence of switch and nonswitch trials is typically unpredictable. In the single task condition, there are two stimulus-response mappings (e.g., for blue press left key; for red press right key) whereas in the task switch condition, there are four (e.g., for blue or square press left key; for red or circle press right key). This design enables the measurement of two costs associated with task switching—*local* and *global*. Local switch cost refers to the RT difference between switch and nonswitch trials in the task switching condition, while global switch cost refers to the RT difference between nonswitch trials in the task switching condition and the single-task. Local and global switch costs are also referred to in the literature as switching cost and mixing costs, respectively (see Kray & Eppinger, 2006; Logan & Bundesen, 2003; Rogers & Monsell, 1995; Rubin & Meiran, 2005). The task switching paradigm enables the measurement of proactive control in the form of global switch costs, and reactive control in the form of local switch costs. West (2004) hypothesized that global switch costs were related to active goal maintenance while local switch costs are related to bottom-up task maintenance.

Evidence for differences in the processing demands of local and global switch costs has been demonstrated by examining age-related changes in the ability to switch between tasks (Kray, Eber & Lindenberger, 2004; Kray & Lindenberger, 2000; Kray, Li & Lindenberger, 2002; Reimers & Maylor, 2005). For example, Cepeda et al. (2001) examined changes in executive control in 7 to 82 year olds who were instructed to switch between a digit naming and digit counting task. They found that children and older adults experienced larger switch costs than adults aged 20 to 60 years. The authors attributed their results to a decline of executive control associated with aging. Similarly, Kray et al. (2004) instructed participants aged 9 to 65 years to switch between two different types of classification tasks with instructional cues. The tasks were presented as single task and task switch blocks. The authors found that children and older adults showed poorer performance on task switch blocks than single task blocks but that the performance of adults aged 20 to 50 remained fairly constant.

The outcomes of task switching studies demonstrate global switch costs and occasionally local switch costs with aging (see Wasylyshyn, Verhaeghen & Sliwinski, 2011 for an extensive meta-analysis). Brain imaging studies using fMRI during task switching paradigms also show differences in brain activation patterns between younger and older adults during switch and nonswitch blocks. DiGirolamo et al. (2001) conducted an fMRI study using a standard task switching paradigm that required younger (mean age of 25 years) and older adults (mean age of 69 years) to respond to whether a number presented in a string was greater than or less than 5 (e.g., 333333 is less than 5 because the target number is "3"), or whether the number of digits in the string were greater than or less than 5 (e.g., 555 is less than 5 because there are only three digits in the string). The brain data showed that both younger and older adults recruited the medial and dorsolateral frontal cortices of the brain when they were switching between the two tasks and older adults also recruited these regions during nonswitch blocks. This pattern indicates that when older adults engage in task switching, there is no difference in brain activation for switch and nonswitch blocks, suggesting that a compensatory mechanism is activated.

*Language switching in bilinguals*. Research on task switching in bilinguals is mostly focused on language switching and has shown that there is a significant switch cost when one language is more dominant than the other (Hernandez & Kohnert, 1999; Macnamara, Krauthammer & Bolgar, 1968), although bilinguals who are equally proficient in both languages do not experience such switching costs (Costa et al., 2006). If no language is dominant, then there is no cost associated with switching between them, but if one language is dominant, it is more difficult to switch into the dominant language because of the greater inhibitory control required to suppress the dominant language making it difficult to re-activate (Green, 1998). In language switching studies, typically local switch costs are calculated to capture the cost of trial-to-trial switching.

An example of this type of research is found in a study by Garbin et al. (2011). They conducted an fMRI study examining activation changes in the brain when bilingual participants who were equally proficient in both their languages were presented with a language switching task. Spanish-Catalan bilingual younger adults (mean age of 20.3 years) were presented with pictures of objects with non-cognate names (words that are phonologically dissimilar in the two languages) and were required to respond either in Spanish or Catalan based on the colour of the picture. Participants were given two single language blocks and one language switching block. The behavioural data revealed no differences between responding in Spanish-only, Catalan-only, or in the switching blocks. In the analysis of the brain imaging data, participants were sorted by language preference. Even though participants were equally proficient in both languages, they had a preference for one language over the other. The preferred language was viewed as L1 (the dominant language) and the other language as L2 for the analysis. The authors compared activation in the language switching block by examining differences between forward switching (switching out of L1 into L2) and backward switching (switching out of L2 into L1). The results revealed that the left caudate region had increased activation when participants switched from L1 into L2 while the reverse (L2 to L1) resulted in greater activation in the pre-supplementary motor area and the anterior cingulate cortex. Also, they found that the intensity of the activation was greater during backward switching. These data suggest that even though there are no local switch costs behaviourally, there is a difference in brain activation that perhaps compensates for the difficulty in switching back to the dominant language. Luk et al. (2012) conducted a meta-analysis on ten language switching studies that used fMRI and found that regions such as the midline pre-supplementary motor area, left middle frontal gyrus, left inferior frontal gyrus, right superior temporal gyrus, and bilateral caudate were activated during language switching. These same regions are also activated during cognitive control tasks. The results of the meta-analysis suggest that language switching involves high level cognitive processes and is not limited to language processing regions.

*Bilingualism and non-linguistic task switching*. Recently, more studies have begun to examine the impact of bilingualism in non-language switching tasks. Prior and MacWhinney (2010) tested younger monolingual and bilingual adults using a task that required participants to respond to either the shape or colour of stimuli by pressing fixed response keys (each hand was assigned to a specific task). As with standard task switching paradigms, there were single task blocks where each task was presented separately, and mixed blocks where half the trials required participants to switch between the two tasks. Their results indicated bilinguals had smaller local switch costs but there were no global switch cost differences between the language groups indicating that the bilingual advantage was limited to reconfiguring stimulus-response mappings on a trial-to-trial basis.

The relationship between language switching and task switching has also been examined but not to a great extent. Prior and Gollan (2011) compared younger adults who were monolingual English, bilingual Spanish-English, and bilingual Mandarin-English on the same task switching paradigm used by Prior and MacWhinney (2010). The bilingual groups were also given a language switching task in which participants verbally responded in either English or their other language in response to a cue. The results showed no differences between groups on local and global switch costs in the task switching paradigm prior to controlling for language dominance and socio-economic status. The language switching task results were more complex due to the fact that there were language dominance and socio-economic differences between the bilingual groups. The Mandarin-English bilinguals reported a lower frequency of switching between their languages than the Spanish-English bilinguals, and there were socio-economic differences between the bilingual groups. When these two factors were controlled, a bilingual advantage in local switch costs emerged, however there were no differences in global switch costs. This type of result is common in the language switching literature if bilinguals are unbalanced and have a stronger L1 than L2. So why was there no overall advantage for bilinguals in this task? Based on the existing literature, it has been shown that increasing task difficulty elicits language group differences. The design of this particular task with stimulus-response mappings fixed to one task per hand could have reduced the task demands. The left hand was assigned to one task while the right hand was assigned to the other. Other task switching paradigms typically use one key for two responses with each hand responding to both tasks. It is possible that in the Prior et al studies, the stimulus-response mappings made the task simple.

Calabria, Branzi, Marne, Hernández and Costa (2015) compared the performance of younger, middle-aged, and older adult bilinguals on language switching and non-linguistic task switching paradigms. The language switching task required participants to name a cognate (word that sounds highly similar and means the same in two languages) or non-cognate (word that sounds similar in two languages but have different meanings) picture in either Spanish or Catalan based on a cue. The non-linguistic switching task was more complex than standard task switching paradigms because it consisted of 9 stimuli (three shapes in three colours) with six responses. Participants saw three stimuli on the screen and had to match the target stimuli to one of the other two stimuli on either colour or shape based on a cue. The results showed that the magnitude of the switch cost (i.e., local switch cost) in the language task was the same across all age groups. While there was an age-related decline in speed, the switch cost was unaffected. In the non-linguistic switching task, older adults experienced general age-related slowing and had larger switch costs than younger and middle-aged adults. In this study, the linguistic and non-linguistic tasks had different features making it difficult to draw any parallels between them. The authors concluded that aging differentially affects language control and cognitive control. However, the substantial differences between the two tasks makes such comparisons difficult so support for their conclusions is weak.

An example of a study that used standard stimulus-response mapping procedures was conducted by Garbin et al. (2010) with an fMRI component using a non-verbal task switching paradigm. Participants were young adults who were Spanish monolinguals and Spanish-Catalan bilinguals. The task required them to respond to either the shape or colour of the stimuli using two keys based on a linguistic cue. Each task was mapped to both buttons (i.e., press left button for circle or red, and right for square or blue). The behavioural data indicated smaller local switch costs for bilinguals than monolinguals. The imaging data revealed differential activation for monolinguals and bilinguals for switch and nonswitch trials. Compared to nonswitch trials, switch trials for monolinguals resulted in greater activation in the regions typically associated with task switching such as the right inferior frontal gyrus, left inferior parietal lobe, and the anterior cingulate cortex. The bilingual participants only had greater activation in the left inferior frontal gyrus, a region typically recruited in language switching, for switch trials compared to nonswitch trials. It was suggested that this additional recruitment contributed to the smaller local switch costs they found in the bilingual group. The design of this study did not permit the measurement of global switch costs so the question remains as to whether a bilingual advantage can be found in global switch costs.

To date, the only evidence for reduced global switch costs in bilinguals comes from two behavioural studies. Barac and Bialystok (2012) presented six-year-old children who were monolingual English and three specific groups of bilinguals (Chinese-, French- and Spanish-English) a non-verbal task switching paradigm that required the children to respond to either the shape (cow or horse) or the colour (red or blue) of stimuli. A blue cow and a red horse appeared along with a cue indicating which task to perform. Participants had to respond with their dominant hand by pressing one of the two images that matched the target stimuli based on the cue. The results indicated that children from the three bilingual groups did not differ from each other and all had smaller global switch costs than their monolingual peers. A bilingual advantage for global switch costs in this task has also been found in young adults (Wiseheart, Viswanathan, & Bialystok, 2014). These results are different from those reported by Prior and MacWhinney (2010) and Prior and Gollan (2011) in terms of identifying where the bilingual advantage lies. In the Prior et al. studies, for half the trials in the mixed block, the key press required was identical to the previous trial resulting in an increase in response compatibility whereas in the Barac and Bialystok (2012) and Wiseheart et al. (2014) studies, all trials were response incompatible. This higher rate of incompatibility could have increased the task difficulty that may have resulted in a bilingual advantage on global switch costs.

An fMRI study conducted by Gold et al. (2013) provides some evidence for reduced global switch costs in older bilinguals. The behavioural data showed that older bilinguals had smaller global switch costs than older monolinguals. There were no significant differences between the language groups for younger adults. When the task was presented again during brain imaging, proportional switch costs on the behavioural data (global switch costs in relation to nonswitch block baseline) revealed the same advantage in older bilinguals. The results of the brain data showed that there was typical age-related increase in brain activation for older monolinguals in the left dorsolateral prefrontal cortex, left ventrolateral prefrontal cortex and, anterior cingulate cortex. Older bilinguals did not show increased activation in these regions during the task switching paradigm. Instead, they exhibited the same reduced activation in these regions like the younger adults. There was no comparison of activation during baseline and the nonswitch blocks, therefore activation during nonswitch (that is typical in aging) is unknown from these data. In addition to highlighting the bilingual advantage in global switch costs in aging, this study also revealed that the regions that were recruited in task switching were similar to those shown to be activated during language switching such as the left prefrontal cortex and anterior cingulate cortex (see Abutalebi and Green, 2007; Luk et al., 2012).

*Summary of task switching*. What are the implications of task switching and language switching for goal maintenance? Do cognitive benefits from switching between languages persist in aging? Differential brain activation during local and global switching suggests that a different process occurs for trial-to-trial processing and for overall task management and that these same regions have been shown to be activated during language switching. While task switching studies provide some evidence for goal maintenance, there also appears to be a strong effect of bottom-up components. The impact of bottom-up components has been investigated by researchers through manipulating the number of stimulus-response mappings, increasing practice times, and altering the interval between stimulus presentations (see Nieuwenhuis, Ridderinkhof, De Jong, Kok, & Van der Molen, 2000). These manipulations significantly change the outcomes of task switching performance and typically lead to older adults' improved performance when they are given more time to respond, when stimuli are presented after long delays, and when there is an opportunity for more practice (Kray & Lindenberger, 2000; Meiran, Gotler, & Perlman, 2001). Tasks that elicit an advantage for bilinguals involve a level of conflict on the stimulus-response level. For example, in the Simon task, younger and older bilinguals outperformed matched monolinguals on incongruent trials where the stimulus and the response were incompatible, especially when congruent and incongruent trials were mixed together (Bialystok et al., 2004). Other studies have shown that when congruent and incongruent trials are presented in separate blocks, there is no apparent bilingual advantage in younger and older adults (e.g., Bialystok, Craik & Ryan, 2006). However, bilingual children have been shown to have faster RTs on incongruent trials (see Bialystok & Viswanathan, 2009). Task difficulty, increasing conflict and manipulating the presence of cues appears to contribute to better performance for bilinguals across the lifespan. If goal maintenance is strong, then cues should have a positive impact on task performance, and older adults should benefit from the presence of task cues.

It is evident from the preceding discussion that bottom-up factors such as the univalent or bivalent nature of stimuli, presence or absence of task cues, and intervals between stimuli presentations and response-stimulus intervals impact task performance, especially in aging (see Sohn & Anderson, 2001). Research in cognitive aging has shown that older adults rely heavily on task cues in order to maintain task goals (see Meiran et al., 2001). While goal maintenance is required for successful task performance, this review has also shown that there is a strong interaction between top-down and bottom-up processes that lead to different outcomes for bilinguals and older adults. According to the ACH (Green & Abutalebi, 2013), salient cue detection, a reactive process, results in the maintenance or modification of task goals. If language usage goals are modified efficiently based on the speaker's environment, the lack of global switch costs in younger (Wiseheart et al., 2014) and older (Gold et al., 2013) bilinguals in a task switching paradigm suggests that reactive processes are engaged to adapt and modify overall task goals. The problem is that there are typically no significant differences in local switch costs between younger and older adults, and as discussed, balanced bilinguals do not experience any language switching costs. Results from studies examining the performance of monolinguals and bilinguals during task switching have yielded conflicting results with some showing reduced local costs and others showing reduced global costs for bilinguals. Differences were also found between older bilinguals and older monolinguals in brain activation patterns for these global switch costs that points towards a greater difference between language groups than just trial-to-trial changes that occur during a task.

**Task expectancies**

Another method of examining task switching performance is to focus on changes in performance across the whole task from beginning to end. During task switching, participants build up expectations about what is going to happen in a series of trials or across blocks of trials. In a single task condition, the focus is on one task so there is an expectation that the remainder of the trials will consist of just one task (or that each trial will be a nonswitch trial). In switching blocks, there is an expectation that two tasks will be presented for the remainder of the trials. Even when a series of nonswitch trials appear, because of the task instructions, the presence of cues, and the experience that is building up through the course of the experiment, an expectation is formed that two tasks will be presented. When this pattern is not met (for example if in a task switching block, the trials suddenly become nonswitch only) it violates the expectancy. Remington (1969) demonstrated that during a block of trials that alternate, participants tend to predict or believe that the two tasks will appear in a somewhat balanced manner. Studies that have used verbal feedback have found that participants naturally tend to predict that in a block where two tasks or trial types alternate, the block will continue to have both tasks throughout the experiment (see Dreisbach, Haider, & Kluwe, 2002 for expectation in a task switching context; see Kareev, 1995 for predicting switches between congruent and incongruent trials in a Stroop task).

In typical task switching paradigms, a task cue indicates which task has to be performed on a particular trial. Knowing what task will be relevant is thought to reduce the number of stimulus-response mapping rules that are valid for that particular trial. For example if there are two tasks (Task A and B) with a total of four mappings and a cue indicates Task A is to be performed, the cue shows the participants that only two of the four possible mappings will be relevant for the upcoming trial. While this has been thought to reduce local costs, research with task expectancies has shown that this is not the case. When participants are given a fixed pattern of expected switch and nonswitch trials, the presence of the cue does not impact local switch costs (Dreisbach et al., 2002; Gotler, Meiran, & Tzelgov, 2003). Lien, Ruthruff, and Kuhns (2008) examined the impact of external cues on internal control in younger and older adults using a repeated/predictable task sequence (e.g. AABB...) without cues (Experiment 1), repeated/predictable sequence with cues (Experiment 2), and single task and mixed task blocks with cues (Experiment 3). In the single task blocks, no cue was present while the mixed tasks blocks contained a cue to indicate the task to be performed on the upcoming trial. Older adults were significantly slower than younger adults in all three experiments. The results of Experiments 1 and 2 showed that the presence or absence of cues yielded similar RTs for older adults meaning that they experienced local switch costs even when a cue was present.

Predictability of the task sequence did not help task switching performance for older adults. In Experiment 3, older adults showed large mixing costs (i.e., global switch costs) than younger adults. While these experiments highlight the interpretation that the cue did not play a role in reducing local switch costs, the results contradict the majority of the literature in that local switch costs were found in aging. One explanation for the presence of significant local switch costs is that in all three experiments, there were six stimulus-response mappings that were mapped to three fingers of the right hand (index, middle and ring fingers). The use of more than two stimulus-response mappings and the use of one hand to map multiple tasks may have resulted in larger local switch costs because the tasks may have been too difficult for older adults. More importantly, the baseline RTs for older adults in single task conditions were much slower than typical multi-hand response paradigms.

The focus in task expectancies research is in examining the impact of task cues on a trial-to-trial basis. The results of these studies do not converge with some showing local switch costs that are affected by task cues (Lien et al., 2008) but most showing that the cue plays no role in local switch costs (Dreisbach et al., 2002). There is overall slowing in aging during task switching performance as evidenced by consistent global switch costs for older adults yet studies do not examine the impact of task predictability over an entire experiment. Another issue in the task expectancy literature is that most of the research appears to focus on task preparation effects. Task preparation is measured by altering the presentation time between the cue and stimulus on a given trial. Koch (2001) demonstrated that a greater cue-stimulus interval led to faster RTs on both switch and nonswitch trials. As discussed earlier, local switch costs are generally not affected by aging (Wasylyshyn et al., 2011) or by the presence or absence of cues (Dreisbach et al., 2002) yet expectancy research is still focused on a local trial-to-trial level.

With regards to bilingualism, local trial-to-trial changes that occur in a task switching paradigm are very different than speaking two languages and managing them in different contexts. Being bilingual does not mean that languages are switched word-to-word. The ACH suggests that in bilingual language control, salient cue detection is a control process that is required to maintain language usage goals.

When task cues create foreknowledge and participants predict that two tasks will continue to be presented in a sequence or randomly, this expectation can continue across blocks of trials. That is, if a series of blocks start off as single-task and switches to task-switch or vice versa, what impact does the presence of cues have on performance? The answer is not clear. The literature sometimes refers to this phenomenon as the carryover effect. It is thought that the foreknowledge and prediction that two or more tasks will alternate results in the activation of two goals and when one goal suddenly becomes irrelevant, it takes time for participants to speed up and perform at the same pace they did when the task was explicitly presented as a single task. To date, only one experimental design has examined task expectancy on a global level and revealed that older adults take significantly longer than younger adults to disengage from the irrelevant task (Mayr & Liebscher, 2001) suggesting that when sustaining two goals is ineffective, reactive control is needed to modify the task goals, and failure to do so results in poor performance.

Is there flexibility in proactive control? What happens when the task demands change during the experiment? Will the task goals that were set proactively remain fixed or will they be adapted to the task demands? Can older adults use task cues to improve task performance resulting in faster RTs? Or do task cues reduce the need to maintain task goals resulting in slower RTs? According to the ACH, bilingual language production requires the maintenance of goals and external cues influence these goals. In other words there is an interaction between internal (or proactive) control and external (or reactive) control. Chapter 2 of this dissertation will examine the impact of task expectancies on task goals using a modified version of the fadeout paradigm used by Mayr and Liebscher (2001) to investigate the interaction between proactive and reactive control in younger and older adults.

**Sustainability of proactive control**

The review thus far has focused on tasks that contain bivalent stimuli and include an inherent conflict on the stimulus level that needs to be resolved in order to make a response— to ignore a prepotent tendency to respond to location (e.g., Simon task), to ignore reading a word which is considered an automatic process (e.g., Stroop task), or to focus on one of two relevant features based on a task cue (e.g., task switching). It is evident from the review that when there is conflict in the stimulus a bilingual advantage appears.

Speaking and managing two languages, and planning to use one or both languages are typical demands in a bilingual speaker's everyday environment. As discussed earlier, the ACH describes successful bilingual language production using several cognitive processes. It is suggested that goal maintenance and the overall coordination of several processes is what leads to a bilingual advantage in non-linguistic tasks. If bilinguals manage dual language input successfully, does this ability enhance the management of multiple task goals that do not contain conflict? In the DMC framework (Braver, 2012), proactive control is the continuous maintenance of goals and this sustained maintenance is ideal for task performance; however, the DMC framework suggests that sustained proactive control is difficult to maintain over long periods of time, especially for older adults. The framework also suggests that sustaining proactive control will result in the reduced capacity to maintain other goals. The DMC framework does not provide any examples of how proactive control may be taxing. If younger and older bilinguals can manage task goals proactively as evidenced by reduced Simon and Stroop effects, will they be able to sustain this control over a long period of time when there is no conflicting information? Does improved performance on conflict tasks by younger and older bilinguals come from a general ability to sustain multiple task goals?

One way to conceptualize this is in terms of mental sets. A mental set is defined as a collection of processes that converge to deal with a specific task (Allport, 1989; Monsell, 1996; Pashler, 2000). This convergence arises from setting task goals and maintaining these goals (De Jong et al., 1999; Meiran, 2010). This explanation is similar to the convergence of processes proposed by the ACH for bilingual language production. De Jong (1995) proposed that goal maintenance should be measured using a dual task paradigm because this type of paradigm consists of two goals that have to be created and maintained, and two mental sets (convergence of processes) have to be recruited to make two specific responses. A dual task paradigm may be an appropriate measure for sustained proactive control because two goals each with multiple rules simultaneously compete for equal attention. The conflict is created not from the stimulus, but from the management of the goals themselves. This will be investigated in Chapter 3 using a dual task paradigm that forces younger and older adults to respond to two tasks that will be presented at the same time. Both responses will be required in order to progress in the task.

## The present dissertation

There is consensus in the literature that goal maintenance is required for the regulation of task-related goals and rules that guide behaviour and the failure to maintain these goals is evident in aging (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Paxton et al., 2008; Posner & Petersen, 1990; Rubinstein, Meyer, & Evans, 2001; Van Veen & Carter, 2006). Cues from the environment not only affect the task goals, but in the case of bilingualism, they can also modify language usage goals. Cues are thought to impact *task expectancy*, which refers to the level of foreknowledge of upcoming tasks (Ruthruff, Remington, & Johnston, 2001). For example, if tasks A and B are consistently presented as AABBAABB, an expectation is built that this pattern will continue throughout. If the pattern is changed, this violates the expectation in the sequence and typically results in a delay in mentally processing the stimuli to make the correct response.

The aims of this dissertation are to (1) examine the flexibility in proactive control through building task expectancies using a task switching paradigm, and (2) examine the overall efficiency in managing task goals over an extended period of time using a dual task paradigm. In Chapter 2, the results from a variation of the task switching paradigm known as the *fadeout task* (Mayr & Liebscher, 2001) will be presented. The fadeout task was devised to measure task switching performance across a block of trials instead of focusing on local trial-to-trial changes. Task expectancy has only been measured on a trial-to-trial basis and there is reason to believe that examining task switching performance as a whole will yield results that can be interpreted as evidence for how reactive control impacts task goals. Analyses were conducted to examine the impact of task cues on task performance to determine if there were any differences between how younger and adults used task cues and if there were differences between monolinguals and bilinguals. In Chapter 3, results from a dual task paradigm will be presented in which participants were presented with two univalent stimuli in two modalities at the same time. Analyses focused on how younger and older adults responded to two streams of information simultaneously by measuring the time taken to make the two responses, and whether there were language group differences in making these responses.

## Chapter 2. The influence of reactive control on proactive goal maintenance: Evidence from task expectancies

### Introduction

Lifelong bilinguals have the experience switching back and forth between their two languages, a situation that requires flexibility to adapt and modify language usage goals to maintain the flow of a conversation. As discussed in Chapter 1, the ACH (Green & Abutalebi, 2013) identifies eight control processes that adapt and interact with each other when frequent language switching is necessary. In the ACH, goal maintenance is a proactive process and cue detection is a reactive process that can modify or alter goals. The study presented in this chapter will investigate how task cues influence proactive control both positively (adapting goals to improve performance) and negatively (succumbing to task expectancies) during task switching. The aim is to further our understanding of the extent to which task goals are adapted to meet task demands and determine if bilingualism boosts this ability.

The first section of this chapter will discuss two influential task switching paradigms in the literature and the two main switch costs that are associated with these paradigms. The second section will discuss task expectancies and how the literature is focused on one type of cost and how this focus can be problematic for understanding the interaction between proactive and reactive control. The study presented in this chapter will attempt to resolve the issues in the literature by changing the focus of analysis from the trial-to-trial changes that occur during a task switching paradigm to examining performance across the entire paradigm.

### Task switching designs and costs

There are two predominant task switching designs: (1) alternating runs and (2) explicit cuing. In alternating runs, two tasks are presented in a predictable sequence (e.g., AABBAABB...) whereas in explicit cuing, a cue is presented prior to or at the same time as each stimulus indicating which task is required for the current trial, making the sequence of tasks random. Thus, in alternating runs, nonswitch and switch trials are consecutive whereas in explicit cuing, they are unpredictable. In typical task switching studies, a single task block is also presented to measure baseline task performance. As discussed in Chapter 1, there are two types of switch costs that are measured in task switching — local and global. Local switch costs are calculated as the RT difference between switch and nonswitch trials in a mixed block, and global switch costs are the RT difference between nonswitch trials in the mixed block and single task block. The objective of the majority of research is to determine how each task is updated and deleted on a trial-to-trial basis (local switch costs). Subsequent versions of the task switching paradigm have resulted in a variety of manipulations on the type of stimuli used, the responses required, the interval between responses, the interval between the cues and the stimuli with the goal of understanding how modifying task components capture differences in local switch costs (Rogers & Monsell, 1995; Rubinstein et al., 2001; Sohn & Anderson, 2001).

Rubin and Meiran (2005) pointed out that local and global switch costs are not given equal consideration in the task switching literature. In addition, the use of univalent or bivalent stimuli alters the task demands. The authors suggest that global switch costs (or mixing costs) capture the ability of top-down control to moderate and sustain task goals while local switch costs (or switching costs) are related to bottom-up rule activation. They conducted two experiments with young adults using univalent and bivalent stimuli to determine differences (if any) between local and global switch costs. In the first experiment, participants were presented with single and mixed blocks using three types of stimuli— (1) univalent, (2) univalent but with an irrelevant feature, and (3) bivalent. Task cues were only used for bivalent blocks to indicate which feature of the stimulus was relevant for each trial. The results showed that there were no effects of stimulus type on local switch costs indicating that on a trial-to-trial level, stimulus attributes did not change task performance. For global switch costs, the authors found that using univalent stimuli did not result in global switch costs while bivalent stimuli resulted in significant global switch costs. The authors suggest that the use of bivalent stimuli resulted in the activation of both task goals making it more difficult to exert top-down control to overcome bottom-up task processes. These results highlight processing differences between univalent and bivalent stimuli, and indicate that global switch costs tap into a top-down ability to maintain task goals when the stimuli are bivalent. The difference between univalent and bivalent stimuli and their impact on local and global switch costs is consistently neglected in the task switching literature because task processing demands continue to be measured mainly using local switch costs. In the second experiment, Rubin and Meiran (2005) increased the task difficulty by adding another task to the mixed blocks requiring participants to switch between two bivalent tasks and one univalent task. The univalent task contained stimuli with an irrelevant feature. Their aim was to determine if increasing the number of stimulus-response mappings contributed to local and global switch costs. The results of Experiment 2 indicated that increasing the number of tasks did not increase global switch costs. The results of these two experiments show that global switch costs appear when there is conflict at the stimulus level (i.e., bivalent stimuli) and that increasing task difficulty by adding more tasks does not directly increase global switch costs.

As discussed in Chapter 1, the majority of studies with adults reveal that local switch costs are generally spared by aging while global switch costs show consistent age-related deficits (Kray et al., 2004; Mayr, 2001; Reimers & Maylor, 2005). Wasylyshn et al. (2011) conducted a meta-analysis of studies that examined the effects of aging on task switching. Their sample included 26 published articles and the data were sorted by local versus global switch costs. There were two notable studies that found greater local switch costs in older adults than younger adults (e.g., Kray et al., 2002; Mayr, & Kliegl, 2003), but these studies were unusually complex and did not employ the standard stimuli used by most task switching paradigms. For example, Kray et al. (2002) used four different discrimination tasks as their baseline. In the first task, images of animals and objects were presented and participants categorized the image as being an animal or not. The second task required categorizing words as having one or two syllables, the third required participants to identify if a string of letters was an odd or even length (i.e., ignore the letters and count the number of letters) and in the fourth task, participants had to identify if a word contained the letter "H" or not. The tasks themselves were difficult resulting in significant RT differences between the single task blocks for all four tasks. In the switching blocks, participants switched between two or more of the tasks. The results showed that some of the task stimuli yielded local switch costs while others did not. The local switch costs were directly related to nature of the stimuli used in the switching blocks. Mayr and Kliegl (2003) found significant differences in local switch cost between younger and older adults in only one of three experiments. The experiment that found age-related differences consisted of stimuli with three dimensions- shape, colour and size. Participants had to remember three stimulus-response mappings that corresponded to three features of the stimuli. It appears that when the type of task changes and the number of relevant features embedded within a stimulus increases, local switch costs are greater in aging.

Local and global switch costs have also been shown to activate different regions of the brain (Braver, Reynolds, & Donaldson, 2003). Global switch costs are thought to be involved in maintaining two task sets and managing attention across the entire task while local switch costs are thought to measure transient changes. Based on the existing literature, it seems aging does not always reduce the ability to activate and deactivate task rules on a trial-to-trial level, but rather it impacts the general ability to manage multiple task goals as evidenced by greater global switch costs for older adults compared to younger adults.

In the bilingualism literature, task switching designs have been used mostly for language switching tasks. The few studies that have examined the performance of monolinguals and bilinguals in non-language switching tasks have found conflicting results, with some showing reduced local switch costs in bilinguals than comparable monolinguals (Garbin et al., 2011; Prior & MacWhinney, 2010; Prior & Gollan, 2011), and others showing reduced global switch costs for bilinguals but comparable local switch costs between monolinguals and bilinguals (Barac & Bialystok, 2012; Gold et al., 2013; Wiseheart et al., 2014). The studies varied in design making it difficult to determine why only certain costs were found. Furthermore, only one study examined the impact of aging and bilingualism in task switching and found that older bilinguals experienced smaller global switch costs than older monolinguals (Gold et al., 2013). The goal of the study presented in this chapter is to understand how task goals are managed and adapted to demonstrate flexibility in proactive control. The impact of bilingualism is believed to be in the management and maintenance of task goals and cues can modify or maintain these goals in order to improve performance.

### Overview for study

In an explicit cuing paradigm, cues indicate which task is to be performed on each trial, leading to the expectation that both task cues will appear, resulting in the continued activation of both task goals (ErEl & Meiran, 2011). The term *task expectancies* refers to the foreknowledge of upcoming trials during a task switching paradigm. Models of task expectancy focus on trial-to-trial task expectations and find that there are no significant differences between trials that are nonswitch and trials that are expected in a sequence even if they are switch trials (Ruthruff et al., 2001; Sohn & Anderson, 2001). For example, in a run that contains Tasks A and B and the trials are presented as AABBAABB and so forth, there are no significant differences between the AB and BA switch trials and the AA and BB nonswitch trials. Alternating runs are more likely to create task expectancy because of the predictability of the sequence whereas explicit cuing paradigms require constant monitoring on a trial-to-trial level to determine the response required. Furthermore, Altmann (2007) argued that there is a confound in the task switching literature because predictable explicit cuing designs typically use univalent stimuli making them the same as alternating runs that generally result in local switch costs only. Task expectancy research has not been examined in detail in random explicit cued paradigms. As discussed in Chapter 1, most of the expectancy research is based on task preparation and carryover effects and both concepts are defined in the same way—using the term "expectancies". Task preparation is measured by modifying the cue-stimulus interval and examining task expectancies on a trial-to-trial level. Carryover effects have not been examined in detail with the exception of one study by Mayr & Liebscher (2001) where RT changes were examined over a large block of trials.

The purpose of the present study is to determine how reactive processes modify task goals in order to maintain successful task performance by examining performing across an entire block of trials. The main experimental task used in the current study is a modification of the fadeout paradigm (Mayr & Liebscher, 2001). In this task, a standard task switching paradigm is presented and at a certain point, the task changes to a single task but without any explicit instructions to the participants. Cues indicate to the participant which task they need to respond to. When the task begins, the cues alternate randomly to specify the upcoming task. When the task changes to a single task, one of the cues is no longer activated. The purpose of starting with task switching is to build up task expectancies so that participants expect both tasks to continuously appear. It is predicted that during this first phase, following existing research, younger adults will experience smaller global switch costs than older adults, and bilinguals will experience smaller costs than monolinguals. When the task switches to a single task, qualitative changes in RT will be examined to determine if changes in task demands result in changes in task performance between language groups and if these changes are similar or not in aging. It is believed that reactive control does not necessarily lead to a failure in proactive control in aging, a commonly held view in the task switching literature (see "stability-flexibility dilemma" in Goschke, 2000). Instead, reactive control is viewed as a positive process to improve proactive control and failure to adapt task goals is what leads to a negative outcome.

## Method

### Participants

One hundred participants belonging to one of two age groups, 30 to 40 years and 60 to 80 years, were recruited in Toronto, Canada and in Chennai, India. A Language and Social Background Questionnaire (LSBQ; see below for details) was given to all participants to determine the details of their language experience. The participants were divided into four groups based on age and language background. The younger adult groups consisted of 25 monolinguals (mean age = 33.7 years, SD = 3.0) and 25 bilinguals (mean age = 34.1 years, SD = 3.5); the older adult groups consisted of 25 monolinguals (mean age = 70.1 years, SD = 7.0) and 25 bilinguals (mean age = 70.3 years, SD = 5.9). For the younger adult bilingual group, 13 participants were tested in India and 12 in Canada. The older bilingual adults were comprised of

8 participants who were tested in India and 17 in Canada. The bilingual participants all spoke English plus one of the following languages -- Arabic, Cantonese, Croatian, Czech, Danish, Dutch, Finnish, Flemish, French, German, Gujarati, Hebrew, Hindi, Kannada, Luhya, Malayalam, Mandarin, Marathi, Ndebele, Norwegian, Portuguese, Russian, Sindhi, Somali, Spanish, Swahili, Tamil, Telugu, Urdu or Yoruba. Within the younger bilinguals, 18 participants were exposed to both languages from birth, 4 participants learned English starting at the age of 4, and 3 participants learned the non-English language starting at the age of 4. In the older bilingual group, 20 participants learned English as a second language (mean age of learning English = 6.7 years, SD = 2.4) and 5 participants learned the non-English language as a second language (mean age of learning non-English language = 7.2, SD = 1.3). In addition to age, the participants were closely matched on the number of years of education (see Table 2). This was done to ensure that the groups of participants were homogeneous in terms of background.

**Materials and Procedure**

Participants were tested in India or in Canada by the same experimenter in quiet places in their home or the experimenter's home, conference room in their place of work, or in a testing room at York University. Tests were administered in a fixed order to all participants. The session began with obtaining informed consent (see Appendix A), the LSBQ (see Appendix B) followed by a set of background measures to assess general intelligence, receptive vocabulary, visuospatial memory and basic processing speed (box-completion and digit copying). Finally, the participants were presented with a choice RT task and the fadeout paradigm (described below). Seventy five participants from this study also participated in the study that will be presented in Chapter 3. For these individuals, the experimental task from Chapter 3 was presented prior to the choice RT and fadeout paradigm.

*Language and Social Background Questionnaire (LSBQ)*. The LSBQ was filled out by the experimenter while interviewing each participant. For bilinguals, the purpose was to determine their level of fluency in both languages and the nature and extent of their use of the two languages; for monolinguals, the purpose was to ensure they had no significant exposure to a language other than English. A language usage chart was also included in the questionnaire requiring participants to determine the percentage of each language they used in various environments (e.g., at home and work). The questionnaire also included questions about age of language acquisition, place of acquisition, and parents' native languages. There was also a chart that each participant filled out regarding proficiency of each language compared to a native speaker of the same language in the form of a percentage with 100% being "native-like" and 0% being "no knowledge". Monolinguals who had some second language exposure were also required to fill out the chart in order to determine if the other language was still relevant in their daily lives.

*Peabody-Picture Vocabulary Test III (PPVT-III; Dunn & Dunn, 1997)*. The PPVT-III is a test of receptive vocabulary that is standardized to include norms for adults. The test consists of plates that contain four different pictures. The experimenter says a word and the participant must select one of the four pictures that best depicts that word. The starting item is selected on the basis of the participant's chronological age. The plates are divided into sets of 12, and the test ends when the participant makes 8 or more errors in one set. If the participant makes these errors on the first set, then the experimenter must test from the previous set until the basal rule of 0 or 1 error is made. The score on the PPVT-III is determined by deducting the number of errors made from the last item in the last administered set. These raw scores were then converted into standardized scores using the PPVT-III age correction manual.

*Cattell Culture Fair Test (Cattell & Cattell, 1960).* The Cattell is a nonverbal standardized test of general intelligence. It consists of four timed tests that begin with examples for each test. Participants were given a fixed amount of time to complete each test as prescribed in the testing manual. The raw scores were converted into IQ scores using a set of norms tables that are based on age and age corrections were made using the formula in the manual.

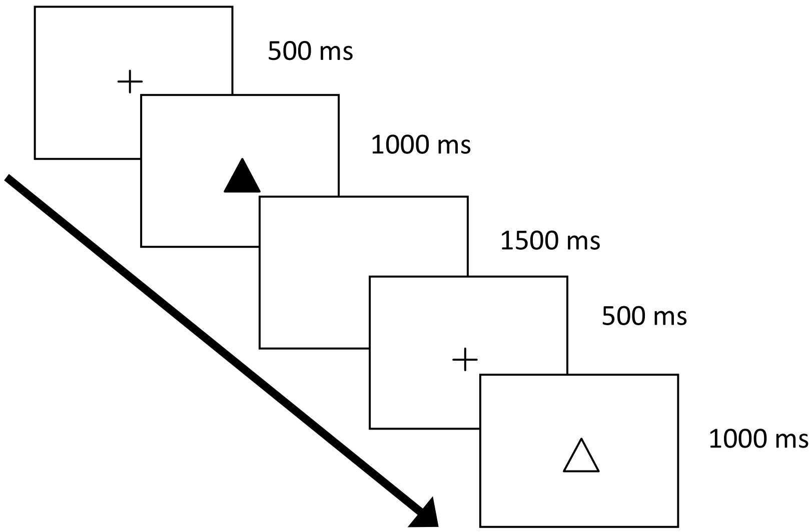
*Spatial span subtest from the Wechsler Memory Scale- Third Edition, WMS-III* (also known as *Corsi Blocks*; Wechsler, 1997). This task was designed as a visuospatial counterpart to verbal memory span tasks. The task consists of a white board with a series of 10 blue blocks that were secured to the board in a random pattern. One side of the blocks is numbered and is only visible to the experimenter. The task requires the experimenter to tap a sequence of blocks (one block per second) after which participants must repeat the sequence. There are two conditions in this task. In the forward Corsi, participants must tap the sequence in the same order, and in the backward Corsi, they are required to tap the sequence in the reverse order. Participants were given sequences that ranged in length from 2 to 10 blocks with two trials at each length. Each condition was presented separately in a counterbalanced order, interspersed with the other background measures. Participants were awarded one point for every correctly reproduced sequence of blocks.

*Box completion (Salthouse, 1996).* This test measures basic processing speed and consists of 35 incomplete line drawings of boxes. Participants were given three examples at the beginning. Once they were ready, participants were told that they had to add the fourth line to all 35 boxes as quickly as possible. The score was the time needed to complete the task in seconds.

*Digit copying (Salthouse, 1993).* This task consists of 80 numbers with blank boxes beneath each number in which participants have to copy the number above as fast as they can.

The time to complete the task in seconds was measured. Like the box completion test, this test was used concurrently as a measure of basic processing speed.

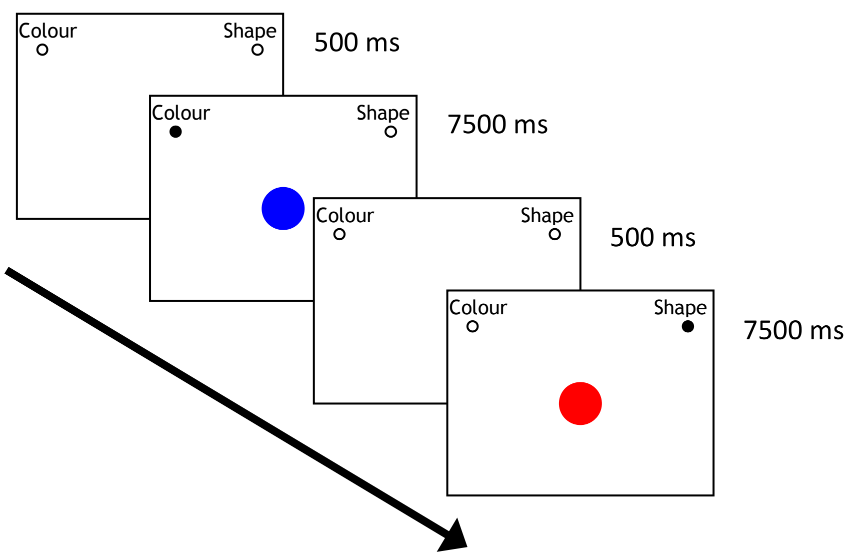
Figure 1. Schematic representation of the choice RT task.




*Basic choice RT task.* This task was programmed using SuperLab version 4.0 (Cedrus Corporation) and presented on an HP Pavillion laptop. The task consisted of 2 blocks of 24 trials each that were presented before and after the main task resulting in a total of 48 trials per participant. A schematic is presented in Figure 1. Each trial began with a fixation "+" in the centre of the screen that remained visible for 500 ms. Following this, a black or white triangle appeared in the same location that the fixation had appeared. The stimulus remained on the screen for 1000 ms and the next trial began only after a response was selected by the participant or after a 2500 ms timeout (inclusive of the 1000 ms stimulus display). Participants were instructed to press the left key marked "X" on the keyboard when they saw a black triangle and the right key marked "O" when they saw a white triangle. The stimulus-response mappings were counterbalanced. The RT clock began when the stimulus appeared on the screen. Following a selection, the fixation "+" appeared and the trials continued. All participants were given 4 practice trials (2 black and 2 white trials) that were presented in a random sequence to familiarize them with the rules of the task. Following a correct response, the remaining trials continued, and an incorrect response produced the same trial again. If the participant made two or more errors, the practice trials were automatically repeated. The purpose of using this task was to determine RTs to univalent stimuli with no cues to ensure there were no processing speed differences between the language groups. It was predicted that there would only be age group differences on this task.

*Fadeout paradigm*. This task is a modification of the paradigm designed by Mayr & Liebscher (2001). The task was also programmed using SuperLab 4.0 and presented on the same HP Pavillion laptop. Participants were presented with stimuli that contained two dimensions- colour (blue and red) and shape (square and circle). A schematic of the fadeout paradigm is presented in Figure 2.

Figure 2. Schematic representation of the fadeout paradigm.




Prior to the presentation of the stimulus, a screen was presented with the cue words “Colour” and “Shape” on the top left and right corners of the screen with white circles under each word (henceforth referred to as a blank cue). When the stimulus appeared, one of the two blank cues was filled in with black to indicate the dimension that was relevant for the current trial. This indicated to the participant the task they had to perform. In the colour task, participants were instructed to press the left key marked “X” for blue and the right key marked “O” for red. In the shape task, participants pressed the same left key marked “X” for circle and the same right key marked “O” for square. The stimulus-response mappings were counterbalanced. The blank cue was presented for 500 ms followed by the cue and stimulus. The stimulus remained on the screen for 7500 ms or until a response was made.

The critical component of the fadeout paradigm began on the 49$^{th}$ trial. Trials 1 to 48 required participants to switch randomly between the two tasks (colour and shape). This part of the paradigm is henceforth referred to as the *task switching phase*. On the 49$^{th}$ trial, one of the dimensions was dropped and the remaining 80 trials in the block required participants to focus on one dimension only (e.g., shape was dropped so colour became the only task). This portion of the paradigm is henceforth the *fadeout phase*. All participants received 8 practice trials (4 colour trials followed by 4 shape trials). Following a correct response, the remaining trials continued, and an incorrect response produced the same trial again. Practice was repeated if the participant made 3 or more errors. Prior to commencing the fadeout paradigm, participants were presented with 24 trials each of the colour and shape task separately (henceforth referred to as *single task block*). The software program recorded the RT and accuracy of each trial.

## Results

### Background measures

The mean scores for the background measures are reported in Table 2. Each of the background measures was analyzed using two-way ANOVAs for language group (monolingual and bilingual) and age group (younger and older). For the PPVT, there were no effects of language group, *F* < 1, age group, *F* (1, 99) = 3.17, *p* = .08, or their interaction, *F* < 1. Cattell scores revealed no effects of language group, age group, or their interaction, all *Fs* < 1.

Table 2. Mean scores (and standard deviations) on background measures by language group and age group.

| **Background measures** | **Monolingual Younger** (n = 25) | **Bilingual Younger** (n = 25) | **Monolingual Older** (n = 25) | **Bilingual Older** (n = 25) |
|---|---|---|---|---|
| Age (yrs) | 33.7 (3.0) | 34.1 (3.5) | 70.1 (7.0) | 70.3 (5.9) |
| Education (yrs) | 17 (2.2) | 17 (2.2) | 17 (2.3) | 17 (2.8) |
| PPVT standard | 112.0 (6.9) | 112.1 (5.7) | 110.5 (8.1) | 108.0 (8.5) |
| Cattell IQ score | 120.0 (13.2) | 118.4 (17.9) | 118.2 (13.6) | 117.8 (16.6) |
| Corsi forward | 9.7 (1.2) | 9.4 (1.3) | 6.9 (1.4) | 7.1 (2.0) |
| Corsi backward | 9.3 (1.4) | 8.9 (1.9) | 6.5 (1.1) | 6.9 (1.6) |
| Box completion [a] | 20.1 (4.1) | 19.9 (3.7) | 40.6 (10.5) | 35.8 (13.3) |
| Digit copying [a] | 36.0 (3.6) | 35.1 (3.4) | 49.1 (9.1) | 45.7 (7.9) |
| Choice RT | 487 (44) | 494 (56) | 771 (131) | 756 (100) |

[a] Values shown are the mean times to complete the tasks in seconds.

For Corsi forward, there was a significant effect of age group only, *F* (1, 99) = 71.45, *p* < .0001, $\eta_p^2$ = .42, in which older adults (*M* = 7, *SD* = 1.7) scored lower than younger adults (*M* = 9.6, *SD* = 1.3). There was no effect of language group, *F* < 1, and no interaction, *F* < 1. This pattern was replicated for Corsi backward with a significant effect of age group, *F* (1, 99) = 66.25, *p* < .0001, $\eta_p^2$ = .40, showing better performance by younger adults (*M* = 9.1, *SD* = 1.7) than older adults (*M* = 6.7, *SD* = 1.4). There was no effect of language group, *F* < 1, and no interaction, *F* (1, 99) = 1.63, *p* = .20. Younger adults (*M* = 20, *SD* = 3.9) were faster than older adults (*M* = 38.2, *SD* = 11.9) on the box completion task, $F$ (1, 99) = 102.19, $p <. 0001$, $\eta_p^2$ = .51. There was no effect of language group and no interaction, *F*s < 1. The digit copying task also revealed a significant effect of age group with older adults being overall slower (*M* = 47.4, *SD* = 8.5) than younger adults (*M* = 35.6, *SD* = 3.5), $F$ (1, 99) = 87.30, $p < .0001$, $\eta_p^2 = .47$. There was no effect of language group and no interaction, *F*s < 1. The effect of age group in Corsi, box completion and digit copying tasks indicates that older adults found these tasks harder than younger adults.

Accuracy for the basic choice RT task ranged from 99.7% to 100% therefore no analysis was conducted due to the high accuracy rates and lack of variance. The basic choice RT data were entered into a two-way ANOVA with language group and age group as factors that revealed only a main effect of age group, $F$ (1, 99) = 92.16, $p < .0001$, $\eta_p^2 = .48$, showing that older adults (*M* = 764, *SD* = 115) were slower than younger adults (*M* = 491, *SD* = 50). There was no effect of language group and no interactions, *F*s < 1.

**Fadeout paradigm**

The first set of analyses examined the single task blocks and the fadeout paradigm as a whole (see Table 3). Accuracy for the single task ranged from 99.6% to 100% therefore the data were not analyzed due to the lack of variance. The single task RT data were subjected to a two-way ANOVA with language group and age group as factors yielding only a main effect of age group, $F$ (1, 99) = 121.26, $p < .0001$, $\eta_p^2 = .55$, and no effect of language group or their interaction, *F*s < 1, showing that younger adults (*M* = 824, *SD* = 60) were faster on the single task than older adults (*M* = 1051, *SD* = 81).

Data from the fadeout paradigm were analyzed using two methods. For the first method, the overall performance in the paradigm was examined comparing the task switching phase (trials 1 to 48) to the fadeout phase (trials 49 to 128). The first 8 trials of the task switching phase were eliminated from all analysis because at the onset of the task, participants were extremely slow with RTs maxing out to 7500 ms for older adults and for some younger adults with no responses.

Table 3. Mean RTs in ms (and standard deviations) for the single task, task switch and fadeout phases by language group and age group.

| **Task or phase** | **Monolingual Younger** | **Bilingual Younger** | **Monolingual Older** | **Bilingual Older** |
|---|---|---|---|---|
| Single task | 802 (64) | 846 (55) | 1076 (88) | 1025 (73) |
| Task switching | 1929 (463) | 1254 (539) | 2838 (879) | 2209 (668) |
| Fadeout | 1102 (184) | 733 (155) | 1744 (378) | 1105 (312) |

*Phase comparison*. The mean RT of the task switching phase and the fadeout phase were analyzed to determine any overall differences in performance between the two phases. The data were entered into a three-way ANOVA with phase (task switching versus fadeout), language group and age group as factors. The results showed that bilinguals ($M$ = 1325, $SD$ = 476) were faster than monolinguals ($M$ = 1903, $SD$ = 419), $F$ (1, 96) = 5.90, $p$ = .017, $\eta_p^2$ = .06, and younger adults ($M$ = 1255, $SD$ = 335) were faster than older adults ($M$ = 1999, $SD$ = 559), $F$ (1, 96) = 60.91, $p$ < .0001, $\eta_p^2$ = .30. There was a main effect of phase, $F$ (1, 96) = 436.05, $p$ < .0001, $\eta_p^2$ = .82, indicating that the fadeout phase ($M$ = 1171, $SD$ = 257) was faster than the task switching phase ($M$ = 2058, $SD$ = 637). The two-way interaction between language group and age group was not significant, $F$ < 1. The two-way interaction between phase and language group was not significant, $F$ (1, 96) = 1.51, $p$ = .22. The two-way interaction between phase and age group was significant, $F$ (1, 96) = 15.4, $p$ = .0002, $\eta_p^2$ = 14, indicating that the magnitude of the difference between the fadeout phase and the task switching phase was greater for older adults (1094 ms for monolinguals and 1104 ms for bilinguals) than younger adults (827 ms for monolinguals and 521 ms for bilinguals). The three-way interaction between phase, language group, and age group was not significant $F < 1$.

Table 4. Mean RTs in ms (and standard deviations) for local and global switch costs by language group and age group.

| **Switch cost** | **Monolingual Younger** | **Bilingual Younger** | **Monolingual Older** | **Bilingual Older** |
|---|---|---|---|---|
| Local | 214 (32) | 200 (47) | 221 (54) | 246 (49) |
| Global | 733 (116) | 308 (90) | 1761 (165) | 855 (115) |

*Local and global switch costs*. Local switch costs were calculated as the RT difference between switch and nonswitch trials in the task switching phase of the fadeout paradigm. Global switch costs were calculated as the mean RT difference between nonswitch trials in the task switching phase and the single task. It was predicted that there would be no significant differences in local switch costs between monolinguals and bilinguals, nor would there be any age-related differences in local switch costs. For global switch costs, it was predicted that bilinguals would experience smaller global switch costs than monolinguals, and older adults would show greater costs than younger adults. These data are reported in Table 4. A two-way ANOVA conducted for local switch costs with language group and age group as factors revealed no main effects, and no interaction, all *F*s < 1. Global switch costs were also entered into a two-way ANOVA showing that monolinguals ($M = 1247$, $SD = 141$) experienced larger global switch costs than bilinguals ($M = 582$, $SD = 103$), $F\ (1, 99) = 130.82$, $p < .0001$, $\eta_p^2 = .57$, and older adults ($M = 1308$, $SD = 148$) had larger global switch costs than younger adults ($M = 521$, $SD = 103$), $F\ (1, 99) = 5.45$, $p < .0001$, $\eta_p^2 = .05$. The two-way interaction between language group and age group was also significant, $F\ (1, 99) = 48.44$, $p < .0001$, $\eta_p^2 = .33$, showing that aging was associated with a larger increase in global switch costs for monolinguals (1028 ms) than bilinguals (547 ms).

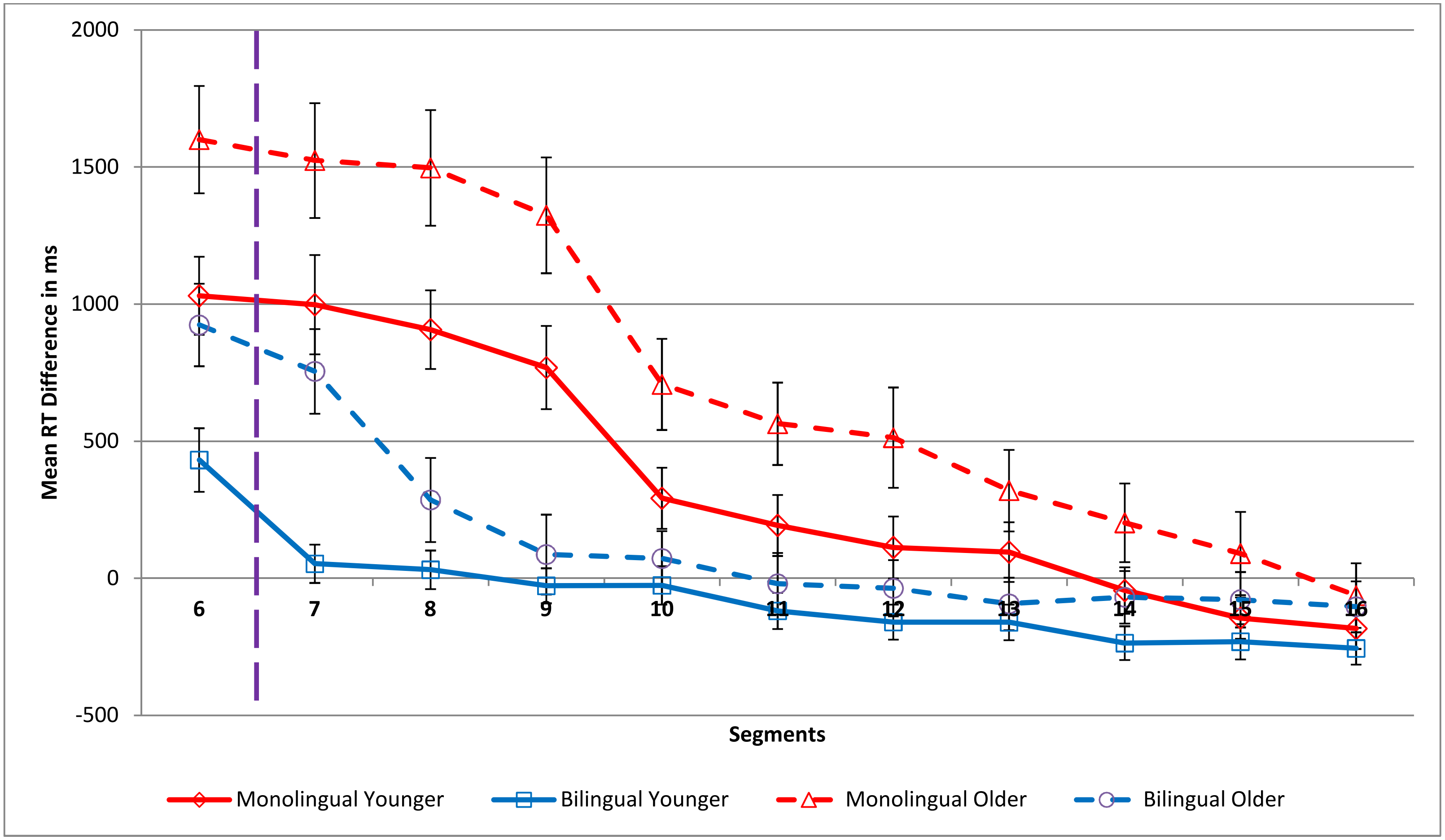
Table 5. Accuracy rates and standard deviations in the fadeout paradigm for each segment by language group and age group.

| **Segment** | **Monolingual Younger** | **Bilingual Younger** | **Monolingual Older** | **Bilingual Older** |
|---|---|---|---|---|
| 2 | .86 (.06) | .89 (.06) | .75 (.09) | .75 (.08) |
| 3 | .88 (.07) | 1.00 (0) | .91 (.07) | .91 (.08) |
| 4 | 1.00 (0) | 1.00 (0) | 1.00 (0) | 1.00 (0) |
| 5 | 1.00 (0) | 1.00 (0) | 1.00 (0) | 1.00 (0) |
| 6 | .91 (.05) | 1.00 (0) | 1.00 (0) | 1.00 (0) |
| 7 | 1.00 (0) | 1.00 (0) | .91 (.02) | 1.00 (0) |
| 8 to 16 | 1.00 (0) | 1.00 (0) | 1.00 (0) | 1.00 (0) |

The second method of analysis of the fadeout paradigm used the data treatment procedures of Mayr and Liebscher (2001) in order to determine the impact of eliminating responses to one dimension of the stimuli. Data from the paradigm were broken down into segments of 8 trials each to quantify changes in performance at the onset of the fadeout phase, creating 16 segments in total to analyze performance from beginning to end. The first segment was not included (first 8 trials).

*Accuracy across segments*. Accuracy rates for the entire paradigm were high, but the breakdown by segments revealed that accuracy rates started low but increased and remained high from the first to last segment (Table 5). Furthermore, with segments consisting of 8 trials, a single error reduces accuracy from 100% to 87.5%. The accuracy data were not analyzed due to the high rates and lack of variance.

Figure 3. Mean RT differences in ms (and standard errors) between segments 6 to 16 and single task blocks of the fadeout paradigm by language group and age group.



*Task expectancies*. Performance in the fadeout phase (segments 7 to 16) was examined to locate the segment in which participants returned to single task block performance. In both cases, participants were responding to one dimension only (colour or shape) with the difference being that in the fadeout phase, they completed 48 trials of task switching and were unaware of the shift to a single task on trial 49 that lasted for the remainder of the task. Individual ANOVAs were conducted for each group (younger monolinguals, younger bilinguals, older monolinguals and older bilinguals) comparing single task block performance (from Table 3) to each segment of the fadeout phase (individual RTs of segments 7 to 16) as well as the last segment of the task switching phase (segment 6) to determine when the fadeout phase RTs became statistically equivalent to single task RTs (i.e., the onset of nonsignificant statistical differences). Figure 3 shows the mean RT difference between segments 6 to 16 of the fadeout task and the single task block RTs. The purple dotted line indicates the change in the task from task switching to the fadeout phase. Segment 6 was included to ensure that reaching single task block RT was not a symptom of increased speed with practice and could be attributable to a reasonable extent to the shift from the task switching phase to the single task phase. Results revealed that RTs in segment 6 were significantly different than single task RTs: younger monolinguals, $F\ (1, 24) = 34.02$, $p < .0001$, $\eta_p^2 = .59$, younger bilinguals, $F\ (1, 24) = 8.19$, $p = .009$, $\eta_p^2 = .25$, older monolinguals, $F\ (1, 24) = 66.77$, $p < .0001$, $\eta_p^2 = .74$, and older bilinguals, $F\ (1, 24) = 30.11$, $p < .0001$, $\eta_p^2 = .56$. These results suggest that while there may be some increase in speed over the course of the fadeout paradigm, participants were still slower during the last segment of the task switching phase than single task block RT. The remaining ANOVAs showed that each group required a different amount of time to increase their speed to match their single task block RT. Only the nonsignificant differences are important. Younger bilinguals reached single task block

RT speed in segment 7, $F < 1$, followed by older bilinguals at segment 9, $F(1, 24) = 2.92$, $p = .10$, younger monolinguals at segment 13, $F < 1$, and older monolinguals at segment 15, $F < 1$. The qualitative pattern in the results suggest that younger and older bilinguals required fewer trials in the fadeout phase to increase their speed to perform similar to single task blocks than comparable monolinguals.

## Discussion

The fadeout paradigm was used to measure the ability of younger and older monolinguals and bilinguals to disengage from a task that was no longer cued. Prior to the experimental task, several background measures were administered. Following standard task switching procedure, two blocks of the single task were also presented. The basic choice RT task was added to determine if there were any differences in processing speed when there was no cue present. The purpose of using white and black triangles (univalent stimuli) was to establish performance when the response was to make a choice between one of two possible responses with no conflicting information. First, it was important to establish that on a basic level, psychomotor abilities were not affected by language experience using the box completion and digit copying tasks. These tasks only revealed age-related differences allaying any concerns that the language groups were different from each other on a basic motor level. The basic choice RT task also revealed that older adults were slower than younger adults and that bilingualism did not boost the ability to respond to univalent stimuli with no conflict. These results replicate previous research finding no language group differences in non-conflict tasks with only age-related decline on baseline RT tasks (Bialystok et al., 2004, 2006). The single task blocks consisted of the stimuli and parameters of the fadeout paradigm. The purpose was to measure performance when participants had to respond to only one feature of bivalent stimuli. Although participants were cued to respond to one dimension only and explicitly told that they would be doing one specific task, the mean RTs were slower than the basic choice RT task for all groups. This aligns with previous research that shows that it takes longer to respond to bivalent stimuli even if one feature is not relevant (Lien et al., 2008).

The fadeout paradigm was used to determine the effect of reactive control on proactive control by measuring the ability to disengage from an irrelevant cue in the fadeout phase. The task switching literature has considered reactive control to be a failure in proactive control, or as a response to difficult stimuli that conflict with task goals (Braver, 2012; Goschke, 2000). The results from the fadeout paradigm suggest that task goals can be adapted using task cues. This can be interpreted as being a positive interaction between proactive and reactive control being greater for bilinguals than monolinguals indicated by the fewer number of trials it took for both younger and older bilinguals to return to their single task block performance.

Research with task expectancies has solely focused on local trial-to-trial changes despite the majority of research indicating no local switch costs in aging (Lien et al., 2008; Ruthruff et al., 2001). Local and global switch costs analyses from the fadeout paradigm provide further evidence for a need to examine task goals across a paradigm in addition to between trials. The results from the study show that local switch costs were spared by aging, a finding that aligns with existing research (Kray et al., 2004; Mayr & Liebscher, 2001; Reimers & Maylor, 2005). Analysis of global switch costs revealed that bilinguals experienced smaller costs than monolinguals. These results support the findings of Gold et al. (2013) who found that older bilinguals experienced smaller global switch costs than older monolinguals, and Wiseheart et al. (2014) who found that younger bilinguals experienced smaller global switch costs than comparable monolinguals. The analysis also revealed a novel finding that the magnitude of the global switch cost was greater for monolinguals than bilinguals suggesting that the overall goal of performing two tasks was more manageable for bilinguals, and the ability to manage two cues is still intact in aging.

The fadeout paradigm is rarely used in the literature. In fact, only two notable studies have employed this task to demonstrate the inability of older adults to disengage from an irrelevant task set when the irrelevant cue remains on the screen (Mayr & Liebscher, 2001; Spieler, Mayr, & LaGrone, 2006). In both studies, younger adults disengaged from the irrelevant task at a faster rate than older adults. In a third and fourth condition of the fadeout paradigm, when the irrelevant task cue was crossed out or removed completely, older adults increased their speed and required fewer trials to return to single task block speed. Both studies are typically cited as evidence for older adults relying on external information to regulate task performance. Spieler et al. (2006) included eye tracking and found that during the fadeout phase, when both cues remained on the screen, younger adults fixated on task cues on 15% to 20% of the trials while older adults fixated on task cues on over 80% of the trials showing that even when one task cue became irrelevant, older adults still looked to the cue to make a task decision. The results from the study presented in this chapter suggest that perhaps older bilinguals did not continue to fixate on the irrelevant task cue as much as older monolinguals.

In summary, the present study set out to examine the impact of reactive control on proactive control using task cues to create task expectancies. The first hypothesis was that local switch costs would show no apparent bilingual advantage and not show any age-related differences while global switch costs would show a bilingual advantage indicating an overall flexibility in task switching compared to monolinguals. The second hypothesis was that task cues would facilitate changes in proactive control as evidence for flexibility in proactive control.

The results from the study suggest that reactive control aids proactive control in bilinguals resulting in greater flexibility in goal maintenance, and monolinguals are more likely to succumb to task expectancies. The ability to use task cues to regulate task performance continues well into aging as evidenced by older bilinguals returning to their single task block speed sooner than older monolinguals. The ACH (Green & Abutalebi, 2013) proposed the interaction between eight control processes with goal maintenance, a proactive process, being flexible based on other reactive processes including salient cue detection. In a bilingual speaker's environment, the constant activation of two languages and adapting language usage goals based on environmental cues appears to have extended to tasks outside the linguistic domain. The fadeout paradigm analysis suggests that task cues failed to buildup task expectancies (the predicted norm in the task switching literature) for bilinguals. Instead, the presence of cues enabled bilinguals to modify task goals rapidly resulting in improved performance than comparable monolinguals.

## Chapter 3. The sustainability of proactive control: Evidence from goal maintenance

### Introduction

In Chapter 2, the fadeout paradigm was used to determine if task cues could lead to the adaptation of task goals to improve performance. The literature consistently views proactive control as a rigid process and reactive control as a negative process that slows down response times (Braver, 2012; Goshcke, 2000). The results from the fadeout paradigm showed that younger and older bilinguals experienced smaller global switch costs and modified task goals sooner than monolinguals when the task demands changed. The improved performance of bilinguals was considered as evidence for greater efficiency in both proactive control and reactive control to manage task goals in a task switching context.

As discussed in Chapter 1, both the ACH (Green & Abutalebi, 2013) and the DMC frameworks (Braver, 2012) highlight the importance of goal maintenance, a process that is required for the regulation of task-related goals and rules that guide behaviour (Rubinstein et al., 2001). Goal maintenance is typically described in conjunction with tasks that measure inhibitory control and task switching. For example, the larger difference in performance between congruent and incongruent trials in a Stroop task in childhood and in older age is considered as evidence for a failure to attend to one goal in the presence of another (respond to colour and ignore word) equally (Braver & West, 2007). In the task switching context, task goals need to be set proactively and retrieved at the proper time in response to a cue (see intention-activation account in De Jong, 2000), and local switch costs reflect the difficulty of managing competition from a previous stimulus-response mapping, or from the competition between the two overlapping tasks (Rubinstein et al., 2001). These explanations of goal maintenance focus on trial-to-trial changes in tasks with conflicting stimuli. It has been established that local switch costs in task switching paradigms are not as sensitive to aging as global switch costs nor are they generally impacted by the experience of bilingualism. The significant differences in aging and the positive impact of bilingualism are mainly found in global switch costs, suggesting an overall increase in efficiency in proactive control. This chapter will investigate the strength of proactive control when the aim is to manage two task goals at the same time. The purpose is to further our understanding of whether proactive control, while being flexible, can be sustained.

The majority of studies that investigate proactive control use tasks that contain bivalent stimuli. The conflict in these tasks comes from the stimuli and not from the task goals. In the DMC framework (Braver, 2012), proactive control is ideal for task performance but at the same time, maintaining proactive control is difficult. According to the ACH (Green & Abutalebi, 2013), the management of language usage goals generalizes to bilinguals' improved performance in non-linguistic tasks. The focus of the ACH is mostly in the language switching context describing control processes that converge when a speaker of two languages has to maintain the use of one language and inhibit the other. The ACH includes descriptions of how and when control processes such as conflict monitoring, response inhibition and task engagement/disengagement are required in single language use, dual language use, and in dense code switching. The ACH proposes that in dense code switching, other than opportunistic planning, control processes are not engaged. There is no demand for them when both languages can be used.

In this chapter, a dual task paradigm will be used to examine how task goals are managed when two goals have to be retrieved and two responses have to be executed at the same time. The first section of this chapter will review the existing dual task literature in a goal maintenance context and provide some examples of dual task models. The second section will discuss design limitations of existing dual task paradigms in measuring goal maintenance and provide a possible solution with a paradigm specifically to be used to measure the ability to manage two task goals.

**The dual task paradigm**

The interest in examining the limits of human cognition by measuring performance in a dual task paradigm dates back to a study conducted by Telford (1931) who was the first to show that when participants are forced to respond to two tasks at the same time, there is a significant delay between making the two responses (for extensive reviews see Meyer & Kieras, 1997a, 1997b; Pashler, 1994). There is a cost associated with trying to simultaneously respond to two tasks and research has consistently shown an age-related increase in this cost (Hartley, 1992; Kramer & Larish, 1996). In the literature, a design factor that affects dual task costs is the interval between the presentations of the two stimuli. This interval is referred to as *stimulus onset asynchrony*. When the stimulus onset asynchrony is reduced, costs are greater (Pashler, & Johnston, 1998). Unlike task switching paradigms which are somewhat standardized, dual task paradigms significantly vary. Some paradigms use two RT tasks and measure accuracy and RT in both tasks while others use one RT task along with a secondary memory task. In these designs, there is a main task that is "filled in" with a distractor task. Full attention conditions enable participants to focus on the main task while divided attention conditions include a secondary task that interrupts the main task.

With varying designs for dual task paradigms, it is difficult to draw solid conclusions on simultaneous processing. The stimulus onset asynchrony between two tasks play a key role in determining performance because studies have consistently shown that longer stimulus onset asynchrony leads to improved performance (Meyer & Kieras, 1997a). However, with longer delays between the presentation of the two tasks, the design results in two tasks being presented one after the other instead of at the same time. This is more akin to an alternating runs task switching paradigm (see introduction to Chapter 2). If the goal is to measure if attention can be shared between two tasks, introducing an asynchrony between the stimuli alters the task demands. A typical task switching paradigms consist of two tasks that are presented in a random sequence with cues indicating which of the two tasks to perform on a given trial e.g., ABBAAABBABA and so on. In alternating runs, the two tasks are presented one after the other in sequence without task cues e.g., ABABABA and so on. In dual task paradigms with long stimulus onset asynchrony, the design is identical to an alternating runs task switching paradigm even though the time between the presentations of stimuli may be varied in the dual task paradigm. Any type of asynchrony results in participants performing one task after the other as opposed to the same time. This issue has not been clearly addressed in the literature.

Verhaeghen and Cerella (2002) conducted a meta-analysis on task switching and dual task paradigms examining the relationship between global switch costs and dual task costs. They found that these two constructs had almost identical trajectories in terms of age-related decline with costs increasing with age. In a follow-up meta analysis including only dual task studies, Verhaeghen, Steitz, Sliwinski and Cerella (2003) found significant age-related increase in dual task costs however, the 48 studies used in the meta-analysis varied in design. While all the studies had an RT measure in one task, the second task was almost always a memory task (e.g., cued recall, mental arithmetic, word span, digit span etc.), and in all cases, the importance of the second task varied. In some instances, the secondary task was presented at regular intervals while in other designs it was used as a filler task. The authors admitted to not including studies that had two RT tasks due to varying stimulus onset asynchronies making it difficult to determine the reason for the dual task cost (i.e., whether the costs were associated with task difficulty or the presence and absence of asynchrony).

Studies that have examined the effects of simultaneously responding to two tasks have shown that older adults experience greater dual task costs in both RT and accuracy than younger adults (Crossley & Hiscock, 1992; Hartley, 1992; Li, Lindenberger, Freund, & Baltes, 2001). These age-related deficits are sometimes reduced when participants engage in two simple tasks such as identifying two colours and two letters of the alphabet at the same time (Hartley & Little, 1999), or if the tasks are presented one after the other with longer stimulus onset asynchronies (Meyer & Kieras, 1997a). Bottom-up factors such as the modality in which the tasks are presented have also been shown to affect dual task costs. For example, the use of the primary motor cortex for two similar movements such as manual key pressing or using a foot pedal to make responses, or if the two tasks require similar responses (e.g., pressing buttons manually for both tasks) increases dual task costs thus reducing the likelihood of parallel processing (Hiraga, Garry, Carsons, & Summers, 2009). Other bottom-up factors such as the stimuli themselves have also been shown to contribute to dual task costs. For example, if both tasks contain visual stimuli but require a different modality of response, dual task costs are higher (see meta-analysis in Verhaeghen et al., 2003).

Several models have been proposed to account for performance on the dual task paradigm. The capacity sharing theory proposes that when two tasks are presented at the same time, both tasks are allocated reduced resources (Kahneman, 1973; Navon & Miller, 2002; Tombu & Jolicoeur, 2003). As a result, if one task requires more processing, it may lead to a delay in responding to that task. Bottleneck models are based on designs that have staggered presentation of two tasks (i.e., varying stimulus onset asynchronies). These models are based on the theory that the execution of the second task can only occur after the first task is completed. It is suggested that while perceptual and motor processing can occur at the same time, a central bottleneck delays the coordination of the responses and results in serial responses (see review in Pashler, 1994). The purpose of including stimulus onset asynchronies in these types of designs is to measure the limits of processing (shorter stimulus onset asynchrony) and the time it takes for the two tasks to become independent (longer stimulus onset asynchrony). That is, as the stimulus onset asynchrony increases, the RT for the second task decreases thus demonstrating no overlap in task processing (Pashler, 1989).

Studies that have included simultaneous onset (0 ms asynchrony) also contained pairs of trials with asynchronies ranging from 1000 ms (Task A before Task B) to -1000 ms (Task B before Task A). None of these studies included blocks with solely 0 ms onset trials and did not find any evidence for parallel processing (Ruthruff, Pashler, & Hazeltine, 2003; Sigman & Dehaene, 2006). For example, Sigman and Dehaene (2008) examined dual task performance in young adults with a design that included intermittent pairs of trials with simultaneous onset. For those particular pairs, fMRI and electroencephalography (recordings of electrical activity in the brain along the scalp) additional regions of the brain were recruited. The behavioural data showed slower response times for the simultaneous onset trials, however in another study without fMRI, the authors found that presenting at the same time resulted in smaller costs (Sigman & Dehaene, 2006). Because the two designs were different, it is difficult to determine why there was an advantage in one experiment and not the other. The varying results could be related to the staggered presentations before and after the simultaneous pairs or due to individual differences in response selection. There were no analyses conducted on the order of responses to determine if one task was always first and if this could have contributed to dual task costs at the onset of the experiment.

A study by Schumacher et al. (Exp. 1, 2001) presented a dual modality paradigm (auditory and visual tasks) to young adults and used only 0 ms stimulus onset asynchrony. The RT difference between single and dual modality blocks for each task was calculated across blocks to determine if the difference reduced over time. Their results revealed that after extensive practice (3400 trials) dual modality trials were no longer significantly different from the single modality baseline trials. The authors did not include analysis of the RT difference between the two tasks within the dual modality blocks to determine if parallel processing in terms of responding to two tasks closely in time was achieved. The focus of their analysis was the ability to return to single modality baseline in the dual modality blocks. In the dual task literature, costs are calculated as the difference between dual task and single task blocks as well as the RT difference between the two responses in the dual task blocks. Examining the RTs of the two required responses sometimes provides more information on the processing demands of each task and where additional differences may lie.

There are a few studies that have measured dual task performance in bilinguals. Craik and Bialystok (2006) examined the ability of younger and older monolinguals and bilinguals on task management and planning using a task known as “cooking breakfast”. This was a divided attention paradigm presented on the computer that required participants to “cook” foods so that they would be ready at the same time and included a filler task that required them to set the table (e.g., plates on the table, forks, spoons). The results showed that bilinguals were more efficient in their overall use of time. They switched between cooking food and setting the table more appropriately than monolinguals. Furthermore, older bilinguals spent less time on inappropriate table setting (setting the table instead of attending to cooking time) compared to older monolinguals. The study suggests that bilinguals have an overall enhancement in their ability to manage multiple task goals.

Further evidence for managing multiple task goals comes from Bialystok, Craik, and Ruocco (2006). Younger (Study 1) and older (Study 2) adult monolinguals and bilinguals performed two classification tasks that required manual responses to visual stimuli presented on a computer while verbally responding to auditory stimuli that they heard through a CD player. There were two types of stimuli, each of which was presented in both the visual and auditory modalities. One type consisted of letter or number strings and the other consisted of sounds from animals or musical instruments. The visual task was considered to be the primary task and participants were explicitly told to focus on it. In half the blocks of trials, the visual and auditory tasks were from the same category, and in the other half, they were different categories. The number of correctly classified items in each condition was the dependent variable. The results showed that bilinguals of both age groups were able to correctly classify more items than monolinguals when the visual task consisted of letters and numbers. The authors claimed that identifying and then classifying images of animals and musical instruments required deeper processing than letters and numbers which are more transparent. There were no language group differences when the visual task consisted of animals and musical instruments. The purpose of the studies were to determine the effects of bilingualism on simultaneous processing however the two stimuli were not presented at the same time nor were there RTs to measure the difference between the two tasks. In addition, participants were explicitly told to focus on the visual task making it the primary task and the auditory task became the secondary filler task. This could have led to unequal attention to the two tasks resulting in delays in the auditory (secondary) task.

The onset of the two tasks did not overlap resulting in varied stimulus onset asychnronies on a trial-to-trial level making it difficult to make any definite conclusions on simultaneous processing. Using a modification of this paradigm, Bialystok (2011) tested 8-year-old monolingual and bilingual children using only the animal and musical instruments stimuli in the visual and auditory modalities. Unlike the previous study, this study presented both tasks at the same time (i.e., with 0 ms asynchrony). The results did not yield any differences in RT between the language groups for the two responses; however, bilingual children were more accurate at responding to the visual task than monolingual children.

## Overview for study

The ACH focuses on the processes involved when an individual is using one language and suppressing the other and switching between them. Research consistently suggests an overall increase in efficiency in task performance for younger and older bilinguals in tasks that measure inhibitory control such as the Simon and Stroop tasks, task switching paradigms, as well as in tasks that require the convergence of the various control processes proposed by the ACH. For example, in the faces paradigm (Bialystok, Craik, & Ryan, 2006; Bialystok & Viswanathan, 2009) response suppression, inhibition, and task switching were all examined within one design and the results showed improved performance by bilingual children and adults than comparable monolinguals on all three components with no differences on baseline tasks.

We can assume that lifelong bilinguals have had extensive practice in managing their language systems to avoid interference, switch between the languages and to use both languages in an efficient manner to maintain a conversation. If bilinguals encounter a situation with two streams of information from equally challenging domains, it is plausible to expect more efficient performance from bilinguals than monolinguals in a dual task paradigm. The dual modality classification task (henceforth DMCT) used by Bialystok, Craik, and Ruocco (2006) was modified to allow for simultaneous presentation of visual and auditory stimuli thereby making both tasks primary. The interest here was to keep two goals active at the same time. Previous research examining the effects of bilingualism across the lifespan have used control conditions to establish performance in single task or simple conditions for the relevant paradigm (see Bialystok et al., 2004, 2006). Single modality blocks of dual task paradigm were created. The major differences in the present task from previous paradigms are in control of the onset of stimuli in the dual task paradigm (i.e., without stimulus onset asynchrony) and the inclusion of low-level psychomotor tasks. In addition, specific aspects of the task such as the type of stimuli used were controlled, allowing for further analysis on how bilinguals and monolinguals are influenced (or not) by bottom-up task processes. The details are discussed in the method section. It was predicted that there would be age-related differences, but no language-based differences in psychomotor speed tasks and in the single modality blocks. There is no reason to expect that bilingualism will boost simple task performance because the effect of bilingualism has been shown to be specific to situations that demand higher order cognitive control. The predictions for the present study are that only age-related differences will appear in single modality blocks and bilinguals and younger adults will experience smaller costs when making two responses at the same time. The stimulus pairings in the dual modality blocks were predicted to have differential effects in aging based on research that shows older adults succumb to bottom-up task processes resulting in poorer performance.

## Method

### Participants

Twenty five new participants (10 younger monolinguals, and 15 older monolinguals) and seventy five participants from the study in Chapter 2 (25 younger bilinguals, 25 older bilinguals, 15 younger monolinguals, and 10 older bilinguals) were recruited for this study. The 25 new participants were closely matched on age and number of years of education to existing participants (see Table 5).

**Materials and Stimuli**

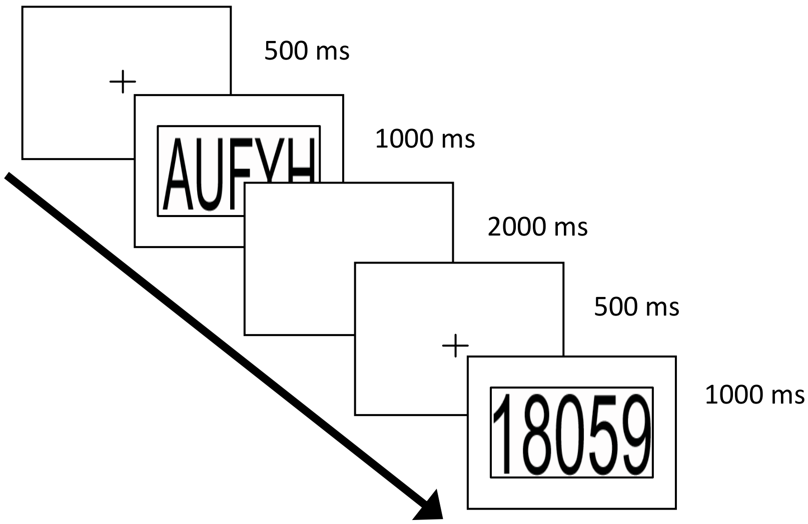
The procedure was identical to Chapter 2. For new participants, the session began with informed consent, the language questionnaire followed by the background measures (see Chapter 2, pages 37 to 39 for descriptions of background measures) and ended with the dual modality classification task.

*Dual Modality Classification Task (DMCT)*. The DMCT was presented on a 17" widescreen HP Pavillion Entertainment Notebook PC equipped with Windows XP Home Edition. The task required participants to classify visual and auditory stimuli presented simultaneously by assigning them to one of two categories. A Windows XP based program to present visual and auditory stimuli simultaneously to control for stimulus onset was created by a computer software engineer using the programming language C that used an FFmpeg library to read the visual and auditory files. The program measured the RTs of manual and verbal responses made by participants as well as recording each verbal response into the computer so that accuracy could be confirmed by replaying each response. The program produced a text file output that contained the trial name, response expected, reaction time, response made and accuracy (indicated by 1 or 0) for each response made manually. For verbal responses, accuracy was determined by the experimenter by coding each verbal response using the software program before the final output was generated. Participants wore a headset with a microphone to hear the auditory stimuli and to make a verbal response. This was done to ensure no external sounds disrupted the testing session.

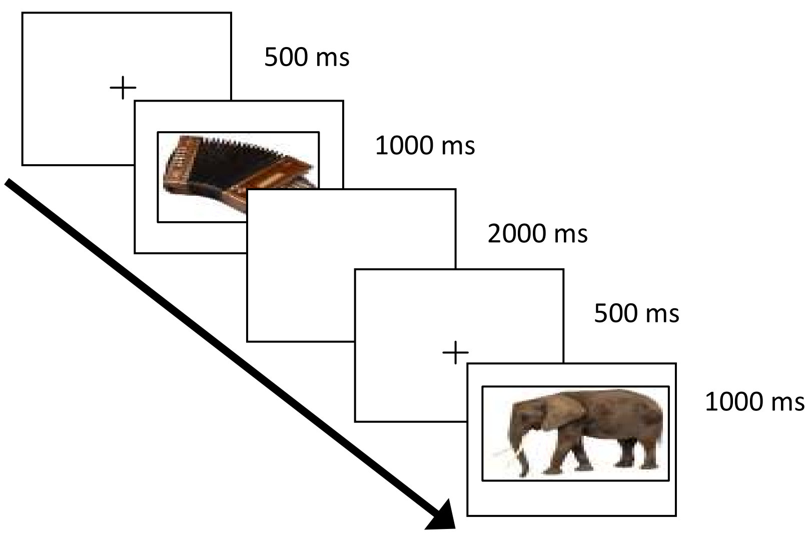
The stimuli belonged to one of two domains-- letters or numbers, and animals or musical instruments. Schematic drawings of the events in the single and dual task conditions are presented in Figure 4. In the visual task (Figure 4a), strings of letters or numbers (e.g., “75498”, “OAJRP”) or colour images of animals or musical instruments (Figure 4b) appeared in the centre of the computer screen. Each trial began with a fixation “+” in the center of the screen that remained visible for 500 ms. Following this, the stimulus appeared in the same location that the fixation had been. The stimulus remained on the screen for 1000 ms and then a blank screen appeared for 2000 ms or until a response was selected. The RT clock began when the stimulus appeared on the screen. Following a response, the fixation “+” appeared and the trials continued. Participants were instructed to press specific keys marked on the centre of the keyboard when they saw letters, numbers, animals or musical instruments. The keys in the centre row of the keyboard (“D”, “G”, “J” and “L”) were covered with white stickers marked “L”, “N”, “A”, and “M” respectively. They were spaced in a manner that enabled participants to use both their index fingers for each pairing. In the auditory task, participants heard letters and numbers in a spoken voice (e.g. “C”, “Five”) that were digitally recorded and actual sounds of animals and musical instruments that were found on the internet and modified to be 1000 ms in duration. When participants heard an auditory stimulus, they responded verbally into a microphone. The responses were given as “animal” for animal sounds, “music” for musical instruments, “letter” to a letter name, and “number” to a number. The next trial came only after a verbal response was made or after a 3000 ms timeout (inclusive of the 1000 ms auditory presentation).

Figure 4.  Schematic representations of the (a) Letter-Number visual task and (b) Animal-Musical instrument visual task.

(a)




(b)




The DMCT contained both single modality and dual modality conditions.  There were two visual single modality blocks (letter-number and animal-music separately) and one auditory single modality block.  The auditory block was not separated by domain (letter-number and animal-music sounds were both included in the same block). The single modality visual blocks consisted of 50 trials each (25 trials of each category in the domain) that were randomized. The single auditory block consisted of 100 trials of the auditory task (25 trials of each category) presented in random order. In the dual modality conditions, each of the visual single modality blocks was paired with the auditory single modality block.

In the dual modality conditions, the visual stimulus and the auditory stimulus began at the same time (0 ms asynchrony). Participants had to make a response to both stimuli within 3000 ms, after which the next pair of stimuli appeared. If participants responded to a trial in one modality and not in the other, the next pair would appear after the 3000 ms limit and the missing responses were recorded as errors. The stimuli were the same as those used in the single modality blocks. Each visual category (letter, number, animal and musical instrument) consisted of 25 stimuli that were randomly presented four times. There were 100 auditory trials that were presented twice each. This resulted in a total of 200 pairs of trials in each dual modality block. In order to measure the effects of relatedness to determine whether hearing and seeing the same type of stimulus facilitated RTs, each visual stimulus was never paired more than once with an individual auditory stimulus. For example, in the dual modality letter-number block, visual item L1 was paired with auditory items L1, N1, A1 and M1. Visual item L1 did not appear again after these four presentations. The auditory items were heard a second time but they were associated with a new visual stimulus. Practice trials were given at the beginning of each block to familiarize participants with the rules of each task. The single visual modality blocks consisted of 4 practice trials each, the single auditory modality block consisted of 8 practice trials and the dual modality blocks consisted of 10 practice trials each. Participants received feedback after each practice session. Practice trials were repeated if more than one error was made in single visual modality blocks, more than two errors were made in single auditory modality block, and more than 4 errors were made in dual modality blocks.

Accuracy was determined for the verbal responses to auditory stimuli using two methods. Correct responses were items in which the verbal response was a direct response (e.g., participant said “animal”) and the RT was included. On occasion, participants said “um” or “ah” before identifying the category (e.g., “ummm- Letter”). In these cases, the RTs were excluded, however if they made a correct classification, the response was included in the accuracy data. If participants said “Mu-Number” (i.e., started to say “music” but changed the response to “number”), it was considered an incorrect response and the RT for that trial was excluded.

## Results

### Background measures

Table 6 shows the mean scores for the background measures. Background measures were examined using separate two-way ANOVAs with language group and age group as factors. For the PPVT, there were no effects of language group, $F < 1$, age group, $F(1, 99) = 4.02$, $p = .06$, or their interaction, $F < 1$. Cattell scores revealed no effects of language group, age group, or their interaction, all *F*s < 1. The PPVT and Cattell scores were standardized for age therefore the lack of an effect of age is not surprising. For Corsi forward, there was a significant effect of age group only, $F(1, 99) = 72.82$, $p < .0001$, $\eta_p^2 = .42$, in which younger adults ($M = 9.6$, $SD = 1.3$) scored higher than older adults ($M = 6.9$, $SD = 1.9$). There was no effect of language group, $F < 1$, and no language group and age group interaction, $F(1, 99) = 1.91$, $p = .17$. This pattern was replicated for Corsi backward with a significant effect of age group, $F(1, 99) = 65.00$, $p < .0001$, $\eta_p^2 = .40$, showing better performance by the younger adults ($M = 9.2$, $SD = 1.7$) than older adults (*M* = 6.7, *SD* = 1.5). There was no effect of language group, $F < 1$, and no interaction, $F(1, 99) = 2.36$, $p = .13$.

Table 6. Mean scores (and standard deviations) on background measures by language group and age group.

| **Background Measures** | **Monolingual Younger** (n = 25) | **Bilingual Younger**[a] (n = 25) | **Monolingual Older** (n = 25) | **Bilingual Older**[a] (n = 25) |
|---|---|---|---|---|
| Age (yrs) | 34.2 (3.3) | 34.1 (3.5) | 69.7 (7.3) | 70.3 (5.9) |
| Education (yrs) | 17 (2.0) | 17 (2.2) | 17 (2.9) | 17 (2.8) |
| PPVT standard | 112.4 (6.1) | 112.1 (5.7) | 110.3 (8.8) | 108.0 (8.5) |
| Cattell IQ score | 119.2 (11.3) | 118.4 (17.9) | 117.7 (15.0) | 117.8 (16.6) |
| Corsi forward | 9.7 (1.2) | 9.4 (1.3) | 6.6 (1.7) | 7.1 (2.0) |
| Corsi backward | 9.4 (1.4) | 8.9 (1.9) | 6.4 (1.4) | 6.9 (1.6) |
| Box completion[b] | 19.1 (3.9) | 19.9 (3.7) | 37.6 (11.0) | 35.8 (13.3) |
| Digit copying[b] | 35.8 (3.9) | 35.1 (3.4) | 48.7 (8.7) | 45.7 (7.9) |

[a] Same participants from Chapter 2. Identical values to Table 1 in Chapter 2.
[b] Values shown are the mean times to complete the task in seconds.

The box completion task revealed a significant effect of age group only, $F(1, 99) = 91.25$, $p < .0001$, $\eta_p^2 = .48$, with faster performance by younger adults (*M* = 19.5, *SD* = 3.8) than older adults (*M* = 36.7, *SD* = 12.2). There was no effect of language group, and no interaction, *F*s < 1. The digit copying task also revealed a significant effect of age group, $F(1, 99) = 84.33$, $p < .0001$, $\eta_p^2 = .50$, showing younger adults (*M* = 35.5, *SD* = 3.7) were faster to complete the task than older adults (*M* = 47.2, *SD* = 8.3). There was no effect of language group, $F(1, 99) = 1.98$, $p = .16$, and no interaction $F < 1$. The effect of age group in Corsi, box completion and digit copying tasks indicates that older adults found these tasks harder than younger adults.

**DMCT: Single modality blocks**

Table 7 shows the mean RTs for the single modality blocks. Accuracy in the single modality blocks ranged from 98.9 to 100% so no analysis was conducted due to the lack of variance in the data.

Table 7. Mean RTs in ms (and standard deviations) for visual and auditory tasks in the single modality blocks by language group and age group.

| **Modality/Task** | **Monolingual Younger** | **Bilingual Younger** | **Monolingual Older** | **Bilingual Older** |
|---|---|---|---|---|
| Visual | | | | |
| Letter-Number | 552 (82) | 520 (39) | 792 (113) | 760 (132) |
| Animal-Music | 548 (94) | 542 (42) | 804 (121) | 729 (149) |
| Auditory | 701 (128) | 663 (139) | 889 (144) | 847 (140) |

The mean RTs from the visual single modality blocks were first analyzed using a three-way ANOVA with domain (letter-number versus animal-music), language group and age group as factors. The results revealed a significant effect of age group only, $F$ (1, 96) = 244.93, $p$ < .0001, $\eta_p^2 = .72$, showing that younger adults ($M$ = 541, $SD$ = 64) were faster to respond to the visual single modality blocks than older adults ($M$ = 771, $SD$ = 129). There was no effect of language group, $F$ (1, 96) = 5.99, $p$ = .10, and no language group by age group interaction, $F$ (1, 96) = 1.35, $p$ = .25. There was also no effect of domain indicating that responding to letters and numbers versus animals and musical instruments were similar in difficulty, $F$ < 1. The two-way interactions of domain and language group, and domain and age group, were not significant, all $F$s < 1, and neither was the three-way interaction of domain, language group and age group, $F$ (1, 96) = 1.44, $p$ = .23.

The mean RTs for the auditory single modality block were entered into a two-way ANOVA with language group and age group as factors. There was only a main effect of age group, $F$ (1, 96) = 45.30, $p < .0001$, $\eta_p^2 = .32$, showing that younger adults ($M$ = 682, $SD$ = 134) were faster than older adults ($M$ = 868, $SD$ = 142) in making verbal responses to auditory stimuli. There was no main effect of language group, $F$ (1, 96) = 2.07, $p = .15$, and no significant interaction, $F < 1$. The results of the single modality blocks are important because they reveal that there are only age-related differences in the visual and auditory tasks, and there is no significant effect of bilingualism indicating that language experience does not enhance or improve baseline single-task performance.

**DMCT: Dual modality blocks**

In the dual modality blocks, participants were instructed to respond to the visual task with a key press and respond to the auditory task verbally at the same time. In the dual modality letter-number block, the visual task consisted of letters and numbers and in the dual animal-music block the visual task consisted of animals and musical instruments. The auditory task for both blocks consisted of all four categories (letters, numbers, animals and musical instruments). The mean RTs and accuracy data for the tasks in the dual modality blocks as a function of modality, language group and age group are shown in Table 8.

*Comparison of Letter-Number and Animal-Music dual modality blocks*. The first set of analyses examined the data from the visual task and the auditory task to test if the dual modality letter-number and dual modality animal-music blocks were different or not from each other. First, the accuracy data for the visual trials of the dual modality blocks were entered into a three-way ANOVA with block (letter-number and animal-music), language group, and age group as factors. The results revealed that older adults ($M$ = .91, $SD$ = .06) made significantly more errors than younger adults ($M$ = .95, $SD$ = .04), $F$ (1, 96) = 22.84, $p$ < .0001, $\eta_p^2$ = .19. There were no effects of language group or block, and no interactions, all $F$s < 1.

Table 8. Mean RTs in ms and accuracy (and standard deviations) of responses to visual and auditory tasks in the dual modality blocks by language group and age group.

| | | Letter-Number | | Animal-Music | |
|---|---|---|---|---|---|
| **RT & Accuracy** | **Age group and language group** | **Visual** | **Auditory** | **Visual** | **Auditory** |
| **RT** | **Younger** | | | | |
| | Monolingual | 1081 (349) | 1270 (344) | 1093 (299) | 1350 (399) |
| | Bilingual | 825 (206) | 889 (177) | 864 (240) | 886 (227) |
| | **Older** | | | | |
| | Monolingual | 1683 (433) | 2031 (374) | 1539 (377) | 2091 (260) |
| | Bilingual | 1453 (295) | 1597 (339) | 1444 (290) | 1611 (283) |
| **Accuracy** | **Younger** | | | | |
| | Monolingual | .94 (.04) | .94 (.04) | .94 (.04) | .94 (.03) |
| | Bilingual | .95 (.04) | .94 (.04) | .95 (.04) | .95 (.04) |
| | **Older** | | | | |
| | Monolingual | .91 (.06) | .88 (.05) | .91 (.06) | .89 (.06) |
| | Bilingual | .91 (.06) | .90 (.06) | .91 (.06) | .92 (.05) |

The same three-way ANOVA was repeated using the accuracy data for the auditory trials from both dual modality blocks and revealed that older adults ($M$ = .90, $SD$ = .06) made significantly more errors than younger adults ($M$ = .94, $SD$ = .04), $F$ (1, 96) = 46.61, $p$ < .0001, $\eta_p^2$ = .33. There was no effect of language group, $F$ (1, 96) = 1.7, $p$ = .1, and no interaction, $F$ (1, 96) = 2.43, $p$ = .12. There was no effect of block, $F$ < 1, and no other interactions were significant, all $F$s < 1. The lower accuracy rate for older adults suggests that these data may show a speed-accuracy trade-off. However, the mean RTs for older adults were quite slow as well.

The mean RT data for the visual tasks in the dual letter-number and dual animal-music blocks were entered into a three-way ANOVA with block (letter-number visual and animal-music visual), language group, and age group as factors. The results revealed that bilinguals ($M$ = 1147, $SD$ = 258) were faster than monolinguals ($M$ = 1349, $SD$ = 365), $F$ (1, 96) = 18.36, $p <$ .0001, $\eta_p^2$ = .16, and younger adults ($M$ = 966, $SD$ = 274) were faster than older adults ($M$ = 1530, $SD$ = 349), $F$ (1, 96) = 142.44, $p <$ .0001, $\eta_p^2$ = .60. There was no effect of block, $F < 1$, indicating that the letter-number visual task and the animal-music visual task were similar in difficulty in the dual modality blocks. The two-way interactions between language group and age group, $F < 1$, language group and block, $F < 1$, and age group and block, $F$ (1, 96) = 1.42, $p$ = .24, were not significant. The three-way interaction of these factors was not significant, $F < 1$.

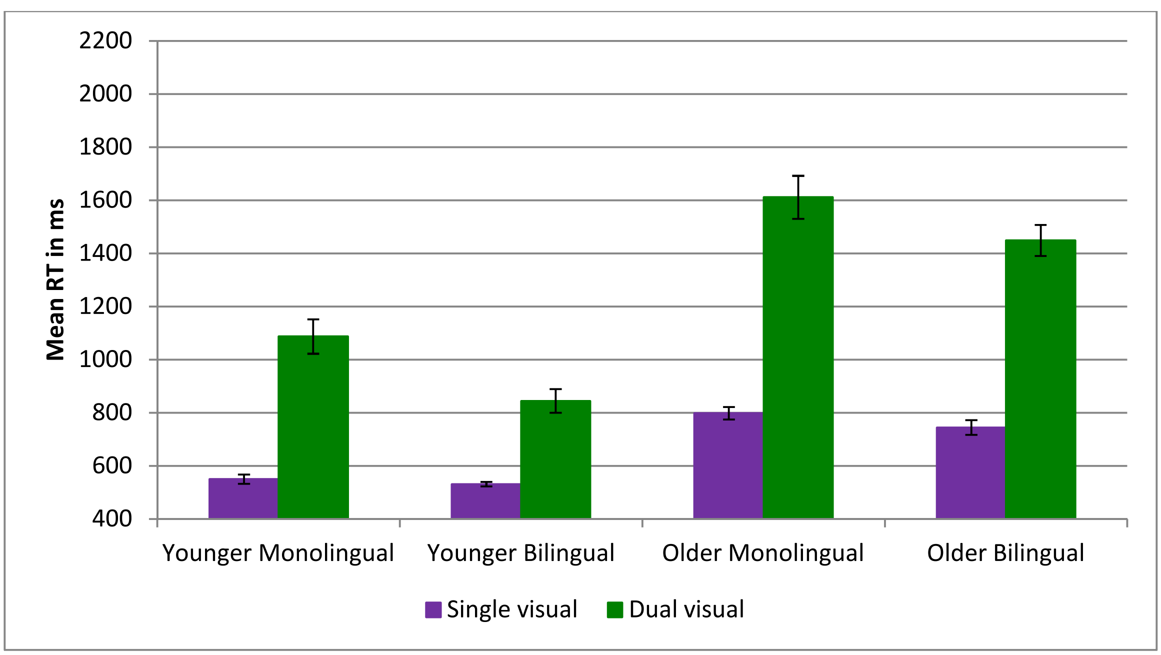
The mean RT data from the auditory tasks from both blocks were analyzed using a three-way ANOVA and showed that bilinguals ($M$ = 1246, $SD$ = 257) were faster than monolinguals ($M$ = 1686, $SD$ = 344), $F$ (1, 96) = 61.04, $p <$ .0001, $\eta_p^2$ = .39, and younger adults ($M$ = 1099, $SD$ = 287) were faster than older adults ($M$ = 1833, $SD$ = 314), $F$ (1, 96) = 183.75, $p <$ .0001, $\eta_p^2$ = .66. There was no effect of block, $F < 1$, indicating that the pairing the same auditory task with letters and numbers or animals and musical instruments did not change performance on the auditory task. The two-way interactions between language group and age group, language group and block, and age group and block were not significant, all $F$s < 1. The three-way interaction of these factors was also not significant, $F$ (1, 96) = 1.28, $p$ = .26. Based on this outcome, the mean RTs for visual task from dual letter-number and dual animal-music blocks were combined and the auditory means were also combined creating one mean RT for visual trials and one for auditory trials for each participant to represent both components of the dual modality blocks.

Subsequent analyses were focused on determining how the bilingual performance differed from that of monolinguals, and how older adults were different than younger adults.

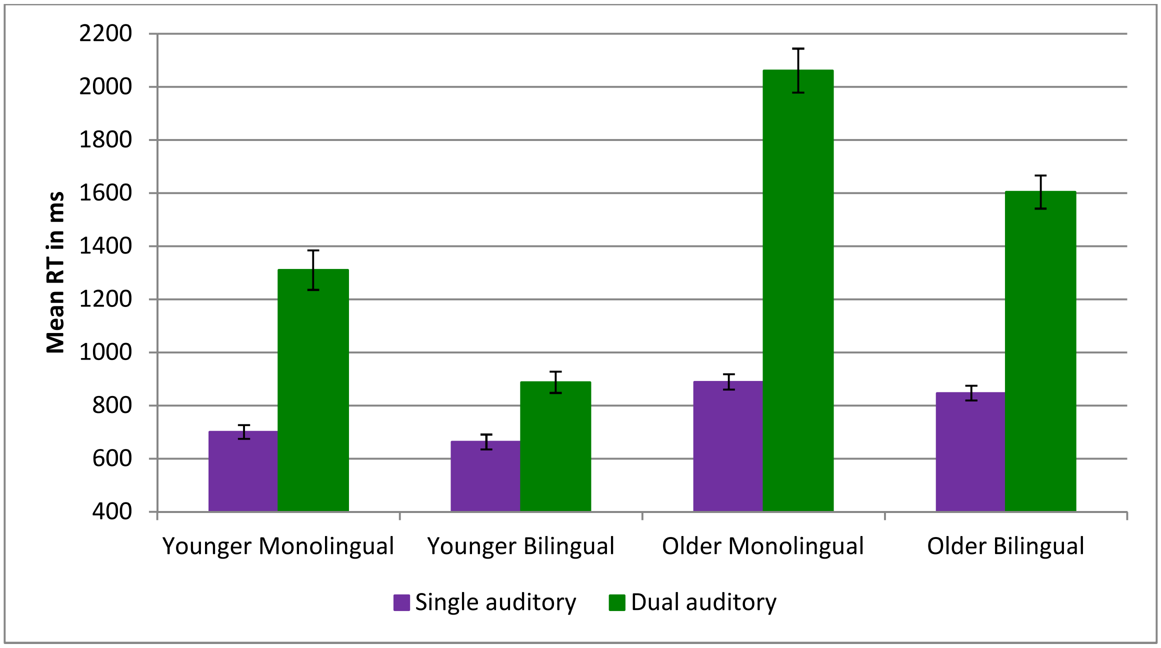
*Dual task costs*. Next, the proportion of extra time required to respond to the visual and auditory tasks in dual modality blocks compared to single modality blocks was calculated to determine the cost of making two responses at the same time. Collapsed data for each task (from Tables 7 and 8) were used to calculate the RT difference between the dual modality and single modality blocks divided by the single modality block (i.e., (dual modality RT – single modality RT) / single modality RT) for each task. The collapsed visual and auditory task RTs by modality are presented in Figure 5.

Figure 5. Mean collapsed RT in ms (and standard errors) for the (a) visual and (b) auditory tasks in single and dual modality blocks by language group and age group.

(a)




(b)



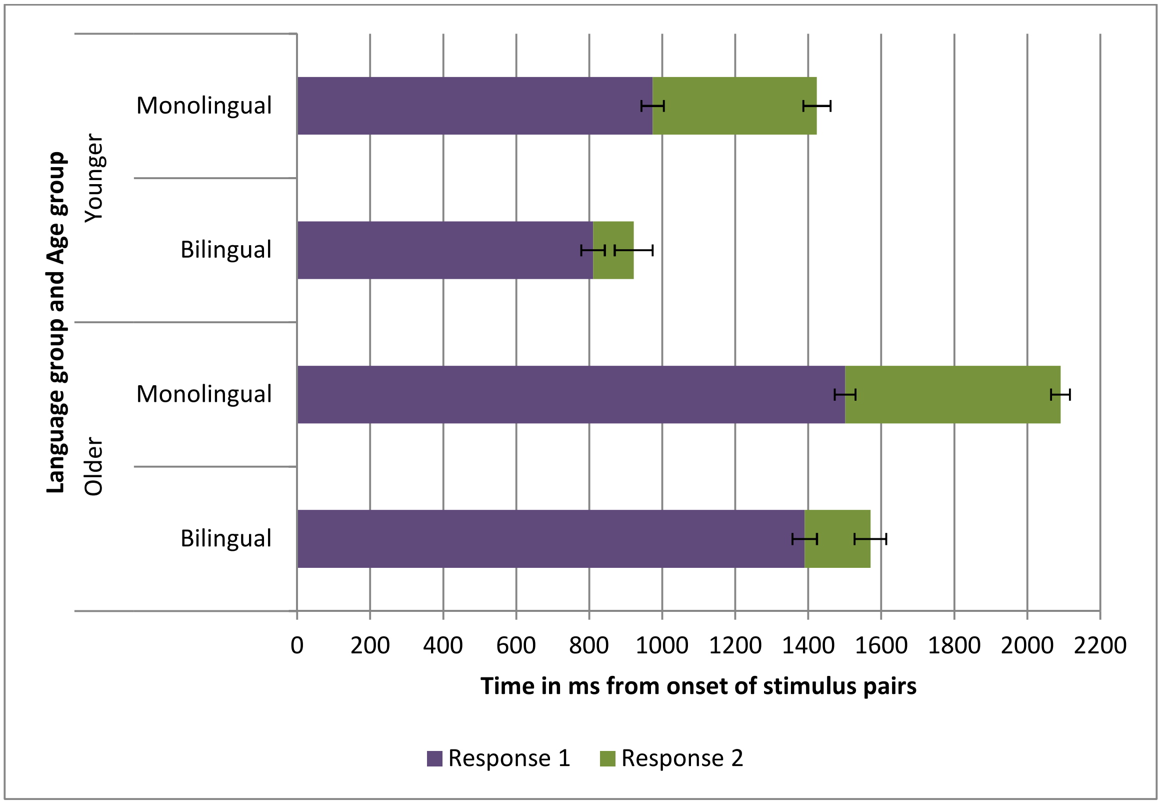

The mean proportion increase in RT in the visual task from single modality blocks to dual modality blocks was .99 for younger monolinguals, .59 for younger bilinguals, 1.03 for older monolinguals, and.98 for older bilinguals. These data were entered into a two-way ANOVA and revealed that bilinguals experienced a smaller proportion increase in RT for the visual task than monolinguals, $F$ (1, 99) = 7.98, $p$ = .006, $\eta_p^2$ = .07. There was also an effect of age group with younger adults showing a smaller increase than older adults, $F$ (1, 99) = 7.47, $p$ = .008, $\eta_p^2$ = .07. The language group and age group interaction was not significant, $F$ (1, 99) = 5.01, $p$ = .08.

The same analysis was conducted on the auditory task with mean proportions increase in time as .95 for younger monolinguals, .40 for younger bilinguals, 1.3 for older monolinguals, and .95 for older bilinguals. The results revealed that bilinguals experienced a smaller proportion increase in RT between the single and dual modality auditory tasks than monolinguals, $F$ (1, 99) = 19.4, $p$ < .0001, $\eta_p^2$ = .16, and younger adults showed smaller costs than older adults, $F$ (1, 99)

$= 18.91$, $p < .0001$, $\eta_p^2 = .16$. The language group by age group interaction was not significant, $F < 1$.

*The relationship between the responses to pairs of trials*. The dual task cost analyses focused on each task in the dual modality blocks as stand-alone tasks that included all correct RTs (visual and auditory separately) not taking into consideration if participants got one task right and the other wrong. This next set of analyses focused on the two tasks treating them as pairs of trials requiring correct responses to both the visual and auditory tasks. As a result, all RTs where there was no response made to one task were eliminated from the subsequent analysis. Capacity sharing theory suggests that resources to both stimuli are reduced when pairs of stimuli are presented at the same time. The theory also states that one response can be slowed down if more resources need to be allocated to a more difficult task (in this case, the auditory task because of slower RTs). To determine if there was any indication of reduction in resources in order to cope with responding to both tasks, the data were compiled by noting the faster RT for each stimulus pair as Response 1 and the slower RT as Response 2. These data are presented in Figure 6 on a timeline showing when the first and second responses occurred at the onset of the stimuli (i.e., from time 0 ms). The green region indicates the additional time it took to make the second response after the first response. Based on the capacity sharing theory, it was predicted that there would only be an age-related difference in the first response with language and age group differences for the second response. Incidentally, 100% of the first response was always made to the visual task for all pairs of trials that were included in the subsequent analyses.

Figure 6. Stacked graph of mean cumulative RTs in ms (and standard errors) for the first and second responses for correct pairs of trials in the dual modality blocks by language group and age group.




Each response was analyzed separately using two-way ANOVAs. The results for the analysis of first response revealed that bilinguals were faster than monolinguals, $F\ (1, 99) = 19.24$, $p < .0001$, $\eta_p^2 = .16$, and younger adults were faster than older adults, $F\ (1, 99) = 315.03$, $p < .0001$, $\eta_p^2 = .76$. The interaction between language group and age group was not significant, $F < 1$. The same pattern was found for the second response with bilinguals responding faster than monolinguals, $F\ (1, 99) = 130.01$, $p < .0001$, $\eta_p^2 = .57$, and younger adults responding faster than older adults, $F\ (1, 99) = 297.33$, $p < .0001$, $\eta_p^2 = .75$. The interaction was not significant, $F < 1$. These results indicate language group and age group differences for each response. To further understand these differences, the proportion of extra time required to make the second response in relation to the first response was calculated as the difference between the mean RT for the first response and the second response divided by the first response (i.e., (Response2 – Response1) / Response1). The mean proportion increase in RT for the second response was .50 for younger monolinguals, .15 for younger bilinguals, .41 for older monolinguals, and .20 for older bilinguals. These data were entered into a two-way ANOVA and revealed that bilinguals experienced smaller costs between the first and second response than monolinguals, $F\ (1, 99) = 36.92$, $p < .0001$, $\eta_p^2 = .27$. There was no effect of age group, $F < 1$, showing that the cost was similar for both younger and older adults. There was no interaction, $F\ (1, 99) = 2.50$, $p = .12$. These results suggest that bilinguals experienced a smaller cost than monolinguals, and there was no age-related increase in the time required to make the second response.

*Impact of stimulus pairings on RTs*. The dual task literature has consistently shown that bottom-up factors such as the relationship between the stimuli, the types of stimuli used, and the response modalities contribute to dual task costs, especially in aging. In order to understand performance differences on the DMCT, the stimuli from the visual and auditory tasks were examined by blocks (Letter-Number and Animal-Music) and categories within the block (letter, number, animal, or music). The data were first separated by block then, the second response to each pair was sorted into "match" and "mismatch" trials in relation to the first response. Match trials comprised of pairs where the visual and the auditory stimuli were the same (e.g., see letter and hear letter; see animal and hear animal), and mismatch trials were pairs that were different within the domain (e.g., see letter and hear number; see animal and hear musical instrument). Pairs of trials that were not within the same domain (e.g., see letter and hear animal; see musical instrument and hear number) were not included. Following this, the data were sorted to produce mean RTs for the second response that were matched or mismatched to the first response. These data are presented in Table 9 with the RT difference between trial types.

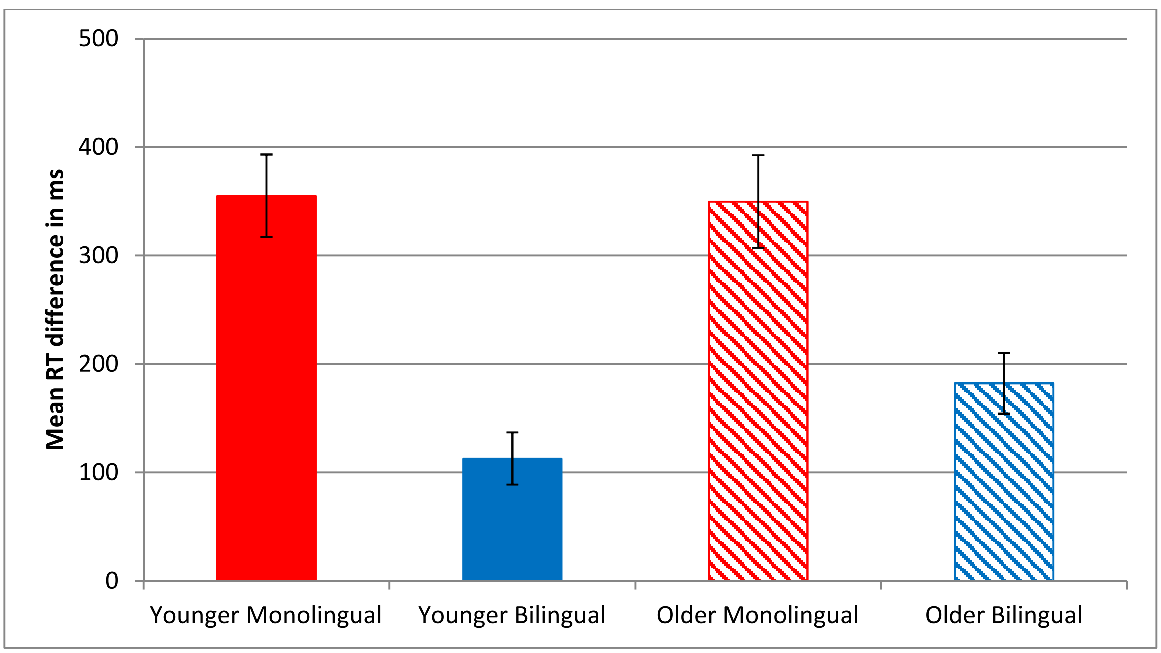
Table 9. Mean RTs in ms (and standard deviations) of second responses that are match and mismatch trials and their difference in the dual modality blocks by language group and age group.

| Block | Relationship | Monolingual Younger | Bilingual Younger | Monolingual Older | Bilingual Older |
|---|---|---|---|---|---|
| **Letter-** | Match | 894 (156) | 793 (134) | 1450 (264) | 1370 (232) |
| **Number** | Mismatch | 1270 (310) | 856 (161) | 1915 (230) | 1535 (230) |
| | Difference | 376 | 63 | 465 | 165 |
| **Animal-** | Match | 922 (136) | 812 (127) | 1336 (172) | 1347 (192) |
| **Music** | Mismatch | 1263 (225) | 916 (136) | 1743 (202) | 1541 (215) |
| | Difference | 341 | 104 | 407 | 194 |

The match RTs from the dual letter-number and animal-music blocks were entered into a three-way ANOVA with type (letter-number and animal-music), language group, and age group as factors. The analysis revealed that bilinguals ($M$ = 1081, $SD$ = 171) were faster than monolinguals ($M$ = 1151, $SD$ = 182), $F$ (1, 96) = 7.83, $p$ = .006, $\eta_p^2$ = .08, and younger adults ($M$ = 855, $SD$ = 138) were faster than older adults ($M$ = 1376, $SD$ = 215), $F$ (1, 96) = 433.38, $p$ < .0001, $\eta_p^2$ = .82. There was no language group by age group interaction, $F$ (1, 96) = 2.0, $p$ = .16. There was no effect of type, $F$ < 1, indicating that letter-number match trials were equivalent to animal-music match trials. The two-way interactions between type and language group, $F$ < 1, type and age group, $F$ (1, 96) = 3.04, $p$ = .08, were not significant. The three-way interaction between all factors was also not significant, $F$ < 1.

The same analysis was repeated using the mismatch RTs showing that bilinguals ($M$ = 1212, $SD$ = 186) were faster than monolinguals ($M$ = 1523, $SD$ = 242), $F$ (1, 96) = 114.04, $p$ < .0001, $\eta_p^2$ = .54, younger adults ($M$ = 1076, $SD$ = 208) were faster than older adults ($M$ = 1684, $SD$ = 219), $F$ (1, 96) = 372.81, $p$ < .0001, $\eta_p^2$ = .80. There was no main effect of type indicating letter-number and animal-music mismatch trials were similar, $F$ < 1. The two-way interactions between type and language group, $F$ (1, 96) = 4.04, $p$ = .06, and type and age group, $F$ (1, 96) = 3.27, $p$ = .07 approached significance. The three-way interaction of factors was not significant, $F$ < 1. For both the dual modality letter-number and animal-music blocks, the results held the same pattern showing that bilinguals were faster on match and mismatch trials than monolinguals, and younger adults were faster than older adults.

Figure 7. Mean RT difference in ms (and standard errors) between match and mismatch trials in the dual modality blocks by language group and age group.




To further investigate the language group and age group differences on match and mismatch trials, using the data collapsed by modality, the RT difference between trial types was analyzed using a two-way ANOVA (Figure 7). Results indicated that bilinguals experienced smaller difference between second responses that were match and mismatch than monolinguals, $F$ (1, 99) = 36.21, $p$ < .0001, $\eta_p^2$ = .28. There was no effect of age group, $F$ < 1, and no interaction, $F$ (1, 99) = 1.20, $p$ = .28. These results suggest that bilinguals of both age groups were not as affected by match and mismatch pairs as monolinguals.

## Discussion

The present study compared the performance of younger and older monolinguals and bilinguals on a dual modality classification task to determine if bilingualism influenced the processing of two simultaneous streams of information. It was predicted that if task goals can be sustained for a period of time, this would result in smaller dual task costs in the DMCT. First, it was important to establish that the language groups were similar on tasks measuring basic processing speed and in the single modality conditions to demonstrate that on a baseline level only age was the relevant factor and that language experience did not boost performance on simple tasks. The background measures did not reveal any language group differences. Results of Corsi blocks (forward and backward), box completion and digit copying tasks showed age-related slowing only. The age-related differences in the two psychomotor tasks (box completion and digit copying) are important because they indicate that bilingualism does not boost low-level basic processing speed. These background measures established that the monolinguals and bilinguals within each age group were similar. The single modality blocks of the DMCT revealed effects of aging only showing that older adults were slower than younger adults in both visual and auditory modalities.

Three important results were revealed in the dual modality blocks. The first finding was that dual task costs were smaller for bilinguals and younger adults. Second, the extra time required to make the second response was greater for monolinguals than bilinguals and did not reveal any age-related increase. Third, the analysis of match and mismatch pairs revealed that the difference between pairs when the second response required the same classification as the first response (e.g., see animal, hear animal) than when the classification was different (e.g., see letter, hear number) resulted in greater costs for monolinguals than bilinguals with no effect of aging.

According to capacity sharing theory, when more than one task is presented, the resource to process both tasks is divided between them, resulting in general slowing and the ability to manage two tasks declines in aging. If there is a significant difference in RT between the responses to both stimuli, the theory states that it is a result of having to allocate more resources to one task thus delaying both responses. If this is the case, then processing the auditory stimuli (which were always the second response) created a longer delay for both responses for monolinguals than bilinguals. It is unclear if there was a reduction in resources, or if the auditory task was slower (the second response) because it was harder (there were four stimulus-response mappings). Based on RT proportion costs analysis, the extra time to make the second response was greater for monolinguals than for bilinguals, suggesting that bilinguals were more efficient in responding to two tasks than were comparable monolinguals.

The data from the current study also show an age-related slowing in the mean RTs of the first and second responses. However, the difference between the first and second response did not show any age-related differences, suggesting that presenting two tasks at the same time with no stimulus onset asynchrony appears to have not hindered older adults. One explanation for this finding is that unlike typical dual task paradigms, there was a relationship between the two tasks that were presented. Whether the responses were verbal or manual, both tasks required the identification of the four stimuli— letters, numbers, animals and musical instruments. In dual task studies that find significant costs for older adults in making two responses at the same time, the two tasks are not similar (for specific details of task pairings in dual task conditions see Verhaeghen et al., 2003). The visual task involved basic choice RT decisions— see letter/number, press the key marked "L" or "N" or see animal/musical instrument, press the key marked "A" or "M"— a factor that could have contributed to improved performance in older adults because there are only two choices with no conflicting information. For example, McDowd and Craik (1988) demonstrated that systematic increases in choice difficulty resulted in greater dual task costs for older adults, and in the most complex conditions, younger adults also experienced greater costs. It is possible that in the DMCT, the first response (which was always a manual response to the visual task) was easier thus allowing more time to configure the four stimulus-response mappings to make the correct verbal response. This possibility will be discussed further in Chapter 4.

The DMCT presented in this chapter has not been used before to examine adult populations. To gauge its effectiveness to other dual task paradigms, the mean RT ranges were examined closely. In the DMCT, there were a total of 8 stimulus-response mappings (4 for visual and 4 for auditory) with 6 of those mappings being relevant for each DMCT block. In dual task paradigms that have more than 4 stimulus-response mappings that have been used with younger and older adults (based on data from monolinguals), the RT range is around 945 ms to 2200 ms indicating that the DMCT is comparable to other dual task paradigms (for specific studies with RT ranges, see Verhaeghen et al., 2003). Another explanation for the long RTs is that there was double the amount of input than used in standard dual task paradigms. For example, the goal maintenance model proposed by Rubinstein et al. (2001) includes several bottom-up processes that are involved from the onset of the stimulus to making a response: 1) Presentation of stimulus, 2) Stimulus identification, 3) Response selection, 4) Movement production, and finally 5) Response. The onset of the RT clock in the DMCT began at the onset of both stimuli in order to determine how and when the stimuli are processed. Since there was no stimulus onset asynchrony in the DMCT, the steps from Rubinstein et al.'s model had double input with the processing of two stimuli (visual and auditory), selecting two responses (choosing 1 of 2 for visual, and 1 of 4 for auditory), making two movements (finger to response key and opening mouth), and finally making two responses (key press and vocal). In addition, the rule activation for these tasks (a top-down process in the model) had to be retrieved in order to mentally select the responses. These multiple stages could account for the slower overall RTs in the DMCT. It is impossible to isolate when rule retrieval occurs and delay the start of the RT clock. Furthermore, the aim was to measure the RTs to indicate when these stimuli were processed and the speed in which a response was made to both of them. The stimulus pairs were presented for a total time of 1000 ms with an additional 2000 ms to make the relevant responses. Younger bilinguals made both responses within 1000 ms and younger monolinguals made only their first response within the 1000 ms stimulus duration whereas older adults of both language groups needed additional time to execute both responses.

Research with bilinguals has shown that the areas of the brain that are activated during language switching are also activated during cognitive control tasks (Garbin et al., 2010; Gold et al., 2013; Luk et al., 2012). This reinforced recruitment of language and cognitive control areas may have resulted in better performance in the DMCT by bilinguals than monolinguals. The fMRI data from Sigman and Dehaene (2008) with young adults showed additional recruitment for simultaneous onset pairs in similar brain regions that are recruited in studies with bilinguals.

In summary, the present study set out to determine if the experience of bilingualism aids in the efficient processing of two streams of information at the same time. The baseline tasks used showed only age-related declines that are typically found in the literature. Results from the dual modality blocks revealed that bilinguals experienced a significant advantage in the DMCT and were more successful at engaging in parallel processing than monolinguals. The data suggest that bilinguals have an improved ability to regulate and maintain two task goals, and this improvement is interpreted as evidence for a greater ability to sustain proactive control well into aging.

# Chapter 4

## General Discussion

The degree to which the experience of lifelong bilingualism impacts cognitive control has been of great interest since a study by Bialystok et al. (2004) showed that younger and older bilinguals performed better than comparable monolinguals on the Simon task (Simon, 1969), a well established task that typically shows age-related decline in task performance (Christ et al., 2001; van der Lubbe & Verleger, 2002). Since that initial study, research has shown that younger and older bilinguals manage task conflict more efficiently than comparable monolinguals when the stimuli are bivalent (contain two pieces of information) and require either the inhibition of one feature (i.e., the Stroop task, Bialystok et al., 2014) or switching between both features randomly (i.e., task switching, Gold et al., 2013; Wiseheart et al., 2014).

In the cognitive aging literature, several models have been formulated to determine where differences in conflict tasks may lie— bottom-up components such as the stimulus-response relationship (Ruthruff et al., 2001), top-down control such as maintaining task goals (Botvinick et al., 2001; Rubinstein et al., 2001), and the efficiency of bottom-up versus top-down control (Braver, 2012). In models of bilingualism such as the Inhibitory Control Model (Green, 1998) and the Adaptive Control Hypothesis (ACH, Green & Abutalebi, 2013), the focus is on how language control exerted by bilinguals in dual-language situations results in a greater overall efficiency in cognitive control that can be captured by tasks that measure conflict resolution. Lifelong bilinguals have shown improved performance in tasks that involve conflict (Bialystok et al., 2004, 2008, 2014) and language switching studies have shown that balanced bilinguals (those with equal proficiency in both languages) do not experience costs when they switch between languages (Costa et al., 2006). These results suggest more fluidity in task goals for bilinguals that possibly extend beyond a language switching context.

The central purpose of this dissertation was to compare two notable theories of cognitive control, the Dual Mechanisms of Control (DMC) framework (Braver, 2012) and the Adaptive Control Hypothesis (ACH) of bilingual cognitive control (Green & Abutalebi, 2013), that have competing theoretical explanations of proactive and reactive control. The ACH proposes that maintaining language usage goals, a proactive process, is flexible because a speaker has to adapt and change language usage goals, a reactive process, based on what is happening around them such as knowing the other speaker only speaks language X, or the entrance of a speaker who speaks both language X and Y. In the DMC framework, Braver (2012) argues that proactive control is preferred because the task goals are sustained and there is no reliance on bottom-up reactive control to remember the goals, but in aging, older adults rely more on reactive control that results in delays in executing responses. The DMC framework also suggests that it is difficult to sustain proactive control for long periods of time and this difficulty will result in the inability to maintain other goals. The framework does not provide any examples of tasks that demonstrate the interference from other competing or new goals. In general, the DMC framework views proactive control and reactive control as separate processes that are used differentially in aging, and thus result in different outcomes whereas the ACH views them as dynamic and interacting with each other to lead to improved outcomes.

In Chapter 1, two main questions were presented, namely, —to determine if proactive control is flexible and to evaluate if proactive control is sustainable. The next section will discuss the outcomes of the fadeout paradigm from Chapter 2 and how they relate to the ACH and DMC frameworks. Following this, the results of the Dual Modality Classification Task

(DMCT) from Chapter 3 will be discussed to determine if the results can be interpreted in terms of the ability to sustain proactive control, a process that models of cognitive control propose as being difficult (Braver, 2012; Goshcke, 2000; Meiran et al., 2012, 2015). The final section will discuss limitations and future directions.

## Is proactive control flexible?

In Chapter 2, it was proposed that proactive control is more flexible in bilinguals than monolinguals and is not as rigid as proposed by the DMC framework. A modification of the fadeout paradigm devised by Mayr and Leibscher (2000) was used to determine if task cues help modify previously held task goals or if proactive control was inflexible resulting in the inability to adapt to new task goals. Following methodologies used in task switching, the ability to change goals when task expectancies (the foreknowledge of upcoming trials) were violated was examined. The fadeout task began with standard task switching (task switching phase) and on the 49$^{th}$ trial, one cue never appeared again (fadeout phase). The number of trials it took to return to single task block performance from responding to bivalent stimuli that consisted of colour (blue or red) and shape (circle or square) dimensions to respond to only one dimension was calculated as a measure for adapting the original task goals. Results showed that after the onset of the fadeout phase, single task block speed was reached earlier for younger and older bilinguals (8 and 24 trials respectively) and later for younger and older monolinguals (56 and 72 trials respectively). These results were interpreted as demonstrating greater flexibility in proactive control for bilinguals and that task cues do not necessarily hinder task performance in aging. This task has never been used with a bilingual population. In aging, the results align with findings by Mayr and Leibscher (2000) showing that older adult take longer to disengage from the irrelevant task cue. The fact that older bilinguals returned to their single task block speed sooner than both younger and older monolinguals suggest that flexibility in proactive control remains efficient in aging and may be attributable to the experience of switching between two languages on a regular basis. The older bilinguals were exposed to both languages either from birth or before the age of 6 years and continuously use both languages in their daily lives.

Following more traditional task switching analyses, local and global switch costs were also examined. As discussed in Chapter 2, Wiseheart et al. (2014) found that younger bilinguals experienced smaller global switch costs than matched monolinguals, and Gold et al. (2013) found that older bilinguals had smaller switch costs than older monolinguals. The task switching phase of the fadeout paradigm was similar to the design used by Gold et al. The data from Chapter 2 showed no significant differences between younger and older adults for local switch costs, aligning with existing research (Kray et al., 2000, 2004; Reimers & Maylor, 2005). For global switch costs, the results showed that bilinguals of both age groups had smaller global switch costs than comparable monolinguals. The reduced global switch cost in bilinguals was interpreted as evidence for an overall efficiency in alternating between two tasks.

The purpose of using the fadeout paradigm was to determine how task goals are managed and whether bottom-up task processes interact with top-down control in a positive way. The rapid disengagement from the irrelevant task by bilinguals suggests that this is indeed the case. The ability to manage two languages resulted not only in smaller global switch costs but also in the ability to modify task goals to improve task performance. Research in cognitive aging suggests that older adults succumb to bottom-up control to manage and guide task performance the result of which is slower response times. In the fadeout paradigm, monolinguals experienced larger global costs and took more trials to return to single task speed in the fadeout phase while bilinguals experienced smaller global switch costs and reached single task speed in fewer number of trials. Even though monolinguals took more trials, the fact that single task speed was eventually reached suggests that there was a positive shift in adapting task goals to improve performance. These results are interpreted as supporting the ACH (Green & Abutalebi, 2013) showing that proactive control is flexible and interacts with reactive control, more so in bilinguals than in comparable monolinguals.

## Is proactive control sustainable?

The second question proposed in Chapter 1 stemmed from existing research showing an overall efficiency in task performance by younger and older bilinguals in task manipulations that did not contain conflict at the stimulus level (e.g., 4-colour centre presentation of the Simon task, Bialystok et al., 2004). The goal was to determine if proactive control could be sustained across a task and if the experience of bilingualism boosted proactive control in aging. The ACH and DMC framework propose conflicting views on the efficiency of proactive control with the former stating that task goals can be sustained while the latter claiming that continuously maintaining goals is taxing and difficult, especially for older adults. In Chapter 3, participants were presented with the DMCT, a task that required manual responses to visual stimuli and verbal responses to auditory stimuli at the same time. The purpose of this task was to determine if there were differences between bilinguals and monolinguals in executing responses to task goals that were presented at the same time with equal importance. Unlike the fadeout paradigm, the conflict in the DMCT arose from the goals. The responses to the visual and auditory tasks were analyzed to determine the speed at which the two tasks were executed when they were presented at the same time. When compiling the data to determine the speed of responses two both stimuli, all participants responded to the visual stimuli first, and the extra time required to make the verbal response was greater for monolinguals. The data suggest that bilingual participants were better able to manage the demand of responding to two tasks at the same time whereas monolinguals experienced larger costs. One explanation for this outcome could be the relationship between the pairs of trials. Analyses were conducted to compare the response times of pairs of trials that were the same or different. The response time difference between pairs that were the same (e.g., seeing a string of letters and hearing a letter) or different (e.g., seeing a string of letters and hearing a number) was greater for monolinguals than bilinguals of both age groups. This result is interpreted as showing that monolinguals were more prone to bottom-up task processes while bilinguals were able to maintain top-down control.

Green & Abutalebi (2013) proposed that goal maintenance is the result of the overall coordination of various control processes (see Chapter 1). The authors suggest that the ability to manage two languages and change language usage goals based on demands from the environment translates to an advantage in non-linguistic tasks. The DMC framework (Braver, 2012) suggests that sustained proactive control in the form of the continuous maintenance of task goals is ideal but difficult to maintain, and leads to a reduction in the capacity to maintain other task goals. The results of the DMCT only partially support the DMC framework’s conception of proactive control. First, the difference between the first and second responses were smaller for bilinguals (111ms for younger bilinguals; 180ms for older bilinguals) than monolinguals (450ms for younger monolinguals; 590ms for older monolinguals) suggesting that the task was more difficult for monolinguals and this may be due to the difficulty of sustaining proactive control. Second, the relationship between the pairs of stimuli affected monolinguals but not bilinguals, supporting the DMC framework because reactive control is mentally “easier” but more inefficient than proactive control and the result was indeed slower response times for monolinguals on pairs of trials that were different.

The measurement of the ability to maintain task goals is rooted in research in working memory (Kane & Engle, 2003), inhibitory control (Braver et al., 2007) and task switching (Vandierendonck, Liefooghe, & Verbruggen, 2010). The results from Chapter 3 provide evidence for the sustainability of task goals in a dual task context, as well as evidence for the ability to manage multiple goals with small costs for younger and older bilinguals but larger costs for comparable monolinguals. Dual task paradigms have mostly been used to test bottleneck effects of responding to two tasks that are presented with small or large delays between the two tasks. Bottleneck models presume that it may be impossible to engage in parallel processing of two tasks that require the same operation. A single mechanism has to actively engage both task demands resulting in a bottleneck in which responses to one or both tasks are delayed (see review in Pashler, 1994).

The only theory that considers the simultaneous onset of two tasks is the capacity sharing theory (Navon & Miller, 2002; Tombu & Jolicoeur, 2003). The theory allows two tasks to receive resources that are equally reduced if they are presented simultaneously. Meyer and Keiras (1997a) argued that interference-free parallel processing is possible and that responses can be executed in succession at a rapid rate indicating that cognitive resources can be shared successfully. Practice improves dual task performance by allowing individuals to take the time to develop strategies to respond to both tasks (Oberauer & Göthe, 2006). Furthermore, extensive practice could allow for the automatization of one or both tasks that could bypass the bottleneck (the delay in responding to the second task) and eliminate dual task costs. The DMCT in Chapter 3 provides evidence for parallel processing in bilinguals, but not in monolinguals. Furthermore, the results indicate a differential reduction in resources between the two language groups because bilinguals responded at rapid rates to one or both tasks than monolinguals. Extensive practice on the task was not required to reduce dual task costs for bilinguals.

## Limitations and future directions

The fadeout paradigm and the dual modality classification task were designed to examine goal maintenance and the interaction between top-down (proactive) and bottom-up (reactive) control. Neither task is standardized and both have been used infrequently in the literature. While it is difficult to draw direct comparisons of the results to existing and well established research, the two paradigms broadened the understanding of cognitive control using task-wide analysis in the case of the fadeout paradigm, and with the manipulation of the presentation of the two tasks in the dual modality classification task. There are several limitations to the design of each task that need to be addressed.

Research has consistently shown that using univalent (one dimension) and bivalent (stimuli that contain two features such as shape and size) stimuli result in differences in local and global switch costs (Rubin & Meiran, 2005), and the use of bivalent stimuli has been shown to slow down performance across an entire block of trials (Woodward, Meier, Tipper, & Graf, 2003). In this dissertation, the fadeout paradigm contained bivalent stimuli (shape and colour) whereas the DMCT consisted of univalent stimuli. In the fadeout paradigm, the conflict was obvious with one stimulus eliciting the activation of two possible responses (e.g., blue square = blue or square). In the DMCT, the conflict arose from the categorical groupings of Letter-Number and Animal-Music. Although the stimuli were univalent, a conflict arose at the response level when the visual stimulus was not the same as the auditory stimulus even though the required responses were in two separate modalities (manual and verbal). This response conflict resulted in greater costs for monolinguals than bilinguals. The DMCT design separated the visual task by letter-number and animal-music while the auditory task consisted of all four categories (letter, number, animal and music). The reason behind this design was that initial pilot data (n = 6 for each language group and age group) showed that the task was too easy when the auditory task contained the same pairings as the visual task. Adding the two additional categories to the auditory task resulted in the task being more difficult and resulting in the opposite effect that was found in the pilot data with RT differences appearing between pairs of trials that were the same and different. Future designs of the DMCT should include blocks of each pairing in the auditory task to establish a baseline and with each block, and task difficulty can be manipulated (adding more stimulus-response mappings) to isolate the point in time when language group differences begin to appear. Another design factor that affected task analysis was that the single modality blocks had significantly fewer trials (50 for each visual block and 100 for the auditory block) than the dual modality blocks (200 trials for each block). The separation by pairings and the addition of more blocks will make the DMCT design comparable to existing dual task paradigms allowing for more direct comparisons. Future designs should also incorporate more trials to determine if single task speed can be reached. The purpose would be to further our understanding of the extent to which resources can be shared and to mitigate any discrepancies in theoretical explanations of the processes involved in dual task performance.

Task switching research examining the relationship between responses to bivalent stimuli occasionally find that repeated responses (e.g., pressing same key for consecutive trials even if it is a task switch) is faster than if the response required changes to a different key press even if the next trial is a nonswitch trial (Kiesel, Wendt, & Peters, 2007). This is known as the response congruency effect in task switching. Currently, there are no studies that examine cross-modality effects of response congruency in a task switching or dual task context. One way to investigate this effect would be to examine dual task performance in bimodal bilinguals. Bimodal bilinguals can speak and use sign language at the same time. Although spoken language and sign languages have different grammatical structures, it is possible that bimodal bilinguals may experience advantages on dual modality tasks compared to spoken bilinguals and monolinguals because of the lifelong experience of cross-modal communication.

To further examine the interaction of top-down and bottom-up control, future designs of the fadeout paradigm should include the re-introduction of the task cue that was removed on the 49$^{th}$ trial. The purpose would be to examine whether the modification of task goals leads to the complete "deletion" of the irrelevant task, or if it temporarily suppressed to increase efficiency in the current task. If there is true convergence of control processes as stated by the ACH (Green & Abutalebi, 2013), then bilinguals should be able to reactivate the irrelevant task again at a faster rate than monolinguals. If the outcome of improved performance in bilinguals is related to the complete "deletion" of the rules associated with the irrelevant cue, monolinguals of both age groups may reactive the irrelevant task sooner based on the finding that it took them longer to return to single task speed, possibly a symptom of continued maintenance of the irrelevant task goal.

Brain imaging studies suggest that the bilingual advantage found in aging is the result of more efficient activation of cognitive control regions that are also activated in dual language tasks. While there was no fMRI component in the studies presented in this dissertation, it might be that bilingualism offers better compensation in aging when multiple task goals need to be managed and when attention to task cues is required to progress quickly in a task. Recent brain imaging research reveals that the lifelong usage of two languages confers stronger functional connectivity within brain networks that impact cognitive control (Grady, Luk, Craik, & Bialystok, 2015). The older bilinguals in that study were lifelong balanced bilinguals, similar to those who participated in the fadeout and dual modality paradigms. Other research has shown that younger adults show similar strength in functional connectivity in multitasking state and resting state suggesting the brain is “ready” to engage in task processing (Cole, Bassett, Power, Braver, & Petersen, 2014). If older bilinguals experience similar benefits as younger adults, it suggests that bilingualism improves the integrity of connections in the brain. It is unclear when the bilingual strength in connectivity emerges. It is important to measure such connectivity in different stages of bilingualism (from childhood to aging), and with different levels of bilingualism to determine if the lifelong experience of bilingualism is necessary to maintain the strengths in connectivity found in aging, and whether these connections continue to be strong or change if dual language use across the lifespan is not sustained.

## Conclusion

Proactive and reactive control have only recently been included in the discussion of bilingual research. Green and Abutalebi (2013) used terms identical to those used by cognitive control researchers to describe how the dual-language experience is similar to inhibitory control and task switching. The outcomes of both the task switching and dual task paradigms were interpreted as showing differences between monolinguals and bilinguals in the flexibility of proactive control as well as the extent to which reactive control helps or hinders task performance. In the task switching paradigm, reactive control resulted in changes in proactive control at a faster rate for bilinguals than monolinguals, and in the dual task paradigm, proactive control was robust in bilinguals whereas monolinguals were differentially affected by bottom-up task processes for conflict trials resulting in an overall slowing. The improved performance by younger and older bilinguals can, to a reasonable extent, be attributable to the experience of using two languages from a young age on a regular basis. The participants were matched on age, number of years of education, and had similar IQs. Baseline tasks such as the box completion and digit copying tasks only yielded age-related differences. Similarly, the choice RT task, single task and single modality blocks all yielded only age-related declines in performance. The effect of language group only appeared in the experimental conditions. Future research could examine differences in task performance in bilinguals who have different levels of experience with both their languages with the aim of isolating how much language experience is required to improve cognitive control.

Another factor that can also be examined is the impact of early childhood bilingualism when it is not maintained into adulthood. Research shows that bilingual children experience cognitive control advantages to comparable monolinguals (Barac & Bialystok, 2012; Bialystok & Viswanathan, 2009). What happens when the use of the second language decays over time? Do the structural changes in the brain that occur in childhood that stem from the experience of bilingualism remain intact? Do early bilinguals who become monolinguals continue to exhibit a cognitive advantage in adulthood and in aging? There are many opportunities to examine the extent to which bilingualism impacts cognitive control. This subsequently raises the issue of the "measurement" of bilingualism. In the studies presented in this dissertation, bilingualism was determined through self-report. Participants either used both languages everyday or they did not. Only participants who used both languages regularly in a variety of contexts were recruited. While the background measures used in this dissertation showed no bilingual advantage, there will always remain a third "unknown" variable in this type of research. One solution is to conduct longitudinal studies examining how children are exposed to both languages from birth and regularly assess children to maintain a language usage record through their lifetime. While this may not be financially feasible, it would be ideal.

This dissertation examined various aspects of cognitive functioning in bilinguals and monolinguals. The results from both studies suggest that using bilingual samples is beneficial in understanding how attention is managed and maintained in aging and how the experience of bilingualism improves cognitive reserve. Bilinguals appear to be more focused in attention, and positively influenced by specific task-related factors when goals need to be maintained and adapted than comparable monolinguals. While there is important work still to be done, the data from this dissertation add to our existing knowledge of how bilingualism ameliorates age-related decline in cognitive functions by providing evidence for the dynamic interaction between top-down and bottom-up processes to improve the overall control of attention.

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Appendix A: Language and Social Background Questionnaire (LSBQ)

**Language and Social Background Questionnaire (LSBQ)**

Date of birth: ________________________________ Today's date: ____/____/____

Place of birth: ___________________________________

Sex: M F Handedness: L R

Highest degree obtained: Bachelor's Master's PhD

Field of study: ______________________________

Current Job: _______________________________________________________________

On average, how many hours do you spend on working on a computer every day? ______

Do you play video games? Yes No If yes, how many hours do you play in a week? ___

What is your first language? ___________________________________________________

What is your second language? _________________________________________________

Do you speak any other language(s)? Yes No

If yes, what are the language(s)?________________________________________

Do you need to speak/read/write in a language other than English at work?
Speak: Yes No
Read: Yes No
Write: Yes No

Have you ever lived in a place where your second language is the dominant communicating language?

Yes No

If yes, where and for how long? _________________________________________

In each of the scales below, indicate the proportion of use for English and your other language in **daily life**. These scales are set up for different activities at home or at work. On one end of the scale, you have 100% which indicates that the particular activity in that environment is carried out in ALL ENGLISH. On the other end, you have 0% which indicates that you do not use English at all to carry out the activity.

**At Home**

| | 0% | 25% | 50% | 75% | 100% |
|---|---|---|---|---|---|
| Speaking | No English | | | | All English |
| Listening | No English | | | | All English |
| Reading | No English | | | | All English |
| Writing | No English | | | | All English |
| Watching TV | No English | | | | All English |
| Listening to radio | No English | | | | All English |

**At Work**

| | 0% | 25% | 50% | 75% | 100% |
|---|---|---|---|---|---|
| Speaking | No English | | | | All English |
| Listening | No English | | | | All English |
| Reading | No English | | | | All English |
| Writing | No English | | | | All English |

Relative to a native speaker's performance, rate your proficiency level in a scale of 0 – 100 for the following activities conducted in your first and second language.

**Language # 1:** ___________________ (please indicate)

| | 0% Non-native-like | 25% | 50% | 75% | 100% Native-like |
|---|---|---|---|---|---|
| Speaking | 0% Non-native- like | 25% | 50% | 75% | 100% Native-like |
| Understanding | 0% Non-native-like | 25% | 50% | 75% | 100% Native-like |
| Reading | 0% Non-native- like | 25% | 50% | 75% | 100% Native-like |
| Writing | 0% Non-native- like | 25% | 50% | 75% | 100% Native-like |

**Language # 2:** ___________________ (please indicate)

| | 0% Non-native-like | 25% | 50% | 75% | 100% Native-like |
|---|---|---|---|---|---|
| Speaking | 0% Non-native- like | 25% | 50% | 75% | 100% Native-like |
| Understanding | 0% Non-native-like | 25% | 50% | 75% | 100% Native-like |
| Reading | 0% Non-native- like | 25% | 50% | 75% | 100% Native-like |
| Writing | 0% Non-native- like | 25% | 50% | 75% | 100% Native-like |

**Additional questions about your second language:**

Where did you learn your second language? Home School Community Work

At what age did you first start **learning** your second language **informally at home**? _____

At what age did you first start **learning** your second language **formally at school**? ______

At what age did you first start **using** your second language actively?__________________

Did you attend a school that primarily used your second language as medium of instruction?

Yes No

**Global self-assessment:**

Overall, how would you describe your levels of bilingualism?

| Not bilingual | | Non-fluent bilingual | | Fluent bilingual |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

1 –predominantly speaks the non-English language

2 – weak bilingual – knows enough to carry out some conversation to a very limited extent (use key words; poor grammar) – need to listen to sentences more than once before understanding.

3 – unbalanced bilingual – able to carry out basic conversation with minor grammatical errors – without the other speaker repeating the sentence – has difficulty producing a fluent conversation.

4 – practical bilingual – can carry out conversation fluently – does not use the second language everyday

5 – fluent bilingual – able to converse fluently and actively use two languages everyday

Experimenter's judgment: __________

Appendix B: Informed consent

***INFORMED CONSENT***

**Sponsor: York University**

**Purpose of the Study**

The purpose of this study is to better understand how bilingualism supports cognitive tasks based on attention. The study will include adults who speak both English and another language ("bilinguals"), as well as adults who speak only English ("monolinguals"). The bilingual adults in the study will be selected on the basis of the age they began learning the second language, whether they continue to use both languages, and their current age. The monolingual adults will be selected on the basis of their age.

**What You are Being Asked to Do**

You will be asked to do the following things during the study:

- To watch a computer screen and make decisions about various pictures and sounds that are presented (by pressing keys and speaking into a microphone) and respond to images on the screen using the keyboard
- Listen to a word and select the correct picture out of a choice of 4 simple pictures
- A tapping task where you recreate the sequences you are presented with
- Recalling words in different categories
- To say as many words as possible that start with a given letter in 60 seconds
- Two timed paper tests where you copy numbers and complete line drawings
- Answer questions about your experience learning and speaking English and a second language (if you are bilingual)

We will also give you clear instructions and examples at the beginning of each part so that you will know just what to do. When using the computer you will give your answers by verbally responding into a microphone and by pressing keys on the keyboard. We will provide you with breaks throughout the testing time and answer any questions you have. The study will take approximately two 1-hour sessions to complete.

**Risks and Discomforts**

We do not expect the study to cause any risks or discomforts for you. However, if you feel uncomfortable or become tired, you can take a break whenever you want.

**Withdrawal from Study**

You can stop participating in the study any time you want, for any reason you want. There is no penalty for withdrawal- financial or otherwise. If you decide to withdraw, you do not need to give a reason, and it will not prejudice your future relations with me, with this university, or any part of this university.

**Confidentiality**

Confidentiality can only be guaranteed to the limit allowed by law. The information (data) we get from you during the study will be kept confidential in our research facility in a locked file cabinet at York University for up to 7 years. Your name will never be used in connection with any of the data we collect. Your signature below indicates that you are willing for the *information* we obtain from you to be used in an article or lecture as long as your name is not revealed. Only my supervisor, Dr. E. Bialystok, and I will have access to the stored data.

**Benefits**
You will not benefit directly from being in the study. However, the results we get will allow us to better understand how knowledge of more than one language benefits our thinking processes. This may help us develop better ways to teach or train people in the future.

**Questions**

If you have any questions about this study, please feel free to contact the Principal Investigator, Mythili Viswanathan (PhD Candidate) at 416-736-2100 x30562 or at mythili@yorku.ca.

Sincerely,

______________________________

Mythili Viswanathan, MA
PhD Candidate
Department of Psychology
York University

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**Legal Rights and Signatures**
You will receive a copy of this informed consent. You are not waiving any of your legal rights by signing this form. Your signature below indicates that you agree to participate in this study.

This research has been reviewed and approved by the Human Participants Review Committee (HPRC) for compliance with Senate ethics guidelines. If you have any questions regarding your rights as a participant in a research study like this one, please contact HPRC, 309 York Lanes, York University, 4700 Keele Street, 416-736-5055, e-mail: research@yorku.ca

Full name (please print): ____________________________ Date: ___________

Signature of Participant: ____________________________