The Influence of Bilingual Language Experience on Working Memory Updating Performance in Young Adults

Deepti Wadhera (DWadhera2@GradCenter.Cuny.Edu)
Department of Speech-Language-Hearing Sciences, 365 5th Avenue New York, NY 10016 USA

Luca Campanelli (LCampanelli@GradCenter.Cuny.Edu)
Department of Speech-Language-Hearing Sciences, 365 5th Avenue New York, NY 10016 USA

Klara Marton (KMarton@Gc.Cuny.Edu)
Department of Speech-Language-Hearing Sciences, 365 5th Avenue New York, NY 10016 USA
Barczi College of Special Education, Eotvos Lorand University, Ecseri ut 3.
H-1097, Budapest, Hungary

Abstract

Reports of the relationship between aspects of cognitive control and bilingual language experience in young adults have been inconsistent. This study compared performance between monolingual and bilingual young adults on working memory (WM) updating as a measure of cognitive control and examined how differences in bilingual language experience manifest in updating performance. A letter N-back task with set size and lure manipulations was used to measure updating processes in the presence of increased memory load and interference. We expected to see an effect of the bilingual experience on WM updating, as well as within task variations related to the use of different updating mechanisms. While the monolingual and bilingual groups did not perform significantly differently, high non-English reading proficiency significantly predicted accuracy and reaction time within the bilingual group, particularly in high load, interference conditions. Results showed that young adults categorized as bilingual in a broadly defined group may be difficult to uniformly compare to a monolingual group as they show large variations in performance depending on their individual language experience.

Keywords: working memory, updating, bilingualism, cognitive flexibility, interference

Introduction

Cognitive control is a broad construct that encompasses processes recruited to configure the cognitive system for goal-directed behavior. According to a widely accepted framework, individual differences in cognitive control are a result of the adaptability of the cognitive system to immediate changes in information that is being processed during task performance (Botvinick, Braver, Barch, Carter & Cohen, 2001).

A large body of research has been focused on the effect of aging, occupation, socioeconomic status and other life experiences on cognitive flexibility. Bilingual individuals rely on adaptive control to process, switch and maintain each of their languages across contexts (Green & Abutalebi, 2013). However, the nature of the relationship between bilingualism and cognitive control is elusive, particularly in young adults (Hilchey & Klein, 2011). Some studies have found that young adults who are bilingual perform better on measures of cognitive control than their monolingual peers (e.g. Wiseheart, Viswanathan & Bialystok, 2016), while others have found no effect of bilingual language experience on general cognition (von Bastian, Souza & Gade, 2016).

There are two likely causes for the inconsistency in results. The first is that there is no uniform method of measurement or definition of bilingualism that is used across studies. Bilingual individuals are commonly defined as individuals who speak two or more languages on a daily basis (Bialystok, 2009; Grosjean, 2015). However, individuals who fit this description may have entirely different bilingual experiences depending on proficiency, age of acquisition, method of exposure, literacy and typological distance between the languages, among others (Kaushanskaya & Prior, 2015). Further, most studies have operationalized cognitive control using tasks that have multiple underlying target functions (Valian, 2015), show no correlation with each other (Paap & Greenberg, 2013) and are ultimately not sensitive measures of cognitive control (Marton, 2015). Tasks that target specific processes involved in goal-directed adaptations are the key to gathering reliable information about the relationship between bilingualism and cognitive control.

When Marton and colleagues (2017) used stepwise experimental manipulations across conditions, they were able to distinguish the aspects of cognitive control that are affected by the bilingual experience from those that are not. For example, performance on a word categorization task was significantly less affected by proactive interference for bilingual young adults than monolingual young adults. The advanced ability to flexibly adjust the cognitive system afforded by the bilingual experience is affected by unique aspects of bilingualism and by the methods by which cognitive control is gauged.

Working Memory (WM) Updating

Working memory updating is one process that particularly reflects the adaptability of the cognitive control system and may be influenced by the bilingual experience (Meier & Kane, 2017).

For the purpose of the present study, the Oberauer (2002) framework of WM will be used to interpret updating performance, which involves rapidly refreshing WM representations to focus on information relevant to the task goal.

The N-back Task One of the most common tasks that measures WM updating is the letter N-back, which entails continuously refreshing WM content while processing incoming information in the form of letters presented one at a time. The task goal is to judge whether the current letter matches the letter that was presented "n" items prior. The participant is required to accept target items and reject distractor items in accordance with the task goal. The encoding, refreshing and retrieval processes during this task require attribution of each letter (content) to the appropriate temporal position (context), known as content-context bindings. Two conceptually different mechanisms that are necessary for successful updating may be implicated in patterns of performance on the N-back task: (1) Strong, stable WM representations of content-context bindings that permit successful, recognition-based judgments of target items (2) Flexible WM representations of content-context bindings that can be refreshed in the presence of interference that arises when incoming items are bound to the same temporal context as previously relevant items (Oberauer, 2005)

The Present Study

In the present study, we attempt to further understand the relationship between bilingualism and cognitive control in young adults with consideration to the heterogeneity of the bilingual experience and the necessity for specific measures of cognitive control.

Only a handful of studies have measured WM updating in bilingual young adults and have often found ceiling effects on performance across groups (e.g. Sover, Rodriguez-Fornells & Laine, 2011). However, an N-back paradigm with manipulations in task complexity may capture how aspects of the bilingual experience affect WM updating performance.

Paradigm Manipulations The N-back paradigm developed for this study has manipulations of set size and interference. For set size, the number of items to be held in WM vary across three conditions: 1-back, 2-back and 3-back. For interference, proactive and retroactive lures are presented as distractors (Gray, Chabris & Braver, 2003). Proactive lures appear before a target and retroactive lures appear after a target. The paradigm allows for interpretation of independent and interactive effects of memory load and interference and provides information about underlying updating mechanisms that are recruited in the face of these manipulations.

Research Questions (1) Do bilingual and monolingual young adults differ in working memory updating if the tasks include interfering lures and manipulations of memory load?

(2) Do any variables of the bilingual experience, such as age of acquisition and literacy better predict WM updating performance than spoken language proficiency in bilingual young adults?

(3) Can the two updating mechanisms explain differences in within-subject performance patterns and display how particular aspects of bilingualism influence WM updating strategies?

Hypotheses to Question 1: (a) The bilingual group will perform significantly better than the monolingual group in the most demanding, third set size condition. (b) The bilingual group will reject significantly more proactive distractors than the monolingual group, particularly in high set size conditions. (c) There will be no between group difference in performance in the retroactive interference conditions across set size.

Question 2: Because WM processes are integrated in several reading mechanisms (Daneman & Carpenter, 1980), English and Non-English reading proficiency will predict updating performance in the bilingual group.

Question 3: Reliance on one updating mechanism over the other may result in different patterns of performance across the four item types: target, new distractor, proactive distractor and retroactive distractor. Bilingual young adults will most likely rely on the flexibility mechanism as use and maintenance of multiple language systems have been reported to heavily influence cognitive flexibility (e.g. Hartanto & Yang, 2016).

Methods

Participants

Sixty-eight healthy young adults were recruited for this study (Table 1). Twenty-five were monolingual speakers of English and 43 were bilingual speakers of English and another language. Participants in both groups reported no history of a communication disorder, neurological disorder, learning disability or other deficit. All participants were recruited and categorized using The Language Experience and Proficiency Questionnaire and reported a composite English proficiency of eight or higher. Bilingual participants also reported a composite proficiency of eight or higher in another language. Composite scores were calculated by finding the average of the reported comprehension and production proficiency (LEAP-Q; Marian, Blumenfeld & Kaushanskaya, 2007).

Table 1: Proficiency and demographic information

Group	n	Age	Edu (years)	Non-English Proficiency
Mon	25	25.6 (4.4)	16.3(1.5)	-----------
Bi	43	22.6 (2.5)	15.7(2.0)	8.9 (1.3)

Stimuli and Procedures

The experimental task was a manipulation of the letter N-back and involved judgments about whether the present letter matched the letter that came “n” letters prior. The paradigm included nine conditions including a baseline recognition task (0-back) and three set size conditions: 1-back, 2-back and 3-back. Each set size consisted of a neutral and proactive interference condition. The 2 and 3-back set sizes also consisted of a retroactive interference condition (Figure 1).

Set Size The set size condition included a baseline recognition task of 72 trials, which required the participant to press the green button when the letter “X” appeared on the screen. The higher set size conditions were designed to measure the effect of WM load on updating performance. The 1-back, 2-back and 3-back contained 75, 78 and 81 trials respectively.

Interference There were two interference conditions in the paradigm in addition to a neutral condition with only new distractor items. In the proactive interference condition, 25% of the distractor items were lures presented prior to a target item at the n-1 position. This condition was designed to measure the effect of previous target items presented as distractors on WM updating performance across set sizes. In the retroactive interference condition, 25% of the distractor items were lures presented after a target item at the n+1 position. This condition was designed to measure the effect of post target presentation of previous distractor items in incorrect temporal positions on WM updating performance. Because of the nature of retroactive interference, it could only be manipulated in set sizes higher than the 1-back.

Stimuli were 26 white letters of the Roman alphabet and were presented one at a time in the center of a black screen for a duration of 600 ms. There was an interval of 2400 ms between each stimulus item. Participants were required to press the green button for a target and the red button for a distractor placed on the “M” or “X” keys. Location of response buttons on the keyboard and presentation order of each condition were both counterbalanced across participants.

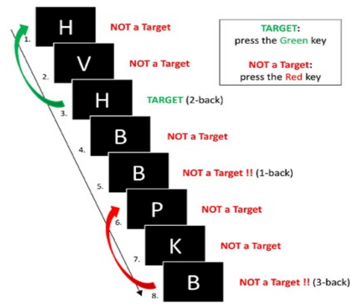

Figure 1: Task paradigm: Presentation of 2-back condition with interference lures.

Data Analysis

There were two dependent variables used to analyze data from this task: accuracy and reaction time for all item types (target, new distractor, proactive distractor and retroactive distractor). Both variables were examined using mixed-effects regression analysis, which allows within- and between-subject effects to be examined in hierarchical data. In this case, responses (level-1) were nested within participants (level-2).

Non-linear accuracy data for all conditions were fit to mixed-effects logistic regressions by specifying family binomial and link logit. Reaction time data, which were only analyzed in accurate responses, were log transformed due to its skewed distribution. Data for all conditions was fit to mixed-effects regressions with Maximum Likelihood estimation. The maximal model of random effects was selected to include random slope and random intercepts (correlated), which is most appropriate for confirmatory hypothesis testing (Barr, Levy, Scheepers, & Tily, 2013).

Outliers for all dependent variables were removed by fitting each data type to the appropriate models and plotting level 1 and level 2 residuals. Any residuals 3 standard deviations above or below the mean were excluded (less than two percent of the data) and the model was re-fitted.

Results

Between groups

To examine the first research question, accuracy and reaction time data were compared between the bilingual and monolingual language groups. For accuracy data, three predictors were included in the logistic regression model: language group, set size and item type (new distractor, proactive distractor, retroactive distractor and target). Results related to proactive and retroactive distractor items are reported together where the two do not differ. The fitted model showed significant effects of both set size ($p <.001$) and item type ($p< .001$) on accuracy, but no significant main or interaction effect of language group. A set size by item type interaction showed that target item accuracy was significantly lower in set size two ($p<.001$) and set size three ($p<.001$) than in set size one. Target item accuracy was significantly lower in set size three than in set size two ($p=.010$). Interference item accuracy was also significantly lower in set size two ($p<.001$) and set size three ($p<.001$) than in set size one. There was no significant difference in interference item accuracy between set size two and three. New distractor item accuracy was not significantly affected by set size.

For reaction time data, the same three predictors were included in the linear regression models. Again, the model showed significant effects of both set size ($p< .001$) and item type ($p<.001$) on reaction time, but no effect of language group ($p=.282$). A set size by item type interaction showed that target item reaction time was significantly slower in set size two ($p=.015$) and set size three ($p<.001$) than in set size one. Target item reaction time was significantly slower in set size three than in set size two ($p<.001$). Interference item reaction time was also significantly slower in set size two ($p=.038$) and set size three ($p<.001$) than in set size one. Interference item reaction time was significantly slower in set size three than in set size two ($p=.021$). New distractor item reaction time was not significantly affected by set size.

Within group; Predictors of bilingual performance

To examine the second research question, accuracy and reaction time data from the bilingual group were fitted to a model with the following predictors: set size, item type, English age of acquisition and non-English reading proficiency.

Each of the reading proficiency predictors were quantified using Likert scale reports on the LEAP-Q (Table 2).

Table 2: Sample size for bilingual predictors

Predictor	M (SD)	Min	Max
Eng AoA	7.4 (8.8)	0	14
Non-Eng Reading	5.3(7.2)	1	10

Accuracy Set size significantly predicted accuracy in that performance across item types and participants was significantly lower in the second and third set size condition compared to the first set size condition. There was also a set size by item type interaction effect ($p<.001$). Accuracy on proactive and retroactive interference distractor items was significantly lower than accuracy on new distractor items in the 2 ($p=.016$) and 3-back conditions ($p=.001$) and accuracy on target items was significantly lower than both new distractor items in the 2 ($p=.022$) and 3-back condition ($p=.004$) and interference items in the 3-back condition ($p<.001$). Non-English reading scores significantly predicted overall accuracy ($p=.005$) and there was a non-English reading proficiency by set size by item type interaction ($p<.001$; Figure 2). Effects and interactions of age of acquisition were not statistically significant.

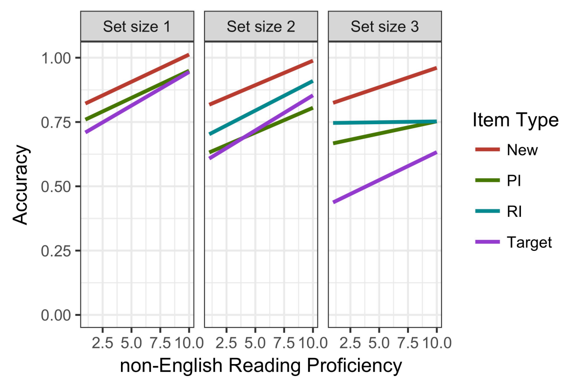

Figure 2: Effect of non-English reading proficiency on accuracy across set size (columns 1, 2 and 3) and item type (new distractor, proactive distractor, retroactive distractor and target).

Reaction Time Set size significantly predicted reaction time in that performance across item types and participants was significantly slower in the second ($p<.001$) and third ($p<.001$) set size condition compared to the first set size condition. There was also a set size by item type interaction ($p<.001$). Reaction time on target items was significantly slower than both new distractor items in the 2-back ($p<.001$) and 3-back ($p=.032$) conditions and interference items in the 2 ($p= .022$) and 3-back conditions ($p<.001$). Non-English reading scores significantly predicted overall reaction time (p=.027) and there was a non-English reading proficiency by set size by item type interaction (p<.001). Reaction time for interference items was not significantly different than reaction time for new distractor items. Effects and interactions of age of acquisition were not statistically significant.

Discussion

The present study aimed to explore the relationship between bilingual language experience and cognitive control abilities in young adults. More specifically, WM updating performance was used to measure how mechanisms of cognitive adaptability manifest in individuals with different language proficiencies. There are three main findings to be discussed. First, WM updating performance did not distinguish bilingual and monolingual young adults. Second, within bilingual participants the effect of increased WM load was not consistent across item types, indicating a reliance on the flexibility mechanism during updating. Third, non-English reading proficiency predicted performance in the bilingual young adult group, particularly in high memory load, interference conditions.

The lack of group difference in performance between bilingual and monolingual young adults may point to the inevitable conclusion that WM updating is not a cognitive process that is affected by frequent use of more than one language. Yow and Li (2015) found that the bilingual experience was related to inhibitory control and attention shifting, but not to resistance to distractor interference and WM updating. While these results in addition to the present results may indicate that WM updating is not relevant to bilingualism, the operational definition of bilingualism in both studies must be considered. Yow and Li used balanced proficiency and balanced use as predictors of n-back performance in the 2 and 3-back task. The present study used high, balanced spoken language proficiency as inclusion criteria for the bilingual group. While these measures of bilingualism are used often in this literature, they may be resulting in broadly defined bilingual groups with individuals that perform entirely differently on the same measures of cognitive control. Importantly, performance of such heterogeneous groups cannot be reliably compared to performance of their monolingual peers. Teubner-Rhodes and colleagues recruited a more homogenous Spanish-Catalan bilingual young adult group who performed better on an interference lure condition of a 3-back task than their Spanish monolingual peers (2016). These results indicate that a bilingual young adult group with a more consistent language experience across individuals may be better suited to highlight the role of bilingualism in WM updating performance. To further examine the specific aspects of bilingualism that are related to WM updating in the current study, within-subject analysis of item and response types and between-subject analysis of language experience was conducted with bilingual participants.

While there were significant effects of WM load and item type on performance across bilingual participants, the effect of task complexity on decision-making in the N-back was not the same for each item type across the three set size conditions. As expected, there was no effect of any manipulation on rejection of new distractor items. Additionally, the effect of interference increased with increasing load. However, the effect of memory load was most prominent in target item accuracy. In the third set size condition, recognition of target items was the most difficult decision for all bilingual participants. This finding was unexpected and may be indicative of an overall bias toward rejection. In other words, the threshold for a "yes" response selection seems to be much higher than for a "no" response selection as the N-back task gets progressively more complex. These findings in relation to the updating theoretical framework show that bilingual young adults rely more on the flexibility (mechanism 2) of WM bindings during updating, which may sacrifice the stability required to recognize target items.

When we looked at other relevant predictors, we found that non-English reading proficiency significantly predicted accuracy and reaction time performance. This finding is in line with the well-documented relationship between reading and WM updating. Individual differences in reading comprehension abilities have been found to be associated with WM updating performance (Palladino et al., 2001). WM updating is also a crucial cognitive component of sentence comprehension development in the native language (King & Just, 1991). The influence of non-English reading proficiency in the present study may indicate that the relationship between bilingualism and cognitive control in WM updating is specific to biliterate populations.

Individuals with high non-English reading proficiency were significantly better at resisting proactive interference effects at the highest set size than individuals with low non-English reading proficiency. In conditions with high interference, bilingual young adults with high reading proficiency in both languages were able to adjust their cognitive system to allow more flexible bindings that were resistant to familiarity based judgments caused by interference.

The role of the bilingual experience in WM updating and its underlying mechanisms can be highlighted with a process-specific task involving specific manipulations. Interestingly, it seems that some aspects of the bilingual experience such as literacy affect the updating performance, while others such as spoken proficiency may not.

Acknowledgments

CUNY Doctoral Student Research Grant, Jungmee Yoon, Zhamilya Yerimbetova

References

Bialystok, E. (2009). Bilingualism: The good, the bad, and the indifferent. *Bilingualism; Cambridge*, *12*(1), 3–11.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, *108*(3), 624–652.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, *19*(4), 450–466.

Egner, E. (2017). *The Wiley handbook of cognitive control*. Chichester, West Sussex ; Malden, MA : John Wiley & Sons Ltd.

Green, D. W., & Abutalebi, J. (2013). Language control in bilinguals: The adaptive control hypothesis. *Journal of Cognitive Psychology*, *25*(5), 515–530.

Grosjean, F. (2015). Bicultural bilinguals. *International Journal of Bilingualism*, *19*(5), 572–586.

Hartanto, A., & Yang, H. (2016). Disparate bilingual experiences modulate task-switching advantages: A diffusion-model analysis of the effects of interactional context on switch costs. *Cognition*, *150*, 10–19.

Hilchey, M. D., & Klein, R. M. (2011). Are there bilingual advantages on nonlinguistic interference tasks? Implications for the plasticity of executive control processes. *Psychonomic Bulletin & Review*, *18*(4), 625–658.

Kaushanskaya, M., & Prior, A. (2015). Variability in the effects of bilingualism on cognition: It is not just about cognition, it is also about bilingualism. *Bilingualism: Language and Cognition*, *18*(1), 27–28.

King, J., & Just, M. A. (1991). Individual differences in syntactic processing: The role of working memory. *Journal of Memory and Language*, *30*(5), 580–602.

Marian, V., Blumenfeld, H. K., & Kaushanskaya, M. (2007). The Language Experience and Proficiency Questionnaire (LEAP-Q): Assessing Language Profiles in Bilinguals and Multilinguals. *Journal of Speech, Language, and Hearing Research*, *50*(4), 940–967.

Marton, K. (2015). Theoretically driven experiments may clarify questions about the bilingual advantage. *Bilingualism: Language and Cognition*, *18*(1), 37–38.

Marton, K., Goral, M., Campanelli, L., Yoon, J., & Obler, L. K. (2017). Executive control mechanisms in bilingualism: Beyond speed of processing. *Bilingualism: Language and Cognition*, *20*(3), 613–631.

Oberauer, K. (2002). Access to information in working memory: Exploring the focus of attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*(3), 411–421.

Oberauer, K. (2005). Binding and Inhibition in Working Memory: Individual and Age Differences in Short-Term Recognition. *Journal of Experimental Psychology: General*, *134*(3), 368–387.

Paap, K. R., & Greenberg, Z. I. (2013). There is no coherent evidence for a bilingual advantage in executive processing. *Cognitive Psychology*, *66*(2), 232–258.

Palladino, P., Cornoldi, C., Beni, R. D., & Pazzaglia, F. (2001). Working memory and updating processes in reading comprehension. *Memory & Cognition*, *29*(2), 344–354.

Soveri, A., Rodriguez-Fornells, A., & Laine, M. (2011). Is There a Relationship between Language Switching and Executive Functions in Bilingualism? Introducing a within group Analysis Approach. *Frontiers in Psychology*, *2*.

Valian, V. (2015). Bilingualism and cognition. *Bilingualism: Language and Cognition*, *18*(01), 3–24.

von Bastian, C. C., Souza, A. S., & Gade, M. (2016). No evidence for bilingual cognitive advantages: A test of four hypotheses. *Journal of Experimental Psychology: General*, *145*(2), 246–258.

Wiseheart, M., Viswanathan, M., & Bialystok, E. (2016). Flexibility in task switching by monolinguals and bilinguals. *Bilingualism; Cambridge*, *19*(1), 141–146.

Yow, W. Q., & Li, X. (2015). Balanced bilingualism and early age of second language acquisition as the underlying mechanisms of a bilingual executive control advantage: why variations in bilingual experiences matter. *Frontiers in Psychology*, *6*.