A CLOSER LOOK AT THE EFFECT OF BILINGUALISM ON WORKING MEMORY

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A THESIS SUBMITTED TO

THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

MASTER OF ARTS

GRADUATE PROGRAM IN PSYCHOLOGY

YORK UNIVERSITY

TORONTO, ONTARIO

JUNE 2019

Abstract

Previous research suggests that bilinguals act as experts when engaged in tasks requiring attentional control (Incera & McLennan, 2015). Experts across various domains are slower to initiate a response, but then produce a more efficient response. We used mouse-tracking to determine whether bilingual (*n* = 51) and monolingual (*n* = 51) young adults (*M* = 20.65) employed different strategies while engaged in two sets of memory tasks, the n-back and item/associative tasks. Language groups displayed similar performance on most tasks, however, bilinguals had longer initiation and reaction times than monolinguals on the associative task. When examined as a continuous factor, degree of bilingualism was positively correlated with initiation time. The results of the regression analysis support the conclusion that bilingualism impacts the strategies that participants display while completing memory tasks. In the future, tasks requiring more controlled processing should be utilized to allow for more robust differences to appear.

Keywords: bilingualism, working memory, mouse-tracking

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A Closer Look at the Effect of Bilingualism on Working Memory

A large body of work has demonstrated that bilinguals show enhancement of multiple executive functions across the lifespan (Bialystok, 2017). This pattern occurs because these individuals must continually manage attention to languages that compete for selection (Kroll & Bialystok, 2013). The mechanism underlying language selection is thought to be part of a domain-general executive control system. This claim is supported by evidence from neuroimaging studies that show overlap in the brain circuits involved in language selection and nonverbal cognitive control (De Baene, Duyck, Brass, & Carreiras, 2015). Constant use of the control system for language processing may strengthen its use in other executive domains, including working memory. Since working memory ability and executive functioning are strongly related, it is logical to expect bilinguals will outperform monolinguals in working memory tasks that involve extensive executive functioning demands.

Despite this link, results of research on the effects of bilingualism on working memory are mixed. Conflicting findings may stem from two related methodological issues. First, a wide variety of tasks are used in working memory studies, and these vary in the extent to which they tap executive functioning. Complex tasks requiring a greater amount of attentional control are more likely to find a significant effect of bilingualism than tasks that are simpler. Second, performance is gauged using outcome measures that offer limited information about the processing that occurred in real-time. Utilizing methods that can more precisely capture temporal information may potentially reveal differences that would otherwise be hidden using conventional measures.

These issues were explored in the current study. A variety of memory tasks that vary in complexity were administered to determine whether bilinguals outperformed monolinguals on complex tasks involving high memory and executive control demands. It is the first study to examine working memory in bilinguals using mouse-tracking technology. This method provides a rich data set and enables analysis of the strategies that individuals use during memory tasks. The data will be used to address contradictions in the literature between studies that find or do not find differences between monolingual and bilingual young adults in working memory performance.

Bilingualism Dependent Plasticity

It is now understood that experience can alter brain structure and cognitive ability throughout the lifespan (Kolb & Whishaw, 1998). This idea was first studied using animals; researchers found that rats who were raised in enriched environments had a thicker cortex and performed better on learning tasks than rats raised in standard laboratory cages (Rosenzweig & Bennett, 1996). In humans, socioeconomic status and education (Noble et al., 2015) have been implicated as factors that can change the brain and cognition, as well as more specific activities such as video game playing (Green & Bavelier, 2008), musical training (Herholz & Zatorre, 2012), and aerobic exercise (Hillman, Erickson, & Kramer, 2008). Given this information, it follows that bilingualism might produce a similar effect, being one of the most pervasive and intense experiences humans possess (Bialystok, 2017).

This potential for neuroplastic effects exists because of the way in which bilingual individuals process language. An abundance of behavioural and neurological data confirms that both languages are active at all times, competing for selection (Kroll & Bialystok, 2013). This joint activation requires a mechanism that allows individuals to select the appropriate language so that the other does not interfere. Evidence suggests that this mechanism is based in the executive control and attention system. Imaging studies show that switching between languages activates the same frontal areas as those involved in selective attention during non-verbal executive function tasks (Luk et al., 2011). The thought is that because bilinguals constantly use this general attentional system to switch between languages, it will become strengthened. Since the mechanism is domain general, it has the potential to impact not only language processing, but cognitive control processes as well.

The relationship between bilingualism and cognitive control has been studied extensively in the last decade, providing ample evidence that bilingualism produces positive effects on cognition throughout the lifespan. Beginning in infancy, those who are exposed to multiple languages develop a more flexible and complex attentional control system (Pons et al., 2015). Bilingual children tend to outperform monolinguals in tasks measuring a number of executive control skills, including the ability to control attention, ignore interference, and integrate information from multiple sources (Barac et al., 2014). In adulthood, most studies also show an advantage for bilinguals in various aspects of executive functioning, such as task switching, flexibility and conflict resolution (Bialystok, Craik, Green, & Gollan, 2009). However, some studies have failed to find any behavioural differences in executive processing between monolingual and bilingual participants, especially in young adults (Paap & Greenberg, 2013; Kousaie & Phillips, 2012). The most robust results are usually found in older adults. This has been proposed to be due to a ceiling effect for young adults (Bialystok, 2017). Typically, studies that fail to find a significant effect use simple tasks and gauge performance using outcome measures such as accuracy or reaction time. Young adults perform at an extremely high level, regardless of language group. Their average speed of response is very fast, around 500 ms on average, and does not have enough variability for group differences to emerge. To remedy this issue, tasks must be challenging enough to allow for more variability. Additionally, methods may be used that test differences in a more qualitative way than do the standard outcome measures.

The Role of Attention in Working Memory

Since bilinguals show an advantage in attentional control and measures of executive functioning, researchers have recently begun to explore whether bilingualism also affects related constructs. One concept that has been increasingly investigated as of late is working memory. While there are numerous conceptualizations of working memory that are continually evolving, its basic premise remains the same; working memory involves the short-term maintenance of information in the absence of sensory information (Baddeley and Hitch, 1974). Most modern theorists believe that working memory is comprised of multiple components that rely on selective and sustained attention (Eriksson et al., 2015). Some maintain that working memory capacity actually reflects an individual's ability to control attention, rather than being a measure of storage space. (Engle, 2002). To maintain information, sustained attention is required, especially in the presence of distraction. Those with a lower working memory capacity find it more difficult to ignore this distracting information, because they are slower in disengaging attention from irrelevant information (Eriksson et al., 2015).

Working memory has also been linked to executive functioning. Performance on measures of working memory capacity predict performance on several tasks measuring higher order cognitive functions, including language processing, fluid intelligence, and abstract reasoning (Engel, 2002). Since working memory is closely related to both attention and executive functioning (McCabe et al., 2010), it is logical to conclude that bilingualism should also have a profound effect on working memory capacity, as it does for attention and executive functioning.

While there is robust evidence for a bilingual advantage in some aspects of executive functioning, research on the link between working memory and bilingualism is less clear. There are fewer studies examining this relationship, although there has been a recent growth in the area. Most studies have found significant positive correlation between bilingualism and working memory capacity, however, some studies fail to show an effect (Bonifacci et al., 2011; Kaushanskaya et al., 2011). Some theorists attribute these conflicting results to differences in methodology (Yang & Yang, 2017). A variety of different tasks have been used to assess working memory capacity, and these tasks vary widely in their demands. Some are more complex and require greater attentional control, while others are simpler. Bilinguals should perform better on measures of working memory capacity that require more controlled processing, since numerous studies have shown that they are better at controlling attention while avoiding interference (Hernandez et al., 2010; Soveri et al., 2011). Results from several studies have supported this conclusion and have found a bilingual advantage in working memory when tasks were more complex and required a high level of attentional control (Bialystok et al, 2008; Morales et al., 2013; Yang & Yang, 2017). This is in line with the ceiling effect mentioned previously and applies especially to young adult populations. Domain also seems to play a role, and effects are more likely to arise in spatial rather than verbal working memory (Luo et al., 2013).

In addition to individual studies, two meta-analyses examining the relationship between bilingualism and working memory have been conducted. The first was published in 2010 by Adesope et al., as part of a larger analysis investigating bilingualism's effect on a range of executive functions in children. Results from seven effect sizes and five independent studies found that bilingualism was associated with greater working memory capacity, resulting in a moderate effect size of .48. Similar conclusions were drawn from a larger meta-analysis was recently conducted by Grundy and Timmer (2016) using 88 effect sizes from 27 independent studies. This analysis included research with children, young adults, and older adults. Results showed a small to medium effect size of 0.20 in favour of greater working memory capacity for bilingual individuals.

Mouse-Tracking

To address conflicting results between studies that find or do not find differences in working memory between monolingual and bilingual young adults, techniques that allow for a fine grained, qualitative analysis should be utilized. One of these novel techniques is mouse-tracking, which allows researchers to measure participants' real-time processing during cognitive tasks as they choose between various responses. This method is especially useful for determining how conflict impacts a response and how decisions evolve over time. Mouse-tracking responses can be recorded using the software package MouseTracker, which tracks the x and y coordinates of the computer mouse as responses are produced (Freeman & Ambady, 2010). MouseTracker can easily be customized to run many different tasks. The experiments can have any number of response alternatives and can include numbers, words, sounds, and video. Once run, mouse trajectories can be visualized, processed and analyzed. The program provides a rich data set including measures of velocity, accuracy, intensity, as well as initiation and overall reaction times. MouseTracker has been adopted as an effective and practical method of measuring cognitive processing, but only a few studies to date have utilized the program to investigate the impact of bilingualism on executive function.

One such experiment was conducted by Incera and McLennan (2015), who used mouse tracking to compare the performance of bilinguals and monolinguals on a colour-naming Stroop task. The results showed no quantitative differences between groups in overall accuracy, but when mouse trajectories were analyzed, bilinguals showed a pattern of response that was qualitatively distinct from monolinguals. Specifically, bilingual participants were slower than monolinguals to initiate a response, but they moved more quickly to the correct answer once they began. This response strategy is typical of experts, who have longer initiation times but subsequently perform more quickly (Ranganathan & Carlton, 2007; Kobus et al., 2001).

This pattern of responding was replicated in a subsequent study comparing English monolinguals to Chinese-English bilingual young adults on three tasks measuring executive function (Damian, Ye, Oh, & Yang, 2018). Researchers compared participants' pattern of responding on the Flanker, Simon, and Spatial-Stroop tasks using mouse movements. Again, bilinguals showed an expert pattern of responding that was distinct from monolinguals. They were slower to initiate a response, but when mouse trajectories were compared, bilinguals' responses were more efficient. In this study, more efficient means that their trajectories contained less deviation and they moved more directly to the correct answer. This pattern indicates that the bilinguals reacted less to the conflicting information contained within the tasks. The bilinguals behaved as experts in controlling attention in the face of distracting information.

Present Study

While a number of behavioural studies examining the effect of bilingualism on working memory exist, conflicting findings continue to be reported. Null results most often occur in studies with young adult participants that quantify performance on simple tasks using outcome measures. These results are thought to occur due to a ceiling effect. The present study addressed this effect in two ways. First, working memory was assessed using two different computer-based tasks, varying in complexity and requiring different degrees and types of attentional control.

Second, in addition to the standard outcome measures like overall reaction time and accuracy scores, the design included mouse-tracking data to allow for a detailed look at processing as it occurs in real-time. The major aim of this study was to determine whether bilinguals and monolinguals employed different strategies while engaged in memory tasks. It was hypothesized that bilingual participants would outperform monolinguals on the more difficult conditions of each task, namely the 2-Back and the Scene test. It was also expected that bilinguals would display the expert pattern of responding that has been found in past mouse-tracking studies during the complex tasks. It was believed that bilinguals would demonstrate this advantageous strategy because of their constant use of the attentional control system for language processing throughout their lives.

Method

Participants

One hundred and two York University students (51 monolinguals and 51 bilinguals) between the ages of 18 and 29 were recruited for this study (*M* = 20.65, *SD* = 2.93). Participants were recruited through the Undergraduate Research Participant Pool URPP (URPP) and received academic credit for their involvement. Participants were categorized as monolingual or bilingual based on their responses on the Language and Social Background Questionnaire (Anderson, Mak, Keyvani Chahi, & Bialystok, 2018).

Instruments

Language and Social Background Questionnaire (LSBQ version 10.0). The LSBQ was administered by trained experimenters to assess participants' language use patterns and level of bilingualism (Appendix A). Participants were asked to list all the languages they could speak in order of fluency, along with the age and location of acquisition. Proficiency in each language was self-rated on a scale of 0 (none) to 10 (high), relative to a highly proficient speaker. Fluency was assessed separately for speaking, listening, reading and writing in each language. Participants were also asked to rate how often they use each language on a scale of 0 (never) to 10 (always).

Shipley-2 Vocabulary and Block Pattern Tasks. To obtain a brief but robust estimate of overall cognitive functioning, the Shipley-2 vocabulary and block pattern tasks were administered in paper-and-pencil form. In the vocabulary test, participants were shown a list of 40 capitalized words (Appendix B). For each, participants had to decide which of four options was a synonym of a word in capital letters. The task became progressively more challenging with each word. The participants responded by circling the word they believed to be correct. In the block pattern test, participants were shown a series of 10 template patterns, and next to each was the same pattern with a missing piece (Appendix C). They had to use the template pattern to decide which option completed the pattern. The participants responded by filling in a bubble with the letter of the option they believed to be correct. The task became increasingly more difficult with each trial. In the last few trials, the patterns were rotated and missing multiple pieces. Participants had 10 minutes for each task and were instructed to take their best guess when they are unsure of the correct answer. The raw scores were obtained and then converted into standard scores using an aged-based norming table.

N-Back (Kirchner, 1958). The N-Back is a widely used working memory task. In the N-Back task, participants are presented with a series of numbers that appear on the screen one at a time. They must decide whether the current number matches the one from *n* steps earlier in the series. N can be adjusted to higher or lower the difficulty of the task. In the current study, two computerized versions of this task were used: the 1-Back and 2-Back (Appendix D). In the 1-Back, participants had to decide whether the current number matched the one that came just before it in the sequence. The 2-Back was more difficult and required participants to decide whether the current number was the same as the number two steps before. In both versions of the task, participants responded by using a mouse. After each number, a start button appeared in the center of the monitor. Once clicked, participants moved the mouse to one of two response buttons (yes and no) located in the top left and top right corners of the screen. The maximum response time was 2000 milliseconds, after which the next trial began. Each version of the task consisted of four blocks of 24 trials. Reaction time, accuracy, and mouse tracking data were collected for these tasks.

Item/Associative Task. The Item/Associative task is a task we developed to examine an individual's ability to remember relevant objects and scenes in the face of distracting information (Appendix E). The task begins with a Learning Phase, where participants were shown a series of twelve item and scene pairs on a computer screen. They were then given one of two tasks. In the Object task, a sequence of 24 items were displayed (12 present in learning phase, 12 new, intermixed). Participants had to decide whether they had seen each of the items before in the Learning Phase. Responses were given by clicking the start button in the middle of the screen with a mouse, and then moving the mouse to either the green or red bordered boxes in the top left and right corners of the screen. The box with the green border was used to indicate that the participant saw the object in the learning phase, while the box with the red border was used to indicate that the participant did not see the object. In the Scene task, a sequence of 12 items were shown. In the corners of the screen were four scenes. Participants had to choose the scene that was paired with each image in the Learning Phase. Responses were given by clicking the start button in the middle of the screen and moving the mouse to one of the scenes in the four corners. Four blocks of each task were performed, intermixed. Each block contained its own learning phase, and none of the items were repeated. The order of the tasks were counterbalanced. Reaction time, accuracy, and mouse tracking data was collected for these tasks to be used in analyses.

Procedure

Participants signed up for the study using York University's Undergraduate Research Participant Pool website. Upon arrival at the laboratory, the participant was provided an informed consent form to read over and sign (Appendix F). A trained experimenter administered the LSBQ orally. Next, the participant completed the Shipley-2 Vocabulary and Block Pattern tasks using a pencil and paper. After the background measures, the experimental tasks were performed on a computer. The experimenter provided instruction to the participant for each task. Once each task become clear, the experimental trials proceeded. Participants were administered the tasks in the following order: 1-Back Task, 2-Back Task, and Item/Associative Task. At the end of the testing session, participants were debriefed about the purpose of the study and granted academic credits for their time. Each session took approximately two hours.

Results

Bilingualism

Bilingualism was assessed both categorically and continuously. For categorical analyses, participants were classified into two groups based on their responses to the Language and Social Background Questionnaire (LSBQ). Participants were classified as bilingual if they reported proficiency greater than 60% in speaking and understanding both languages, and monolingual if they reported English language proficiency greater than 60% and second-language proficiency at less than 20%.

For continuous analyses, a calculator that computes factor scores based on responses to the LSBQ was used to obtain a measure of degree of bilingualism. An overall composite score and three component factor scores were calculated for each participant, using weights obtained from an earlier factor analysis (Anderson et al., 2018). The composite score was based on three component factors, (1) Non-English Home Use and Proficiency, (2) Non-English Social Use, and (3) English Proficiency. Factor 1 included items that assessed proficiency in speaking and understanding a non-English language. It also included items that evaluated how often a non-English language was used in the home and with family members. Factor 2 was comprised of questions that measured how often a non-English language was used in various social contexts outside of the home (e.g. with friends, during work, at a doctor's appointment). Factor 3 measured proficiency in speaking, understanding, reading, and writing in English. It also included a measure of English writing use.

To examine the effect of bilingualism on working memory performance, first the categorical division was used to examine the difference between two distinct language groups using between groups ANOVA. Next, the composite factor score was used to assess whether a continuous measure of bilingualism contributed to the participants scores or strategies on each task using Regression analyses.

Background Measures

Mean scores for the background variables are presented in Table 1. One-way ANOVAs showed that monolingual and bilingual participants were similar in age and fluid intelligence, as measured by Shipley-2 Block scores, *F*s < 1. English receptive vocabulary, indicated by Shipley-2 Vocabulary scores, differed between language groups, $F(1, 100) = 6.03$, $p = 0.02$, d = 0.49. Consistent with previous research, monolinguals obtained higher scores than bilinguals (Bialystok & Luk, 2012). Not surprisingly, degree of bilingualism also differed by language group, such that bilinguals received higher scores on the composite factor score than did monolinguals, $F(1,100) = 308.00$, $p < 0.001$, d = 3.47. Differences between language groups were also apparent in each of the three component factors. Bilinguals scored higher on Non-English Home Use and Proficiency, $F(1,100) = 550.30$, $p < 0.001$, d = 4.65, and Non-English Social Use, $F(1,100) = 83.53$, $p < 0.001$, d = 12.81, while monolinguals received higher scores on English Proficiency, $F(1,100) = 19.03$, $p < 0.001$, d = 0.86.

A Pearson's product-moment correlation was computed to determine whether performance on the N-Back was related to performance on the Item/Associative task. A moderate positive correlation between the two tasks was found, r = 0.33, p = 0.001. Participants with high accuracy scores on the N-Back tended to also have high accuracy scores on the Item/Associative task. This result is typical of most cognitive tasks, which tend to correlate moderately with each other.

N-Back Task

Mean accuracy scores for the N-Back task are shown in Table 2. The data were divided into target and non-target rials to account for the four different types of responses that can be produced. During the N-Back, participants can correctly identify a target (hit), fail to identify a target (miss), correctly detect a non-target (correct rejection), or incorrectly detect a target when none is present (false alarm). Hits, false alarms, misses, and correct rejections were each analyzed using 2 x 2 mixed factorial ANOVAs, with language (bilingual versus monolingual) as the between-subject variable and condition (1-Back and 2-Back) as the within-subject variable. There was a significant main effect of condition for hits, F (1, 100) = 88.73, $p < 0.001$, d = 0.50, false alarms, F (1, 100) = 199.22, $p < 0.001$ d = 0.32, correct rejections, F (1, 100) = 199.22, $p <$ 0.001, d = 0.32, and misses, F (1, 100) = 88.73, $p < 0.001$, d = 0.50, with better performance on the 1-back in all cases. There was no significant main effect of language or interaction of language and condition, Fs < 1.

Mean reaction times for correct Target trials on the N-back tasks are shown in Table 2. A 2 x 2 mixed factorial ANOVA for language group and condition was conducted. There was a significant main effect of condition, $F(1, 100) = 138.54$, $p < 0.001$, d = 0.95, but no effect of language group or interaction of language group and condition, Fs <1. Participants performed significantly faster on the 1-Back (M = 1012, SD = 116) than they did on the 2-Back (M = 1135, SD = 142).

In addition to conventional methods of analyses, mouse-tracking measures were used to investigate how participants performed the tasks in real time. These measures were recorded using MouseTracker (Freeman & Ambady, 2010), and processed in R using mousetrap, a software package designed to import, analyze and visualize mouse-tracking data (Kieslich et al., 2017). Of the large number of mouse-tracking variables that can be produced in mousetrap, initiation time and maximum absolute deviation were of the most interest. These variables were important because they allowed us to determine whether bilinguals displayed the expert strategy that they have shown in past mouse-tracking studies. Initiation time is defined as the time at which the first mouse movement is performed after pressing the "Start" key in each trial. Maximum absolute deviation (MAD) is a measure of deflection that records the maximum deviation in pixels from the optimal path connecting the start and end points of the mouse trajectory. Maximum absolute deviation is denoted by a positive value if it occurs above the optimal line, and negative if it occurs below.

Mean initiation times for correct Target trials on the N-Back tasks are shown in Table 2. A 2 x 2 mixed ANOVA showed a significant main effect of condition, $F(1,100) = 6.52$, $p = 0.01$, d = 0.19, indicating that participants initiated their responses earlier on the 1-Back (M = 190, SD = 91) than they did on the 2-Back (M = 211, SD = 122). There was no significant effect of language or interaction of language and condition *F*s < 1.

Maximum absolute deviation for the N-Back tasks are shown in Table 2. A 2 x 2 analysis of variance showed no significant effects or interactions, *F*s < 1.

The continuous scores for degree of bilingualism were entered into regression analyses to assess the contribution of bilingualism on the N-Back tasks after controlling for other factors. The results of the regression analysis measuring the relationship between bilingualism and initiation time are presented in Table 3 and Figure 1. The results indicated that bilingualism, as measured by Non-English Social Use, had a significant effect on initiation time, F (1,00) = 10.69, $p < 0.01$. Therefore, a participant with a higher degree of bilingualism initiated their responses more slowly than a participant with a *lower* degree of bilingualism. LSBQ factor scores did not have a significant effect on reaction time (as exhibited in Table 4 and Figure 2), accuracy, or maximum absolute deviation *F*s < 1.

Object and Scene Tasks

Mean accuracy scores for the Item and Associative task are shown in Table 5. A 2 x 2 mixed factorial ANOVA was conducted with language (bilingual versus monolingual) as the between-subject variable and condition (object test and scene test) as the within-subject variable. There was a significant main effect of condition, F (1,100) = 167.52, $p < 0.001$, d = 1.34, indicating that participants were more accurate on the object test (M= 0.92, SD = 0.08) than they were on the scene test (M = 0.75, SD = 0.16). No significant effect of language or interaction of language and condition was found, *F*s < 1.

Mean reaction times for the Item and Associative task are shown in Table 5. A 2 x 2 mixed analysis of variance revealed a significant main effect of condition, $F(1,100) = 639.28$, $p < 0.001$, d = 2.54. Participants responded faster on the object test (M= 1039, SD = 119) than they did on the scene test (M= 1513, SD = 235). There was no significant effect of language group on reaction time, *F*s < 1, but the interaction of language group and condition was significant, $F(1,100) = 6.18$, $p = 0.01$. This interaction indicates that the effect of language group differs between conditions. Bilinguals performed more slowly than monolinguals on the scene task, $F(1,100) = 4.71$, $p = 0.03$, d = 0.43, but no difference was found between language groups on the object task, *F*s < 1.

Mean initiation times for the Item and Associate task are shown in Table 5. The results of a 2 x 2 mixed ANOVA showed a significant main effect of condition, $F(1,100) = 100.31$, $p < 0.001$, d = 0.71, such that responses were initiated earlier on the object test (M = 311, SD = 125) than they were on the scene test (M = 431, SD = 203). There was no main effect of language group on initiation time, Fs < 1. However, the interaction of language group and condition was significant, $F(1,100) = 8.13$, $p = 0.005$. Bilinguals initiated their responses more slowly than monolinguals on the scene task, $F(1,100) = 4.78$, p = 0.03, d = 0.31, but no difference was found between language groups on the object task, Fs < 1.

Maximum absolute deviations for the Item and Associate task are shown in Table 5. A 2 x 2 mixed factorial ANOVA revealed a significant main effect of condition, $F(1,100) = 127.17$, $p < 0.001$, d = 1.49, but no significant effect of language group or interaction of language and condition, Fs < 1. Participants produced more direct trajectories during the object task (M = 53.96, SD = 46.26) than they did during the scene task (M = -7.34, SD = 35.59).

A regression analysis that was performed to assess the contribution of bilingualism to initiation time on the Item and Associative tasks once other factors had been controlled for is shown in Table 6 and Figure 3. The results showed that bilingualism, as measured by Non-English Social Use, had a significant effect on initiation time, $F(1,100) = 4.46$, p=0.04. Participants with a higher degree of bilingualism initiated their responses more slowly than did participants with a lower degree of bilingualism. Bilingualism had no significant effect on overall reaction time (shown in Table 7 and Figure 4), accuracy or maximum absolute deviation during the Item and Associate tasks, Fs < 1.

Discussion

The present study examined possible differences in working memory between monolingual and bilingual young adults using conventional behavioural and mouse-tracking measures. Two sets of tasks, the N-Back and Item/Associative task, were utilized in order to vary the level of complexity and executive control required to perform each. Using a variety of response variables and tasks allowed for a more nuanced examination of working memory than what would typically be seen using a simpler design and analysis.

The easier versions of each task, namely the 1-Back and the Object test, were used as baselines for their more difficult counterparts. Each of the two more difficult tasks, the 2-Back and the Scene test, introduced conflict and increased cognitive load in some way. In the 2-back task, participants had to indicate when the number on the screen matched a number from two steps earlier in the sequence. This required participants to not only maintain a representation of the sequence in mind, but also to continually update the series of numbers and manage interference from irrelevant items. In the Scene test, participants first viewed a series of items and scenes. They later had to select the scene that was paired with each image while ignoring three familiar distractor scenes. In both tasks, participants had to selectively maintain relevant information while ignoring conflicting stimuli. As expected, participants in both language groups performed more accurately and responded faster during the simpler version of each task. This result supports the idea that both the 2-Back and Scene required more controlled processing than the control conditions.

In order to determine whether bilingualism affected performance on these memory tasks, a thorough investigation into each participant's language history was conducted using the Language and Social Background Questionnaire. The responses were then used both to categorize individuals into a language group and to assess bilingualism as a continuous variable. Bilingual and monolingual participants were first compared on conventional measures of each task (i.e., accuracy and reaction time) to determine if any language group differences existed. We did not anticipate any language group differences to emerge on the easier version of each task but hypothesized that bilinguals would outperform monolinguals on the more complex tests.

Unexpectedly, bilinguals and monolinguals did not show any significant differences in accuracy or reaction time in most of the tasks, except when examining reaction time during the Scene test. While this finding was not expected, it may be explained by the type of participants who were included and the specific tasks involved. Previous studies using young adult undergraduate students have often failed to show significant group differences when the tasks performed were simple (Bialystok, 2017). This result may occur because young adult participants are performing at ceiling levels. Their high performance does not allow enough variability for individual differences related to bilingualism to emerge. If group differences are to be found, tasks need to be challenging enough so that participants display a wider range of performance. The results suggest that despite being more complex than their baseline versions, the 2-Back and the Scene tests were still too simple to elicit group differences in young adults. While the tasks did introduce some conflict, they may not have required a sufficient amount of attentional control for the effect of bilingualism to become apparent.

In order to maximize executive load, some adjustments in the design of the study could have been made. One method of raising the complexity of the n-back is to increase the *n,* so that the current number has to be compared to a number further back in the sequence. Including a 3-Back instead of a 2-Back would have increased the difficulty of the task because participants would have had a greater number of items to manage and update. A second approach would be to reduce the time-limit for each trial. In all tasks, participants had 2000 milliseconds to respond before the screen timed out. The lengthy response deadline increased the simplicity of the task and probably contributed to the extremely high accuracy rates that were observed. A final method of increasing the complexity of the task would be to include lures, which are items that are presented in the sequence but not in the correct *n* location. In these trials, participants must disregard the interference that comes from the familiarity of the item in order to come to a decision based on the position of the number in the sequence. In this way, lures introduce a large amount of conflict that requires attentional control to overcome. Since bilinguals tend to outperform monolinguals on tasks requiring attentional control, it is more likely that group differences will be apparent in n-back designs containing lures compared to traditional versions of the task. Consistent with this claim, one group of researchers found that during a 3-back task, bilingual young adults outperformed monolinguals, but only on trials containing lures (Teubner-Rhodes et al., 2016). On low-conflict trials that did not contain any lures, no language group differences were observed. Including lures in the present study would have improved our ability to systematically control the amount of conflict involved, in order to ensure that the task required adequate cognitive control.

In addition to conventional measures, we included mouse-tracking variables in order to examine performance on each task over time. While research using mouse-tracking is still novel, a few studies have found differences in the strategies that bilingual and monolingual individuals employ while engaging in executive function tasks. Specifically, researchers have found that bilinguals tend to act as experts, waiting longer to initiate a response but carrying out a faster or more efficient trajectory (Incera & McLennan, 2015; Damian et al., 2018). In the current study, we expected the same pattern of results to emerge for the more complex tasks. However, when performance between monolingual and bilingual participants was compared, the results were more ambiguous.

There were no group differences in the efficiency of the participants' responses in any of the tasks, as measured by maximum absolute deviation. Language group did not have any significant effect on initiation time during the n-back but in the Item/Associative task, the effect of language on initiation time differed depending on the condition. Monolingual and bilingual participants initiated their responses equally as fast during the Object task, but bilinguals were slower to respond on the more difficult Scene test. This result converges with previous findings that suggest bilinguals act as experts, however, in this instance bilingual's responses were not more efficient or faster, as they were in other mouse-tracking studies. Instead, bilinguals' total response time was slower during the Scene test, probably as a result of their slower initiation time. The lack of convergence between the current study and past mouse-tracking experiments seems to be a result of the type of task used. In the studies where bilinguals acted as experts, the design included tasks that required attentional control. The tasks involved in the present study probably did not contain enough conflict to recruit the attentional control mechanism that drives the bilingual advantage in some measures of executive function. Modifying the design to include a greater amount of conflict would more closely align with the tasks used in previous research.

In addition to examining the effect of language experience using two distinct groups, a continuous measure of bilingualism was also obtained from responses on the LSBQ. Regression analyses of bilingual participants found that on both the N-Back and the Item/Associative tasks, the more bilingual a participant, the slower their initiation time. This supports the interpretation that the slower initiation time was in fact a consequence of bilingualism. Interestingly, overall reaction time was not related to level of bilingualism as measured by participants' factor scores.

Previous research has suggested that this pattern of responding is characteristic of experts in various domains. Experts take more time to assess the environment before initiating a response, but then respond more efficiently (Incera & McLennan, 2015). In a cognitive task, a more efficient response is one that is faster or displays a more direct trajectory. In this case, highly proficient bilinguals were more efficient than less proficient bilinguals because despite their longer initiation times, their overall reaction time was not compromised. The more bilingual participants allocated their time differently, spending more time evaluating each trial before beginning a response and less time completing the response. This pattern is similar to results found in a study by Incera and McLennan (2015), who determined that bilinguals initiated their responses on a Stroop task more slowly than monolinguals did, without decreasing their overall speed. However, while researchers in the previous study uncovered a difference between language groups, our investigation revealed an effect when bilingualism was examined as a continuous factor. Finding a continuous effect is powerful because the underlying cause of the effect is clearer. Since group differences may be driven by other unknown differences between groups, a continuous effect tied to the degree of bilingualism in a model that includes other potential sources of variation bolsters the interpretation that the difference in initiation time is in fact a consequence of bilingualism. It is especially compelling that the same relationship was not observed between overall reaction time and bilingualism, even though a group difference was found on the Scene test. The results of the regression analysis support the conclusion that bilingualism impacts the strategies that participants display while completing memory tasks. In the future, tasks requiring more controlled processing should be utilized to allow for more robust differences to appear.

Conclusion

The present study provided a close examination into the effect of bilingualism on two sets of memory tasks, using conventional and mouse-tracking methods. While there is a plethora of research examining the relationship between bilingualism and various components of executive functioning, research on working memory is more limited. Given that working memory requires the ability to control attention, and bilinguals often show increased performance in EF tasks requiring attentional control, it is logical to assume that bilinguals would also show better working memory performance than monolinguals. While some studies support this conclusion, others have found no significant language differences. A number of factors may contribute to the ambiguous findings, including the characteristics of the participants as well as the tasks. As with other components of executive function, the greatest language differences in working memory seem to emerge in children rather than young adults. The language participants complete the task in also matters, as bilinguals tend to outperform monolinguals only when carrying out tasks in their first language (Grundy & Timmer, 2017). Other components of the task may also contribute to the language effect, including the level of required attentional control (Teubner-Rhodes et al., 2016) and WM domain (Luo et al., 2013). The relationship between bilingualism and working memory is complex and more research is needed to uncover the factors that moderate the bilingual advantage that is sometimes found.

The current study attempts to illuminate some of these factors. It is the first study exploring the effect of bilingualism on working memory using mouse-tracking software. This method is important because it allows for a detailed analysis of performance in real time. Utilizing mouse-tracking allowed us to not only evaluate outcome variables, but also the strategies that participants employ while they execute their responses. Without this approach, it would not have been possible to record the initiation time results that distinguished bilingual performance from that of monolinguals. It was also essential that a continuous measure of bilingualism was used, as it provided a more precise and realistic picture of bilingualism than solely relying on discrete groups. Since bilingualism research using young adult participants often produces conflicting results, this study helps clarify the reasons why bilinguals do not always show an increase in performance. In this instance, the study design did not provide an adequate amount of attentional control for group differences to emerge. The tasks may have been appropriate for older adults but were too simple for young-adult university undergraduates. When tasks are too simple, group differences are unlikely to appear because the attentional control system that underlies the bilingual advantage is not activated. Additionally, using numbers and objects instead of a purely non-verbal stimulus, such as nonsense line drawings, could have contributed to the nonsignificant findings. Monolinguals often outperform bilinguals on tasks that require linguistic processing (Bialystok, Craik & Luk, 2012). While not as verbally demanding as a task involving words, memory tests using numbers and nameable objects still contain a verbal element that may disadvantage bilingual participants. The results of this study suggest that future research in this area should employ memory tasks that introduce a large amount of conflict, rely on attentional control, and are purely non-verbal. Considering that working memory ability is associated with real world outcomes such as problem solving, reading comprehension and over all academic achievement, more closely understanding the benefit that second-language experience has on this ability is extremely important.

References

Anderson, J. A., Mak, L., Keyvani Chahi, A. K., & Bialystok, E. (2017). The language and social background questionnaire: Assessing degree of bilingualism in a diverse population. Behavior Research Methods, 1-14.

Adesope, O. O., Lavin, T., Thompson, T., & Ungerleider, C. (2010). A systematic review and meta-analysis of the cognitive correlates of bilingualism. *Review of Educational Research, 80*(2), 207-245.

Baddeley, A. D., & Hitch, G. (1974). Working memory. *Psychology of learning and motivation, 8*, 47-89.

Barac, R., Bialystok, E., Castro, D. C., & Sanchez, M. (2014). The cognitive development of young dual language learners: A critical review. *Early Childhood Research Quarterly, 29*(4), 699-714.

Bialystok, E. (2017). The bilingual adaptation: How minds accommodate experience. *Psychological bulletin, 143*(3), 233.

Bialystok, E., Craik, F., & Luk, G. (2008). Cognitive control and lexical access in younger and older bilinguals. *Journal of Experimental Psychology: Learning, memory, and cognition, 34(*4), 859.

Bialystok, E., Craik, F. I., & Luk, G. (2012). Bilingualism: consequences for mind and brain. Trends in cognitive sciences, 16(4), 240–250. doi:10.1016/j.tics.2012.03.001

Bialystok, E., Craik, F., Green, D., & Gollan, T. (2009). Bilingual minds. *Psychological Science in the Public Interest*, *10*, 89–129.

Bialystok, E., & Luk, G. (2012). Receptive vocabulary differences in monolingual and bilingual adults. *Bilingualism: Language and Cognition, 15*(2), 397-401. doi:10.1017/

S136672891100040X. h

Bonifacci, P., Giombini, L., Bellocchi, S., & Contento, S. (2011) Speed of processing, anticipation, inhibition and working memory in bilinguals. *Developmental Science 14*, 256–69.

Damian, M., Ye, W., Oh, M., & Yang, S. (2018). Bilinguals as “experts”? Comparing performance of mono- to bilingual individuals via a mousetracking paradigm. *Bilingualism: Language and Cognition*, 1-18. doi:10.1017/S1366728918000901

De Baene, W., Duyck, W., Brass, M., & Carreiras, M. (2015). Brain circuit for cognitive control is shared by task and language switching. *Journal of Cognitive Neuroscience, 27*(9), 1752-1765.

Engle, R. W. (2002). Working memory capacity as executive attention. *Current directions in psychological science, 11*(1), 19-23.

Eriksson, J., Vogel, E. K., Lansner, A., Bergström, F., & Nyberg, L. (2015). Neurocognitive architecture of working memory. *Neuron, 88*(1), 33-46.

Freeman, J. B., & Ambady, N. (2010). Mouse Tracker: Software for studying real-time mental processing using a computer mouse-tracking method. *Behavior Research Methods, 42* (1), 226-241.

Green, C. S., & Bavelier, D. (2008). Exercising your brain: a review of human brain plasticity and training-induced learning. *Psychology and Aging, 23*(4), 692.

Grundy, J. G., & Timmer, K. (2016). Bilingualism and working memory capacity: A comprehensive meta-analysis. *Second Language Research*, 0267658316678286

Herholz, S. C., & Zatorre, R. J. (2012). Musical training as a framework for brain plasticity: behavior, function, and structure. *Neuron* 76, 486–502.

Hillman, C.H., Erickson, K. I., & Kramer, A. F. Be smart, exercise your heart: Exercise effects on brain and cognition. *Nature Reviews Neuroscience, 2008*(9), 58–65.

Incera, S., & McLennan C. T. (2015) Mouse tracking reveals that bilinguals behave like experts. *Bilingualism: Language and Cognition, 19*(3), 610-620.

Kaushanskaya, M., Blumenfeld, H. K., & Marian V. (2011). The relationship between vocabulary and short-term memory measures in monolingual and bilingual speakers. *International Journal of Bilingualism 15,* 408–425.

Kieslich, P.J. & Henninger, F. (2017). Mousetrap: An integrated, open-source mouse-tracking package. *Behavior Research Methods, 49*(5), 1652-1667. https://doi.org/10.3758/s13428-017-0900-z

Kolb, B., & Whishaw, I. Q. (1998). Brain plasticity and behavior. *Annual Review of Psychology, 49*, 43-64.

Kousaie, S. & Phillips, N. A. (2012). Conflict monitoring and resolution: are two languages better than one? Evidence from reaction time and event-related brain potentials. *Brain Research, 1446,* 71–90.

Kroll, J. F., & Bialystok, E. (2013). Understanding the consequences of bilingualism for language processing and cognition*. Journal of Cognitive Psychology, 25*(5), 497-514.

Luk, G., Bialystok, E., Craik, F. I., & Grady, C. L. (2011). Lifelong bilingualism maintains white matter integrity in older adults*. Journal of Neuroscience, 31*(46), 16808-16813.

Luo, L., Craik, F. I., Moreno, S., & Bialystok, E. (2013). Bilingualism interacts with domain in a working memory task: Evidence from aging. *Psychology and Aging, 28*(1), 28.

Marian, V., Spivey, M., & Hirsch, J. (2003). Shared and separate systems in bilingual language processing: Converging evidence from eyetracking and brain imaging. *Brain and*

Language, 86(1), 70-82.

McCabe, D. P., Roediger III, H. L., McDaniel, M. A., Balota, D. A., & Hambrick, D. Z. (2010). The relationship between working memory capacity and executive functioning: evidence for a common executive attention construct. *Neuropsychology, 24*(2), 222.

Morales, J., Calvo, A., & Bialystok, E. (2013). Working memory development in monolingual and bilingual children. *Journal of Experimental Child Psychology, 114(*2), 187-202.

Paap, K. R., Greenberg, Z. I. (2013). There is no coherent evidence for a bilingual advantage in executive processing. *Cognitive Psychology, 66,* 232–258.

Pons, F., Bosch, L., & Lewkowicz, D. J. (2015). Bilingualism modulates infants' selective attention to the mouth of a talking face. *Psychological science*, 0956797614568320.

Porter, G., Troscianko, T., & Gilchrist, I. D. (2007). Effort during visual search and counting: Insights from pupillometry. *Quarterly Journal of Experimental Psychology, 60*, 211–229.

Noble, K. G., Houston, S. M., Brito, N. H., Bartsch, H., Kan, E., Kuperman, J. M., ... & Schork, N. J. (2015). Family income, parental education and brain structure in children and adolescents. *Nature neuroscience, 18*(5), 773-778.

Rosenzweig, M. R., & Bennett, E. L. (1996). Psychobiology of plasticity: effects of training and experience on brain and behavior. *Behavioural brain research, 78*(1), 57-65.

Singh, N., & Mishra R. K. (2013) Second language proficiency modulates conflict-monitoring in an oculomotor Stroop task: Evidence from Hindi-English bilinguals. *Frontiers in Psychology, 4,*1-10.

Susan E. Teubner-Rhodes S. E., et al. (2016). The effects of bilingualism on conflict monitoring, cognitive control, and garden-path recovery. *Cognition, 150, 213-231.* https://doi.org/10.1016/j.cognition.2016.02.011.

Yang, H., & Yang, S. (2016). Are all interferences bad? Bilingual advantages in working memory are modulated by varying demands for controlled processing. *Bilingualism: Language and Cognition,* 1-13.

Table 1

Mean scores and standard deviation for Background Measures

Background Measures	Monolingual (n=51)	Bilingual (n=51)
Age	20.21 (3.17)	21.08 (2.63)
<u>LSBQ Factor Scores</u>		
Non-English Home Use and Proficiency	-21.32 (6.04)	30.94*** (14.72)
Non-English Social Use	-7.40 (0.42)	24.37*** (3.48)
English Proficiency	6.63 (0.00)	4.27*** (3.86)
Composite Factor Score	-8.53 (2.05)	17.99*** (10.60)
<u>Shipley-2 Scores</u>		
Shipley-2 Standardized Vocabulary	103.47 (9.96)	98.25* (11.43)
Shipley-2 Standardized Block	102.39 (10.71)	101.12 (12.82)
Shipley-2 Standardized Composite	103.75 (10.26)	100.45 (11.03)

Note: * < 0.05, *** < 0.001

Table 2

Mean scores and standard deviation in N-Back task

	Condition			
	1-Back		2-Back	
	Monolingual	Bilingual	Monolingual	Bilingual
Hit Rate	0.95 (0.006)	0.94 (0.12)	0.82 (0.12)	0.81 (0.13)
False Alarm Rate	0.03 (0.17)	0.02 (0.15)	0.12 (0.31)	0.11 (0.32)
Correct Rejection Rate	0.97 (0.17)	0.98 (0.15)	0.89 (0.31)	0.88 (0.32)
Miss Rate	0.05 (0.22)	0.06 (0.23)	0.18 (0.38)	0.19 (0.39)
Reaction Time (ms)	1006 (105)	1018 (128)	1126 (165)	1144 (114)
Initiation Time (ms)	190 (91)	205 (99)	210 (114)	210 (125)
Maximum Absolute Deviation (pixels)	178.77 (134.69)	194.41 (138.87)	200.14 (138.07)	189.89 (149.31)

Table 3

Linear Regression Analysis for N-Back Task initiation time

Variable	B	SE B	β	ΔR^2	F
N-Back Task $R^2 = 8.0\%$					
Age	1.26	2.97	0.03	0.1%	0.12
Gender	-64.36	20.77	-0.22	3.0%	6.16 *
Shipley-2 Composite	0.03	0.73	0.003	0.2%	0.54
Bilingualism (L2 Social Use)	1.04	0.33	0.23	4.7%	10.69 **

Note: * < 0.05, ** < 0.01

Table 4

Linear Regression Analysis for N-Back Task reaction time

Variable	B	SE B	β	ΔR^2	F
N-Back Task $R^2 = 9.4\%$					
Age	8.93	3.53	0.17	3.0%	6.38*
Gender	49.08	24.14	0.14	2.1%	4.14*
Shipley-2 Composite	-2.48	0.83	0.20	4.1%	6.68**
Bilingualism (L2 Social Use)	0.31	0.85	0.23	0.2%	0.67

Note: * < 0.05, ** < 0.01

Table 5

Mean scores and standard deviation in Item and Associate Task

	Condition			
	Object Test		Scene Test	
	Monolingual	Bilingual	Monolingual	Bilingual
Accuracy	0.92 (0.08)	0.92 (0.09)	0.74 (0.18)	0.77 (0.15)
Reaction Time (ms)	1036 (125)	1042 (113)	1464 (214)	1563 (246)
Initiation Time (ms)	315 (119)	308 (133)	400 (173)	462 (226)
Maximum Absolute Deviation (px)	50.46 (51.20)	57.46 (51.20)	-8.16 (29.84)	-6.51 (40.82)

Table 6

Linear Regression Analysis for Item and Associative Task initiation time

Variable	B	SE B	β	ΔR^2	F
Item and Associative Task $R^2 = 7.2\%$					
Age	7.81	7.58	0.10	1.6%	1.68
Gender	1.26	52.97	0.003	0.2%	0.16
Shipley-2 Composite	-1.04	1.85	-0.06	1.2%	1.19
Bilingualism (L2 Social Use)	1.77	0.84	0.22	4.3%	4.46 *

Note: * < 0.05

Table 7

Linear Regression Analysis for Item and Associative Task reaction time

Variable	B	SE B	β	ΔR^2	F
Item and Associative Task $R^2 = 5.9\%$					
Age	14.25	12.12	0.09	1.4%	1.38
Gender	100.15	83.00	0.13	1.4%	1.42
Shipley-2 Composite	-5.02	2.86	-0.17	3.0%	3.09
Bilingualism (L2 Social Use)	0.25	1.34	0.02	0.1%	0.03

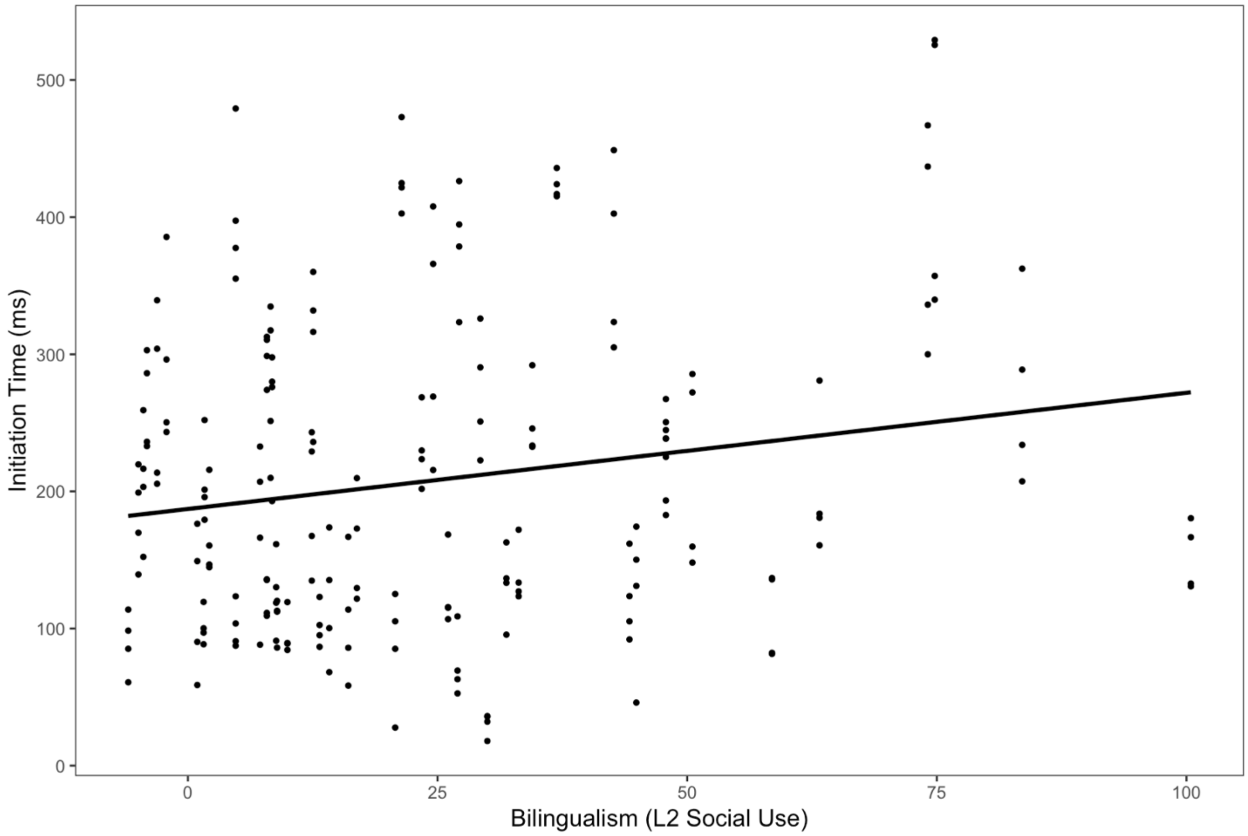

Figure 1. Relationship between bilingualism and initiation time for N-Back Task

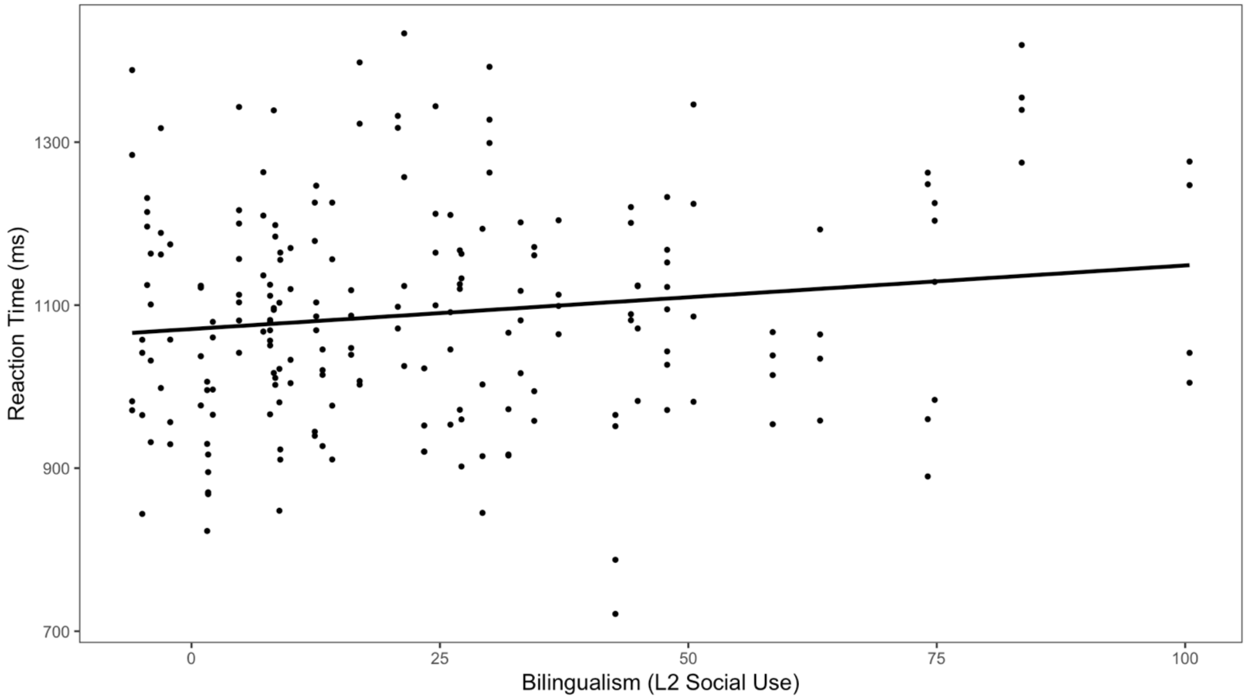

Figure 2. Relationship between bilingualism and reaction time for N-Back Task

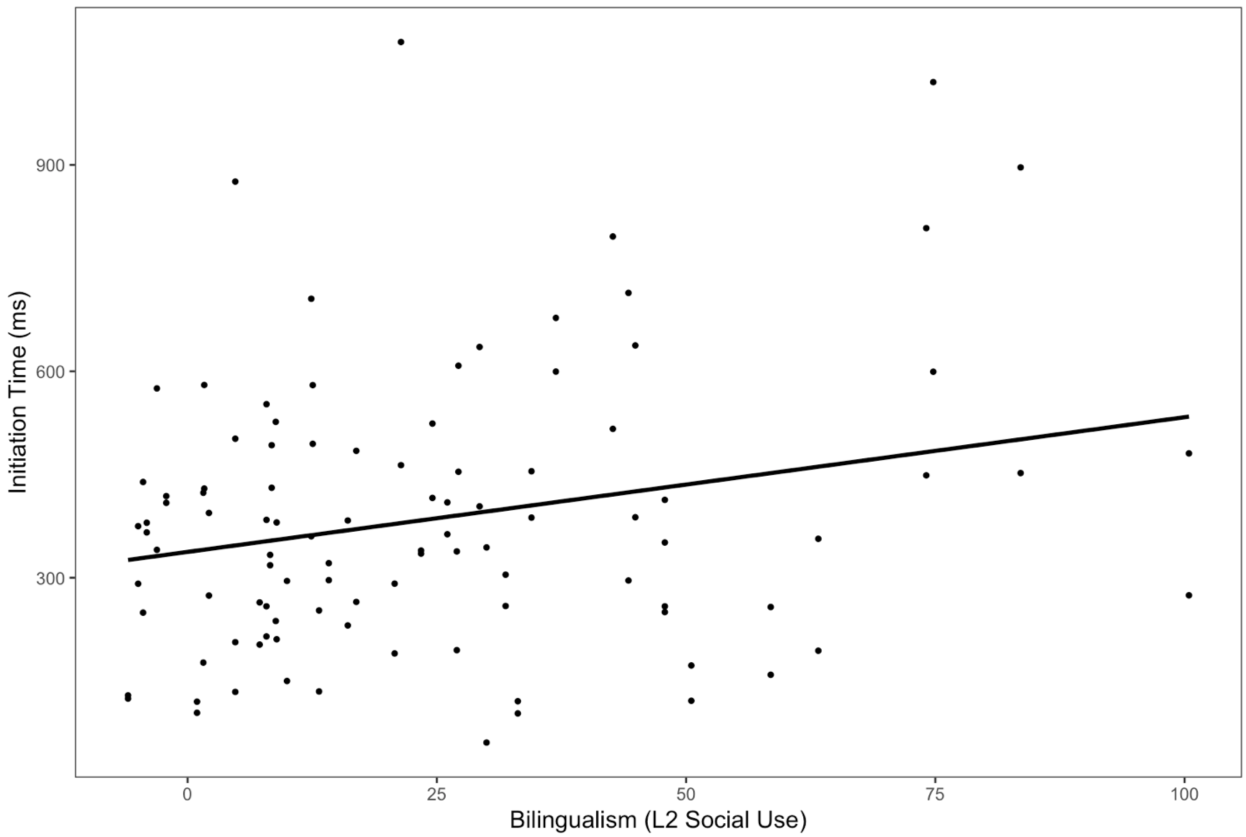

Figure 3. Relationship between bilingualism and initiation time for Item and Associative Task

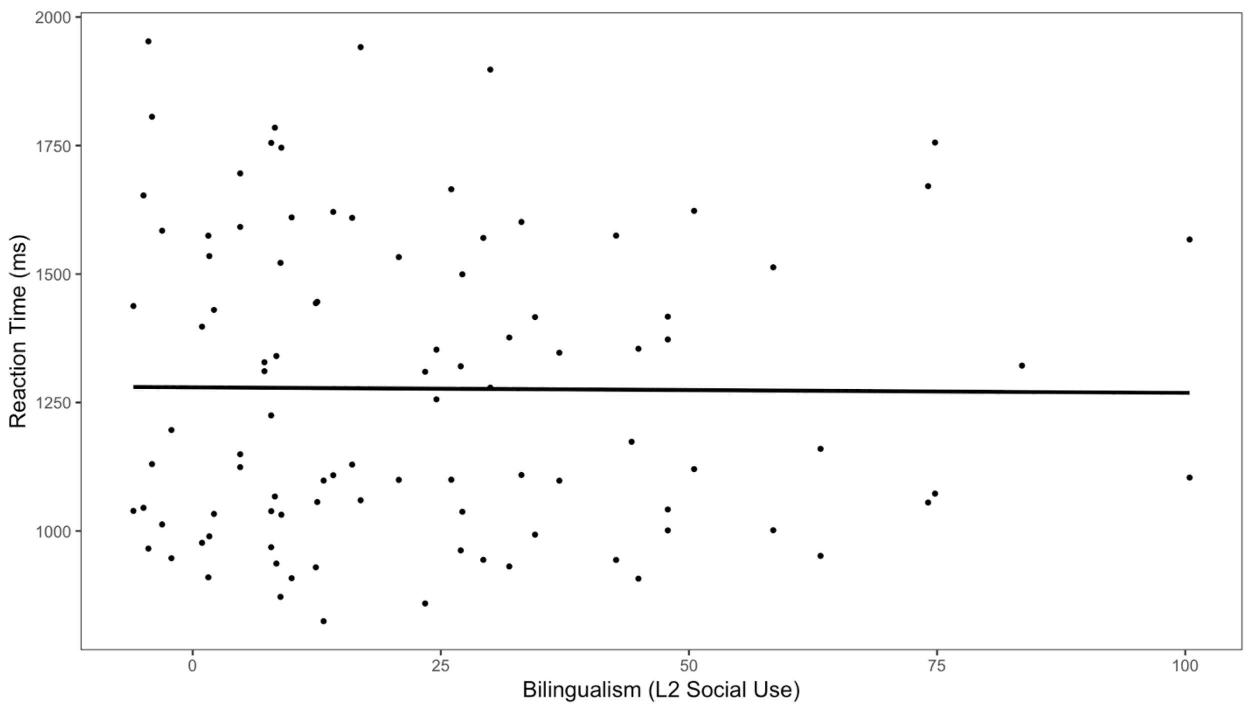

Figure 4. Relationship between bilingualism and reaction time for Item and Associative Task

Appendix A: Language and Social Background Questionnaire (LSBQ)

YAV Reference ID ____________________

Lifespan Cognition and Development Laboratory
Ellen Bialystok, Ph.D., Principal Investigator
Department of Psychology, York University

Language and Social Background Questionnaire

Today's Date: ____________________
Day **Month** **Year**

1. Sex: Male ☐ Female ☐
2. Occupation/Student Status (i.e. FT/PT, current year of study): ____________________
3. Handedness: Left ☐ Right ☐
4. Date of Birth: ____________________
Day **Month** **Year**

5. Do you play first-person shooting (FPS)/action video games? **Yes** ☐ **No** ☐
   If **yes**, on average how many hours do you play per week? ____________________
6. Do you have hearing problems? **Yes** ☐ **No** ☐
   If **yes**, do you wear a hearing aid? **Yes** ☐ **No** ☐
7. Do you have vision problems? **Yes** ☐ **No** ☐
   If **yes**, do you wear glasses or contacts? **Yes** ☐ **No** ☐
   Is your vision corrected to normal with glasses or contacts? **Yes** ☐ **No** ☐
8. Are you colour blind? **Yes** ☐ **No** ☐
   If **yes**, what type? ____________________
9. Have you ever had a head injury **Yes** ☐ **No** ☐
   If **yes**, please explain: ____________________
10. Do you have any known neurological impairments? (e.g., epilepsy etc) **Yes** ☐ **No** ☐
    If **yes**, please indicate: ____________________
11. Are you currently taking any psychoactive medications? **Yes** ☐ **No** ☐
    If **yes**, please indicate: ____________________

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YA Version 10.0 (2015)

12. Please indicate the highest level of education and occupation for each parent:

Mother			Father		
1.	_____	No high school diploma	1.	_____	No high school diploma
2.	_____	High school diploma	2.	_____	High school diploma
3.	_____	Some post-secondary education	3.	_____	Some post-secondary education
4.	_____	Post-secondary degree or diploma	4.	_____	Post-secondary degree or diploma
5.	_____	Graduate or professional degree	5.	_____	Graduate or professional degree
Occupation:		____________	Occupation:		____________
First Language:		____________	First Language:		____________
Second Language:		____________	Second Language:		____________
Other Language:		____________	Other Language:		____________

13. Were you born in Canada? **Yes** ☐ **No** ☐

If **no**, where were you born? ____________

When did you move to Canada ____________

Year

14. Have you ever lived in a place where English is not the dominant communicating language? **Yes** ☐ **No** ☐

		From	**To**
If **yes**, where and for how long?	1. ____________	________	________
	2. ____________	________	________
	3. ____________	________	________
		Year	**Year**

Language Background

15. List all the language and dialects you can speak including English, ***in order of fluency***:

Language	Where did you learn it?	At what age did you learn it? (If learned from birth, write age "0")	Were there any periods in your life when you did not use this language? Indicate duration in months/years.
1.____________	**☐Home ☐School ☐Community ☐Other:** ____________		
2.____________	**☐Home ☐School ☐Community ☐Other:** ____________		
3.____________	**☐Home ☐School ☐Community ☐Other:** ____________		
4.____________	**☐Home ☐School ☐Community ☐Other:** ____________		
5.____________	**☐Home ☐School ☐Community ☐Other:** ____________		

16. Please indicate how often you heard or used a ***non-English language*** in the following life stages, both inside and outside of the home. If you do not know any language(s) other than English, fill in all the questions with 0, as appropriate.

		Always English 0	5	Always non-English 10
16.1	Infancy			
16.2	Preschool age			
16.3	Primary School age			
16.4	High school age			
16.5	College/University age			

Relative to a highly proficient speaker's performance, rate your proficiency level on a scale of 0-10 for the following activities conducted in English and your other language(s).

17.1 **English**

	No Proficiency 0	5	High Proficiency 10
Speaking			
Understanding			
Reading			
Writing			

17.2 Of the time you spend engaged in each of the following activities, how much of that time is carried out in English?

	Never English 0	5	Always English 10
Speaking			
Listening			
Reading			
Writing			

18.1 **Other Language:** ____________________

	No Proficiency 0	5	High Proficiency 10
Speaking			
Understanding			
Reading			
Writing			

18.2 Of the time you spend engaged in each of the following activities, how much of that time is carried out in this language?

	Never this language 0	5	Always this language 10
Speaking			
Listening			
Reading			
Writing			

19.1 **Other Language:** ____________________

	No Proficiency 0	5	High Proficiency 10
Speaking			
Understanding			
Reading			
Writing			

19.2 Of the time you spend engaged in each of the following activities, how much of that time is carried out in this language?

	Never this language 0	5	Always this language 10
Speaking			
Listening			
Reading			
Writing			

20.1 **Other Language:** ____________________

	No Proficiency 0	5	High Proficiency 10
Speaking			
Understanding			
Reading			
Writing			

20.2 Of the time you spend engaged in each of the following activities, how much of that time is carried out in this language?

	Never this language 0	5	Always this language 10
Speaking			
Listening			
Reading			
Writing			

The following questions refer to the language you know best aside from English.
If you do not know any language(s) other than English, fill in all the questions with 0, as appropriate.

21. How well are you able to engage in an informal conversation about daily routines and activies in your best non-English language?

No ability at all — Perfect Ability
0 — 5 — 10

22. How well are you able to talk about work/school in your best non-English language?

No ability at all — Perfect Ability
0 — 5 — 10

23. How well are you able to understand a TV show or movie in your best non-English language without subtitles?

No ability at all — Perfect Ability
0 — 5 — 10

24. How well are you able to understand the news on TV or the radio in your best non-English language?

No ability at all — Perfect Ability
0 — 5 — 10

25. How well are you able to talk about current events and items in the news in your best non-English language?

No ability at all — Perfect Ability
0 — 5 — 10

26. How well are you able to complete a banking or government transaction in your best non-English language?

No ability at all — Perfect Ability
0 — 5 — 10

27. During a debate or an emotional conversation in your best non-English language, how well are you able to express your opinions or emotions?

No ability at all — Perfect Ability
0 — 5 — 10

28. How well can you switch between formal (official) and informal (slang) styles of speech in your best non-English language?

No ability at all — Perfect Ability
0 — 5 — 10

29. How well are you able to act as an informal translator between English and your best non-English language for a new immigrant who speaks no English?

No ability at all — Perfect Ability
0 — 5 — 10

30. How well are you able to tell children's stories/fairy tales in your best non-English language?

No ability at all — Perfect Ability
0 — 5 — 10

YAV Reference ID ____________________

Community Language Use Behaviour

31. Please indicate how often you use a non-English language with the following people. If you do not know any language(s) other than English, fill in all the questions with 0, as appropriate.

		Always English 0	5	Always non-English 10	N/A
31.1	Parents				☐
31.2	Siblings				☐
31.3	Grandparents				☐
31.4	Other Relatives				☐
31.5	Partner				☐
31.6	Roommate(s)				☐
31.7	Neighbours				☐
31.8	Friends				☐

32. Please indicate how often you use a non-English language in the following situations. If you do not know any language(s) other than English, fill in all the questions with 0, as appropriate.

		Always English 0	5	Always non-English 10	N/A
32.1	Home				☐
32.2	School				☐
32.3	Work				☐
32.4	Social activities (e.g. hanging out with friends, movies)				☐
32.5	Religious activities				☐
32.6	Extracurricular activities (e.g. hobbies, sports, volunteering, gaming)				☐
32.7	Shopping/ Restaurants/ Other commercial services				☐
32.8	Health care services/ Government/ Public offices/ Banks				☐

33. Please indicate how often you use a non-English language when performing the following activities. If you do not know any language(s) other than English, fill in all the questions with 0, as appropriate.

		Always English 0	5	Always non-English 10	N/A
33.1	Reading	●		●	☐
33.2	Emailing	●		●	☐
33.3	Texting	●		●	☐
33.4	Social media (e.g. Facebook, Twitter etc.)	●		●	☐
33.5	Writing shopping lists, notes, etc.	●		●	☐
33.6	Watching TV/ listening to radio	●		●	☐
33.7	Watching movies	●		●	☐
33.8	Browsing on the Internet	●		●	☐
33.9	Praying	●		●	☐

34. Some people switch between the languages they know within a single conversation (i.e. while speaking in one language they may use sentences or words from the other language). This is known as "language-switching". Please indicate how often you engage in language-switching. If you do not know any language(s) other than English, fill in all the questions with 0, as appropriate.

		Never language switch 0	5	Always language switch 10
34.1	With parents and family	●		●
34.2	With friends	●		●
34.3	On social media (e.g. Facebook, Twitter)	●		●

35. Please indicate your agreement with the following statements regarding language use in your community.

		Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
35.1	I mix my languages most of the time when interacting with people in my community.	☐	☐	☐	☐
35.2	I prefer to speak to people in English even if we speak a common non-English language.	☐	☐	☐	☐
35.3	I only use my other language(s) when it is necessary (i.e. with people who have difficulties understanding English.)	☐	☐	☐	☐
35.4	Using languages other than English is viewed positively in my community.	☐	☐	☐	☐
35.5	Mixing languages in the same conversation is viewed positively in my community.	☐	☐	☐	☐
35.6	I feel comfortable using my other language(s) in public.	☐	☐	☐	☐

Thank you for participating!

Appendix B: Shipley-2 Vocabulary Test

SHIPLEY-2 INSTITUTE OF LIVING SCALE - VOCABULARY TEST

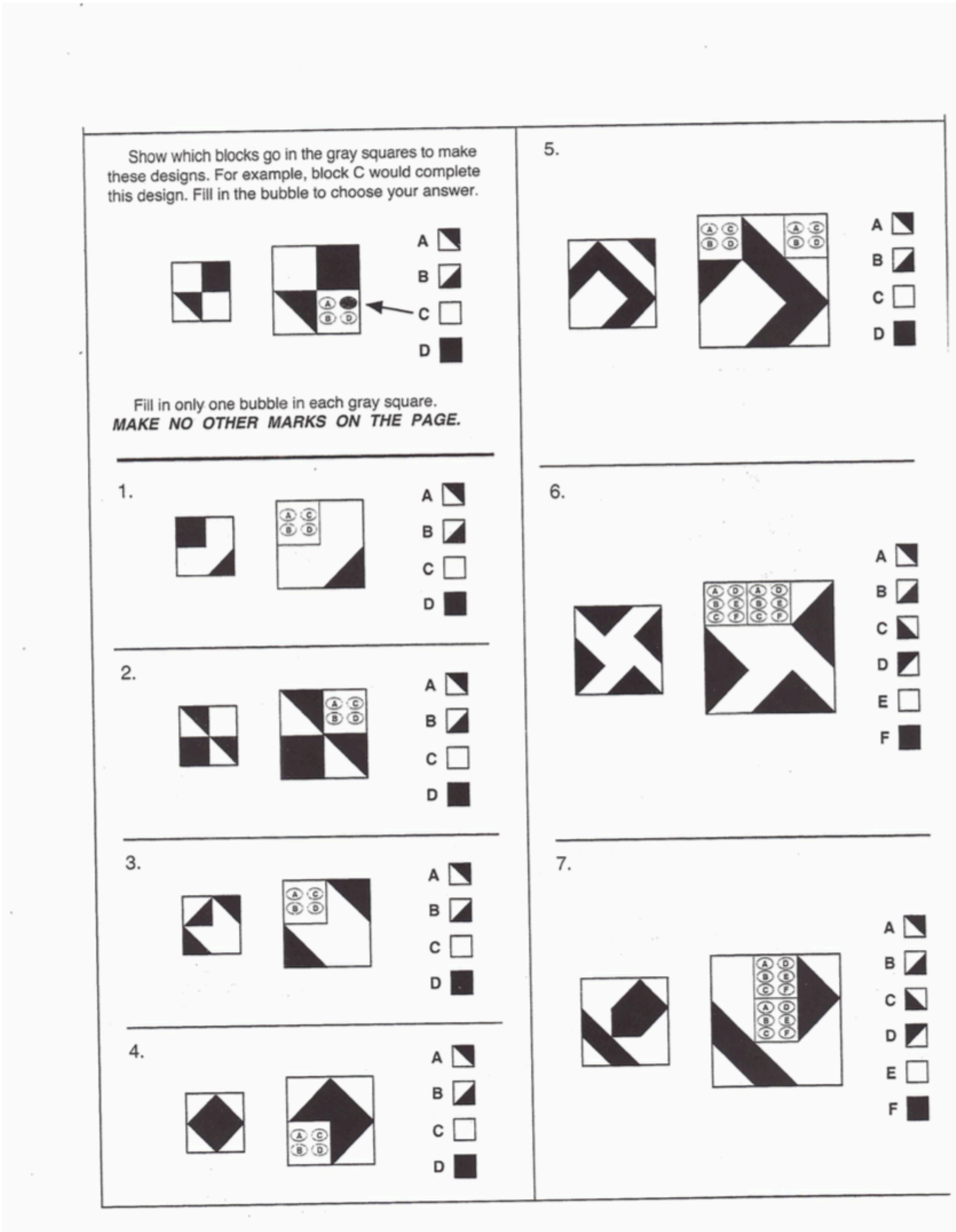
Instructions: Circle the word that has the same meaning as the one written in capital letters. If you want to change an answer, draw an **X** through your first answer and then circle your new choice. Please press hard when marking your responses.

EXAMPLE:

	LARGE	red	big	silent	wet
1	TALK	draw	eat	speak	sleep
2	COUCH	pin	eraser	sofa	glass
3	REMEMBER	swim	recall	number	plan
4	PARDON	forgive	pound	divide	crash
5	HIDEOUS	silvery	tilted	young	dreadful
6	MASSIVE	bright	large	speedy	low
7	PROBABLE	likely	portable	friendly	comprehensive
8	IMPOSTER	conductor	officer	book	pretender
9	FASCINATE	welcome	fix	stir	enchant
10	EVIDENT	green	obvious	skeptical	afraid
11	NARRATE	yield	buy	associate	tell
12	HAUL	respond	twist	pull	realize
13	HILARITY	laughter	speed	grace	malice
14	IGNORANT	red	sharp	uninformed	precise
15	CAPTION	drum	ballast	heading	ape
16	INDICATE	defy	excite	signify	bicker
17	SOLEMN	serious	satisfying	rough	tremendous
18	FORTIFY	submerge	strengthen	vent	deaden

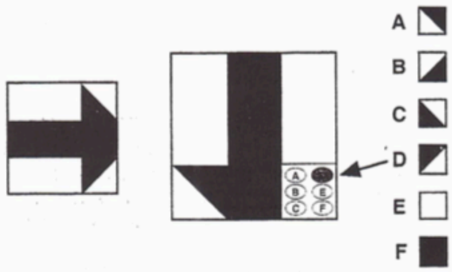
19	MERIT	deserve	distrust	fight	separate
20	RENOWN	length	head	fame	loyalty
21	FACILITATE	turn	help	strip	bewilder
22	AMULET	charm	orphan	dingo	pond
23	STERILE	barren	illegal	helpless	tart
24	CORDIAL	swift	muddy	leafy	affable
25	SQUANDER	tease	belittle	slice	waste
26	SERRATED	dried	notched	armed	blunt
27	PLAGIARIZE	maintain	intend	revoke	pilfer
28	ORIFICE	brush	hole	building	lute
29	PRISTINE	vain	sound	unspoiled	level
30	INNOCUOUS	powerful	pure	medicinal	harmless
31	JOCOSE	humorous	paltry	fervid	plain
32	RUE	deal	lament	dominate	cure
33	INEXORABLE	untidy	inviolable	relentless	sparse
34	DIVEST	dispossess	intrude	rally	pledge
35	MOLLIFY	mitigate	direct	pertain	abuse
36	QUERULOUS	maniacal	curious	devout	complaining
37	ABET	waken	ensue	incite	placate
38	DESUETUDE	disuse	remonstrance	corruption	inanity
39	PEREGRINATE	contemplate	mince	solidify	traverse
40	QUOTIDIAN	travesty	everyday	calculation	promise

Appendix C: Shipley-2 Block Patterns Test



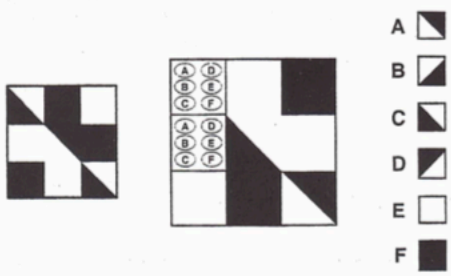
In the items below, each pair of boxes shows two versions of the same design. Show which blocks go in the gray squares to make these designs. Fill in one bubble in each gray square.

For example, block D would complete this design.

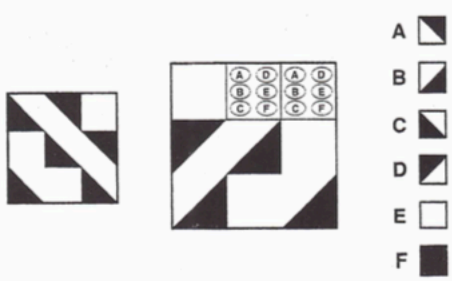


Fill in only one bubble in each gray square.
MAKE NO OTHER MARKS ON THE PAGE.

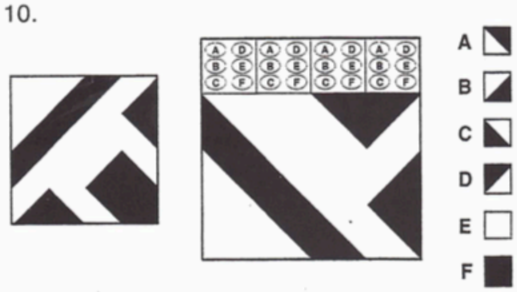
8.



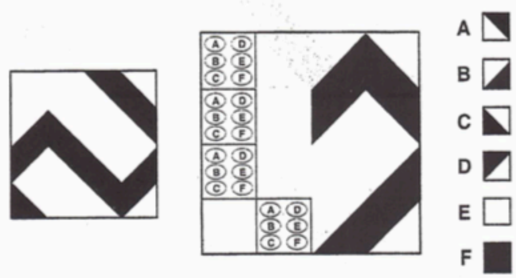
9.



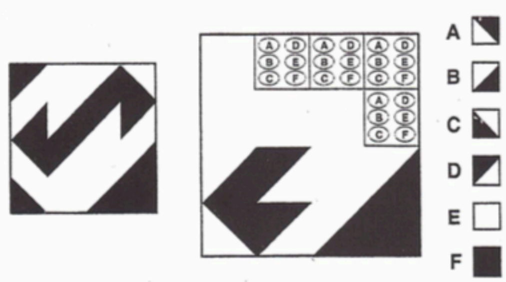
10.



11.



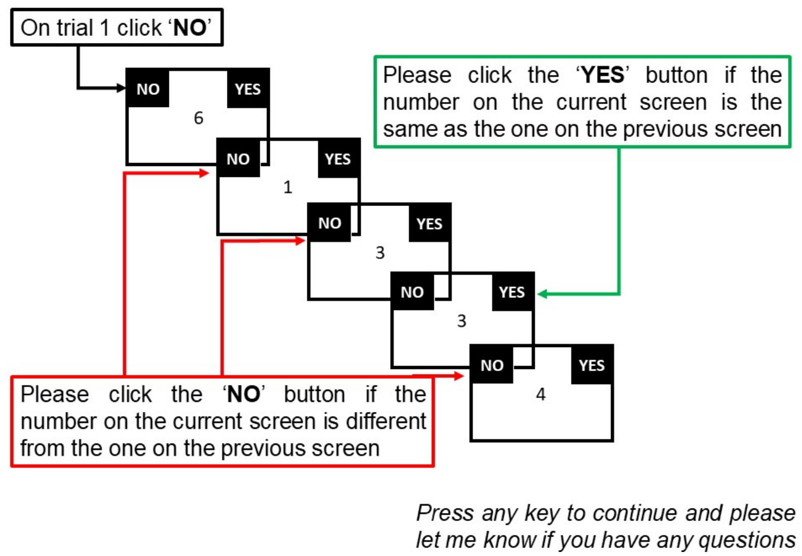
12.



Appendix D: N-Back Task

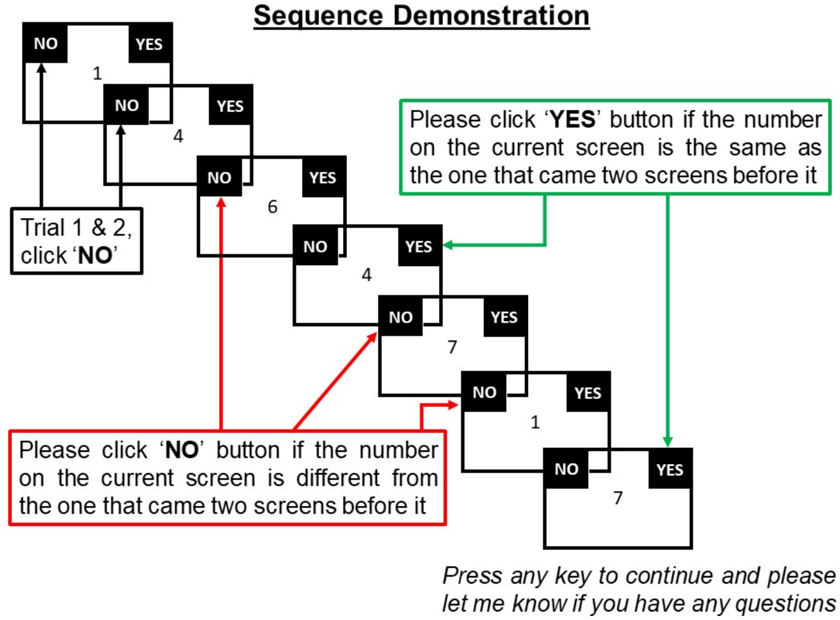
1-Back

Sequence Demonstration



2-Back

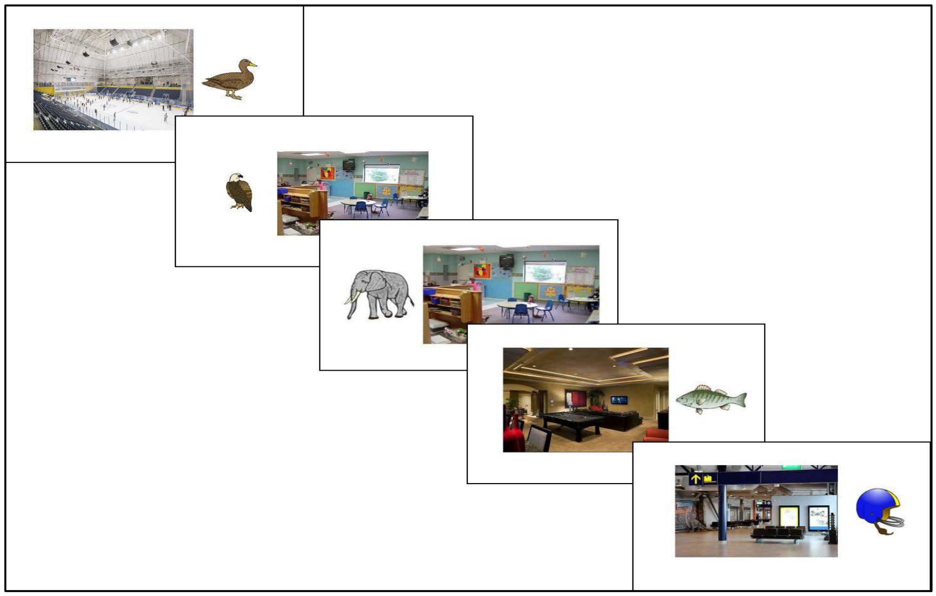
Sequence Demonstration



On a computer monitor, participants are shown a series of numbers presented one at a time. In the 1-Back task, they must decide whether the number on the screen is the same as the number that appeared just before it in the sequence. Participants respond by pressing the start key at the bottom of the screen, and moving the mouse to click on the response keys located at the top left and right corners of the display. The 2-Back task is similar, except participants must decide whether the number on the screen is the same as one that appeared *two* steps before in the sequence.

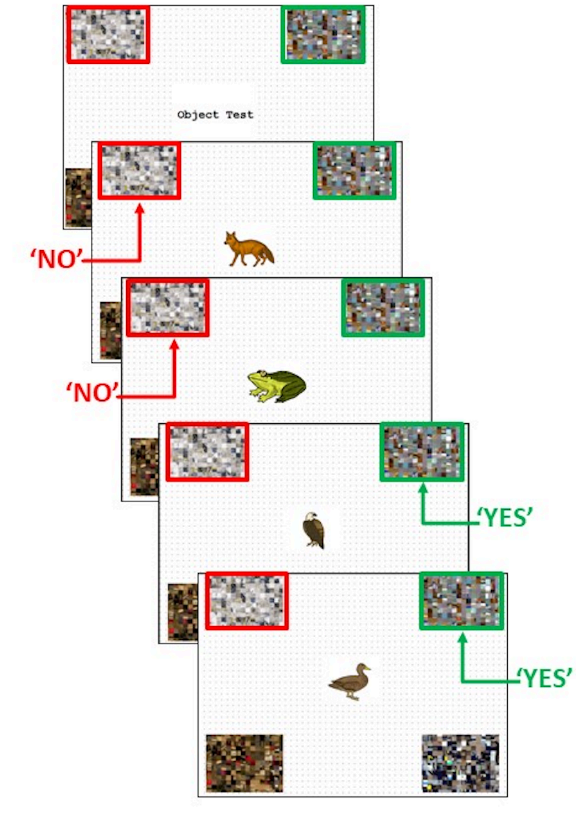
Appendix E: Item/Associative Task

Learning Phase



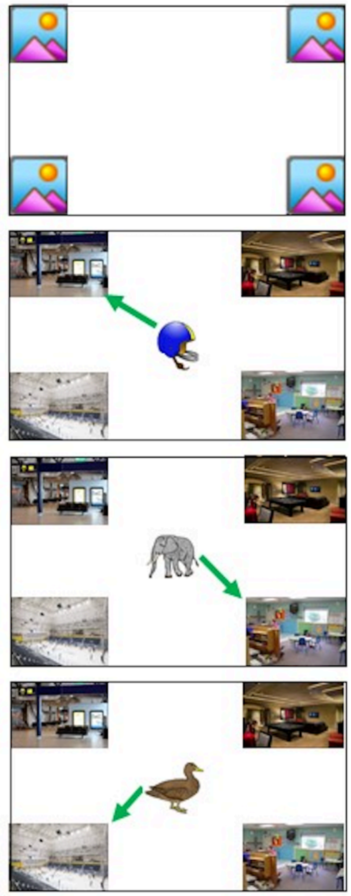
The Item/Associative task begins with the Learning Phase. On a computer monitor, participants are shown a series of twelve items paired with scenes, and asked to remember the pairs. After the Learning Phase, participants are given either the Object or Scene test.

Object Test



In the object task, participants are presented with a series of 24 items. They have determine whether or not they have seen the item before in the Learning Phase. Participants respond by clicking the start button in the center of the screen, and moving the mouse to the response keys at the top left and right corners of the screen. Clicking on the box with the green border indicates that they have seen the object, while clicking the box with the red border indicates that they have not seen the object.

Scene Test



In the Scene Test, participants are presented with a series of twelve items. Participants must decide which scene each item was paired with in the learning phase. They respond by moving the mouse from the start button in the center of the screen and clicking on the correct scene, located in one of the four corners of the screen.

Appendix F: Informed Consent

INFORMED CONSENT
Language Experience and Working Memory

Researcher: Dr. Ellen Bialystok

Sponsor: York University
This research has been approved by the Human Participants Review Subcommittee (HPRC) of York University for compliance with York University Senate Ethics policy.

Purpose of the Study
The purpose of the study is to better understand the effect of language on working memory and executive control. We will study adults form the York University URPP. Participants are selected based on their history of only using English or actively using another language in addition to English.

What You will be Asked to Do in the Study
You will be asked to complete some paper-based and computer-based cognitive tasks, for example:

- Answer some questions about your experience learning and speaking English and a second language.
- Select the corresponding picture upon hearing a word.
- Look at a pattern and fill in the missing piece.
- View pictures of objects and scenes and make decisions about them
- Monitor a series of digits to determine which ones you have seen before

We will provide you with clear instructions and examples at the beginning of each task so that you will know what to do. When using the computer, you will give your answers by pressing a key on the keyboard or clicking a mouse. We will provide you with breaks throughout the testing time if you wish to take them, and we will answer any questions that you may have. The study will take approximately 2 hours to complete. You will receive course credit for the time you spent with the researcher.

Voluntary Participation
Participation in this study is completely voluntary. The decision to participate is entirely up to you.

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. 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. If you decide to stop participating for any reason, you will still be eligible to receive the promised pay (URPP credits) for agreeing to take part in the study. Should you withdraw from the study all of your data generated will be destroyed.

Confidentiality
The information (data) we get from you during the study will be kept confidential. 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 got from you to be used in an article or lecture as long as your name is not revealed. Your data will be safely stored in a locked file cabinet and only my supervisor and I will have access to this information. The data will be stored for seven years, after which it will be destroyed (e.g. paper copies will be shredded, electronic files will be deleted). Your confidentiality will be maintained to the extent allowed by law.

Benefits
You will not benefit directly from being in the study. However, your participation will facilitate our understanding the role of language on various cognitive processes involved in decision making and problem solving.

Questions
If you have any questions about the research in general or about your role in the study, please feel free to contact the principal investigator, Dr. Ellen Bialystok. This research has been reviewed by the Human Participants Review Sub-Committee, York University's Ethics Review Board and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines.

Ellen Bialystok, Ph.D.
Principal Investigator

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.

Name of Participant (Print): ________________________ Birth date: ___________________

Signature of Participant: __________________________ Today's Date: ______________

Signature of Experimenter/Principle Investigator: _______________________ Date: _______